CEBA-IARW Guide to Effective Warehouse Design, Maintenance, and Modernization

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Core Partners of the Global Cold Chain Alliance (GCCA)

CEBA
Controlled Environment Building Association

IARW
International Association of Refrigerated Warehouses

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About the Global Cold Chain Alliance

Comprised of its Core Partners, including the International Association of Refrigerated Warehouses (IARW), the World Food Logistics Organization (WFLO), the International Refrigerated Transportation Association (IRTA), and the Controlled Environment Building Association (CEBA), the Global Cold Chain Alliance (GCCA) represents all major industries engaged in temperature-controlled logistics. GCCA unites partners to facilitate communication, networking, and education for the perishable food industry. For more information about GCCA, visit www.gcca.org.

Vision

The Global Cold Chain Alliance will be the recognized authority in forging a universally strong cold chain where every product retains quality and safety through each link.

Mission

The Global Cold Chain Alliance unites partners to be innovative leaders in the temperature-controlled products industry.

About the Controlled Environment Building Association (CEBA)

As a Core Partner of the Global Cold Chain Alliance, CEBA supports the organization's overall mission of growing the industry and leading the cold chain through the development of best practices, research, networking, and education related specifically to the design, build, and maintenance of controlled environment buildings.

CEBA Vision

CEBA is where anyone looking to build, renovate, or modernize a first-rate, innovative facility comes to find the most experienced designers, contractors, and manufacturers and suppliers.

CEBA Mission

CEBA represents the expert builders who specialize in the design and construction of controlled environment buildings, including cold storage warehouses, food processing facilities, clean rooms, pharmaceutical facilities, and foodservice and retail distribution centers.

About the International Association of Refrigerated Warehouses (IARW)

As a Core Partner of the Global Cold Chain Alliance, IARW promotes best practices in temperature-controlled warehousing and logistics industry through research, industry benchmarking, networking, and education. IARW also advocates for members in legislative and regulatory arenas.

IARW Vision

IARW will build, strengthen and represent the global temperature-controlled third party warehousing and logistics industry.

IARW Mission

IARW promotes excellence in the global temperature-controlled warehouse and logistics industry.

More information on GCCA and all its Core Partners can be found at www.gcca.org.

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Chapter 1: Design

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Joseph Bove, PE Stellar, Jacksonville, Florida USA

Bruce Gillings, AIA ATI Architects and Engineers, Costa Mesa, CA, USA

Portions of this chapter have been reprinted with permission from the Controlled Environment Building Association, United Kingdom Division. The chapter is from the 2008 Guidelines for the Design, Specification, Construction, Maintenance and Fire Management of Insulated Envelopes for Temperature Controlled Environments.

This chapter provides general design principles for the construction of new warehouses or major refurbishments of insulated envelopes. Specific design guidance for the various components of refrigerated warehouses is provided in each of the individual chapters.

Insulated envelopes enclosing controlled temperature environments are usually purely functional buildings. Although aesthetics of the completed scheme are a consideration, they are secondary to the functional engineering design and detailing; the objectives to optimize safety in both construction and operation; construction costs and construction program; and long term maintenance costs and long term running costs. At the same time, the design of the insulated envelope and the building should not compromise the maximum efficiency of the processes and functions within the envelope while ensuring that the required internal environment is achieved at all locations within the envelope at optimal cost and that the design complies with statutory requirements, insurance conditions, codes of practice and client requirements, again at optimal cost.

Modern plants are usually carefully designed and installed using the correct materials and equipment. It should be recognized that the cost implications of not optimizing storage racking, mechanical handling or production lines as appropriate may far outweigh the cost savings to be obtained by minimizing building construction costs.

The insulated envelope must sustain forces applied to the envelope such that the envelope as a whole remains stable and serviceable, and that individual elements of the envelope are not overstressed or become unserviceable to the extent that the controlled environment enclosed within the insulated envelope is compromised, or is difficult or costly to maintain for the specified design life. The size of self-supporting insulated envelope structures is determined by the structural capacity of the prefabricated insulating sandwich panel to sustain applied forces. Such self-supporting structures are generally limited to smaller insulated envelopes within existing buildings, for example a cold room in a supermarket.

Where the insulated envelope structure is provided with supplementary support, it is most important that the structural action of the insulated envelope and the

supporting structure is considered as a unified structure and not as two separate structures. The serviceability of the insulated envelope particularly in relation to performance of joints between prefabricated insulating sandwich panels, which are critical to the performance of the envelope, is very dependent upon the load/deflection response of the supporting structure.

1.1 Owner's Role in the Design Process

There are a variety of reasons an owner has to initiate a project. These may include expansion, entry into new markets, renovation, consolidation or segregation of operations, applications of new technologies, revamping of the supply chain, etc. Often project initiation includes owner-generated budgets if the owner has a history of projects. For newer companies that do not have such a history, budgets may come either from outside consultants, potential general contractor partners, or wait until the first response to an RFP is received.

Project initiation will include conceptualizing the "why, when, where and how" of a project. In defining these, the owner has a very significant responsibility with regard to the overall outcome of a project. Within the owner's organization, stakeholder input is vital and all parties must understand the project's significance and potential to impact on their future. This involves identifying the expectations that all of the involved parties such as operations, production/throughput, engineering, and business logistics have with regard to the project result.

- Questions to be answered in the initiation phase include the following:
- Why this project?
- Is it feasible?
- Who are possible partners in this project?
- What should the results be?
- What are the boundaries of this project (what is outside the scope of the project)?
- Does the project has an adequate payback?
- Can the project meet the desired opening date (schedule)?
- Will the project be phased and how should that be factored in?

It is important to identify the requirements as early in the process as possible and key and critical decisions must be made with respect to:

- Preconditions
- Functional requirements
- Operational requirements
- Design limitations
- Procurement and delivery method (i.e. Design/Build vs Design/Bid/Build)

The project leader may elect to engage a consultant or personally write a request for a proposal (RFP), which contains a description of the project (either very detailed or a high-level scope of work), announces the completion date and identifies the location.

The list of requirements that is developed and included in the RFP can be used to make design choices. Depending on the requirements of the project, the RFP package can include diagrams, sketches, conceptual drawings, renderings and a preliminary project specification. This tool serves the purpose to define the project. However, the definition

may be improved or altered as the designer and builder contribute during the bidding phase and comment on the means and methods to implement the work. In the design phase, one or more designs may be developed, with which the project result(s) can be achieved.

Qualified design and / or construction firms are identified and invited to a project pre-bid meeting. During the meeting the scope of work is reviewed in detail, a site walk occurs, topics such as coordination with operations, communication methods, safety goals, materials and methods discussions, quality expectations, governing agencies interface, alternates, budget and schedule are clarified. For smaller or less complex projects, some roles and action steps may be combined.

The attendees then submit a response to the RFP for the owner's project team to evaluate. A selection is made and the project officially begins with an authorization to proceed to key team members.

At this point the owner's role does not end. Rather, their involvement intensifies with the onset of the detailed design phase. The owner's internal team should be actively engaged in communication with the design team throughout the design process.

1.2 Project Design Phase

With the establishment of the building and operational criteria and contract terms secured the project design phase commences.

The design phase generally follows the American Institute of Architects(AIA) work flow; Schematic Design Phase, Design Development Phase, Construction Document Phase and Construction Administration Phase Services.

1.2.1 Schematic Design Phase

During the schematic design phase the design professionals (architects and engineers) consult with the owner to confirm project goals and requirements. Often this work has already been completed as part of the RFP.

Schematic design also is the research phase of the project, when zoning requirements or jurisdictional restrictions are discovered and addressed.

This phase produces a final schematic design, to which the owner agrees after consultation and discussions with the design team.

Deliverables: Schematic design often produces a site plan, floor plan(s), sections, and an elevation, and other illustrative materials: computer images, renderings, or models. Typically, the drawings include overall dimensions, and a construction cost is estimated. General project scoping, which may impact the budget, is also refined.

1.2.2 Design Development Phase

Design development (DD) services use the initial design documents from the schematic phase and advances the mechanical, electrical, plumbing, structural refrigeration, and architectural details. Other project elements, such as material handling/storage, equipment, etc, are identified and, at least at a conceptual level, factored into the design.

The DD phase typically also incorporates the planning/zoning submittals and approvals to lead governing agencies that will provide conditions for the project to obtain a go-ahead to move into the Construction Document phase. These conditions may alter timelines and budgets depending on interpretation and application of agency codes. The DD phase often ends with a formal presentation to, and approved by, the owner.

Deliverables: Design development often produces floor plans, sections, and elevations with full dimensions. These drawings typically include door and window details and outline material specifications. Preliminary engineering plans and/or scoping documents are included, as are material handling/storage, equipment and other components.

1.2.3 Construction Document Phase

The next phase is construction documents (CDs). Once the owner is satisfied with the documents the design team moves forward and produces drawings in sufficient detail to permit bid and construct the project. These drawings typically include specifications for construction details and materials.

At or near completion of the CDs, the plans are submitted to the agencies having jurisdiction over the project, including but not limited to building, fire, health, engineering/public works, water/waste, and storm water departments, as well as other agencies where required. The agencies having jurisdiction will review the plans and apply various codes. Due to the interpretive nature of the codes, revisions that may affect schedule and budget may be necessary. Once these are incorporated into the plans, a final budget is prepared and a building permit is pulled.

Deliverables: the construction document phase produces a set of drawings that include all pertinent information required for the contractor to price and build the project. Engineering calculations, specifications, and plans are included. Incorporation of design criteria and interface with material handling/storage, equipment and other critical components is included. Process for agencies having jurisdiction approvals/permits is performed.

1.2.4 Construction Phase Services

Contract administration (CA) services vary based upon the project delivery method and require different levels of services based upon the complexity of the project.

The design professionals are responsible to help the contractor to build the project as designed in a safe work environment with quality and in conformance with the plans

and project scope. Questions may arise on site that require professional opinion and even revised designs.

Deliverables: Reports, sketches, shop drawing review and administrative functions.

The owner's role during the design process remains critical. It generally consists of day-to-day communication with the design and/or construction team(s), as well as ongoing monitoring of updates to the construction and/or fees budget. It is also important to make sure everyone has the project information and scoping/scheduling updates they need to succeed.

1.3 Commissioning and Project Close Out

Towards the completion of construction, the next step is to manage the commissioning of systems and to organize the data for the owner's future use. Key activities to be performed by the design professional, contractor and owner include, but not limited to, initial startup procedures, emergency shutdown procedures, testing and startup of mechanical systems and major equipment and establishing safe maintenance practices. A spare parts list and preventative maintenance schedule may be developed. Employee hiring and training may be included. Some or all of these functions may be performed by either the design/construction team, or by third-party specialized consultants.

1.3.1 Testing and Commissioning

The team needs to coordinate inputs as required and documented in the project specifications related to testing, commissioning, and handover.

Obtain all required construction certificates as required by the design team. This ensures all required certificates are secured to finalize building approvals.

Arrange for relevant design team members, owner's representative, and commissioning consultants (where applicable), to review the operations and maintenance manuals submitted by the contractor or sub-contractors. All team members should ensure incorporation of comments into the final operations and maintenance manuals submission.

The owner should engage the design team to evaluate the as-built documentation submitted by the contractor. This guarantees that all contract obligations are met.

The design team and contractor should manage the required inspections by the agencies having jurisdiction, and should respond to and complete actions from these inspections, as required.

1.3.2 Completion and Defects Lists

The entire project team needs to prepare the inspections and defects list and monitor the progress. This is the final list of defects to attend to prior to the contractor's

final completion. A schedule of remedying defects meeting the project scoping requirements is to be agreed upon and appropriate action taken.

1.3.3 Compliance Reports

The design team needs to evaluate the project performance with respect to the functional design goals and project specifications. Any shortfalls in performance will need to be reviewed and resolved to avoid affecting operation of the building. The design team shall secure and provide a Final Certificate of Occupancy and Completion documents to the project owner.

1.3.4 Training

Input from the design team needs to be incorporated to any required user training program. This allows the end user to better understand the completed project's use and operation.

1.3.5 Owner's Manual and Final Drawing Set

The red lined field modifications should be formally incorporated into the final as-built design documents. If part of the project scope, design documents are to be provided to the owner for use in maintenance and facility upgrades going forward. These are typically utilized by the owner's facility engineering department.

All technical documents such as surveys, soils reports, testing inspection reports, drawings, specifications, cut sheets and shop drawings, manufacture and vendor listings, and data sheet which have relevance to sustaining the operation shall be organized and presented to the owner for their future use.

1.3.6 Legal Aspects

The final release of Liens, and all other legal agreements, including but not limited to, easements, variances, and similar agreements established between the design team, contractor, and agencies having jurisdiction on behalf of the owner required to permit the work shall be provided to the owner.

1.3.7 Project Follow-Up

The design team and contractor should be available on an ongoing basis for an agreed-upon time frame to address any issues that appear after the project has been formally handed off to the owner. Beyond industry-standard time frames, and beyond warranty work, it is typically in the owner's best interests to continue to utilize the design team and contractor for ongoing work or modifications.

Chapter 2: Maintenance

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2.1 Introduction

The type of maintenance program and system you select for your refrigerated warehouse will directly affect the overall success and longevity of your Cold Storage facility. Its a given fact that a well-maintained facility can be expected to operate for seventy plus years. There are many types of preventative maintenance tasks to be performed on a routine basis to ensure a safe, clean, and a well running warehouse.

The maintenance portion of this guide may be considered a good starting point for your facility preventative maintenance task along with your manufacturers recommends. Please keep in mind that it may not be possible or practical to complete all manufacturers recommended maintenance items throughout the life of the equipment, thus when looking at manufacturers recommended maintenance schedule it is important to realize that they are just recommendations after the "break-in" (warranty) period. Depend on your maintenance materials and program your equipment may need less or more attention than the manufacturers recommend.

The type of service and supplies that your equipment is under will properly determine the intervals between maintenance activities. Over-maintaining equipment may generate a "short life" of the equipment just as the same as no maintenance. This chapter should give you a good idea of what areas should be addressed. Having said that, we need to keep in mind that new equipment requires the manufacturer's preventative maintenance to maintain its warranty and if you are thinking of changing the maintenance schedule or maintenance supplies (Oil and/or grease) it is strongly recommended to contact the manufacturer. Our Cold Storage facilities are unique in many ways, each requiring a skilled team of trained employees to keep them running. Preventative maintenance not only extends the life of an asset but allows them to run at peak efficiency and prevent down time. Further a well-maintained facility may provide a safer warehouse for our employees and customers' product as well as deferring major capital purchases.

Any facility can get away with not doing plant maintenance for months or even years at a time with little to no short-term consequences. The problem with this philosophy is that when something breaks it is unexpected. Often a breakdown may result in additional costs in repair and eventually premature replacement of that asset. Early failures of major assets due to a lack of maintenance will decrease company profits.

A well-maintained building is also a well-organized building that is able to plan and set goals for its work force. It's also able a quick reaction by the maintenance department which reduces downtime and collateral expense at many operating levels.

2.2 Maintenance Matrix

This maintenance matrix provides a representative set of maintenance guidelines for different components relevant to warehouse operations. It should be considered as a general reference guide. Please also refer to specific maintenance guidelines provided by equipment manufacturers, and consult applicable federal, state, and local laws and regulations and codes, such as the National Fire Protection Association's NFPA 25-Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems.

Component	Sub Component	Related Equipment/ Task	Not Applicable (N/A)	Walk Through	Daily	Weekly	Monthly	Quarterly	Semi Annual	Annual	3 year	5 year	Other
Batteries & Battery Chargers													
NOTE: Proper Personal Protective Equipment (PPE) must be worn to perform all of the following tasks!													
Batteries		Visual inspection of battery looking for signs of damage wear and leaking.			x								
		Check electrolyte level in all cells				x							
		Add water if required. The battery must be completely charged				x							
		Equalizing charge				x							
		Test specific gravity					x						
		Clean top of battery					x						
		Inspect water system injectors						x					
		Check battery cell voltage						x					
Battery Chargers		Verify charger output						x					
		Check time of day on charger for proper scheduling							x				
Dock Equipment													
NOTE: Before starting the following work/inspection ensure that dock leveler safety bar is in place and work area has safety cones in place with proper signage!													
Dock Leveler	All Types	Check operation of leveler by warehouse employees			x								
		Clean debris off top of lip spools by warehouse employees			x								
		Clean & sweep out pit					x						
		Inspect the top and bottom leveler welds						x					
		Inspect leveler structure/sub-frame						x					
		Ensure that all dock leveler shims are in place						x					
		Inspect rear hinges for wear						x					
		Lubricate rear hinge pins as per manufacturers' recommendation						x					
		Inspect dock leveler weather seal for wear						x					
		Inspect full range toe guards						x					
		Inspect dock bumpers for minimum projection						x					
		Inspect dock seal/shelter for rips, holes or missing parts						x					
	Mechanical Levelers	Check main spring adjustment as per manufactures' recommendation						x					
		Check lip assist rod & spring adjustment as per manufactures' recommendation						x					
		Inspect/clean pawl & ratchet bar on hold-down as per manufactures' recommendation						x					
		Lubricate all pins & pivot points as per manufactures recommendation						x					
		Lubricate lip hinge & spools as per manufactures' recommendation						x					
		Inspect snubbing cable as per manufactures' recommendation						x					
		Inspect chains & "S" hooks as per manufactures' recommendation						x					
		Lubricate lifter arm (roller, bearings) as per manufactures' recommendation						x					
		Inspect lip extension as per manufactures' recommendation						x					
		Inspect cam as per manufactures' recommendation						x					
		Check for proper operation leveler extension, lip extension/retraction, lip fall speed, and below dock end load as per manufactures' recommendation						x					
		Check oil level (top off if necessary) as per manufactures' recommendation						x					
		Check wire harness as per manufactures' recommendation						x					

Component	Sub Component	Related Equipment/ Task	Not Applicable (N/A)	Walk Through	Daily	Weekly	Monthly	Quarterly	Semi Annual	Annual	3 year	5 year	Other
	Hydraulic Dock Levelers	Inspect main cylinder as per manufactures' recommendation						x					
		Check clevis pins on all cylinders & lubricate as per manufactures' recommendation						x					
		Check lip cylinder & mount as per manufactures' recommendation						x					
		Lubricate lip hinge as per manufactures' recommendation						x					
		Inspect limit switch harness as per manufactures' recommendation						x					
		Inspect limit switch (adjust if necessary) as per manufactures' recommendation						x					
		Check for proper operation of leveler extension, lip extension/retraction, automatic return to dock (if equipped) as per manufactures' recommendation						x					
Restraint	Vehicle/Trailer Restraint	Inspect and adjusted as per manufactures' recommendation or as necessary to ensure proper safety and functionality											
		Have user check operation before each use to ensure that the trailer is engaged			*								x
		Clean track as per manufactures' recommendation					x						
		Inspect mounting bolts and welds as per manufactures' recommendation						x					
		Inspect vertical barrier or Rotating Hook as per manufactures' recommendation						x					
		Inspect electrical harness as per manufactures' recommendation						x					
		Inspect control box, lights, horn, override as per manufactures' recommendation						x					
		Inspect all interior and exterior positional/warning lights as per manufactures' recommendation						x					
		Inspect sign location, mounting and legibility						x					
		Inspect mounting bolts, including the control box, lights, and signs						x					
		Inspect all conduit & junction box hardware to ensure compliance with all state and local electrical codes						x					
		Inspect bumpers as per manufactures' recommendation						x					
		Inspect seal/shelter as per manufactures' recommendation						x					
Freezer Doors													
Vestibule Freezer Air (Curtains) Doors	Air System	On an ongoing basis (constantly) remove any debris accumulation from air intake screens as per manufactures' recommendation					x						
	Blower V-Belts (not present on direct drive units)	Replace annually but examine for slack regularly								x			
	Blower's Flywheel & Pulley	Inspect and maintain as per manufactures' recommendation								*			x
	Blower Bearings	Grease as per manufactures' recommendation						x					
	Hot Gas Air Heater (Condenser Coil)	Check for correct heat output and clean as needed as per manufactures' recommendation						x					
	Electric Heater	Check heater's amperage as per manufactures' recommendation								x			
	Controllers	Verify humidistat or temperature controller and heater relay works								x			
	Hot Gas Coil	Keep clean and maintain as per manufactures' recommendation					x						
All Freezer Doors	Complete door assemblies	Visually inspect each for obvious damage or operating problems observe one (1) to two (2) full cycles		x	x	*							
	Doorways	Check for ice and water (condensation) by all door openings		x									

Component	Sub Component	Related Equipment/ Task	Not Applicable (N/A)	Walk Through	Daily	Weekly	Monthly	Quarterly	Semi Annual	Annual	3 year	5 year	Other
	Safety devices	Check all safety devices as per manufacturer's recommendation (Lock releases, sensitive edge)		x									
Doors													
Hinged doors		Check all mechanical components for wear and damage		x				x					
	Hinges	Lube hinges and, when applicable, test locking mechanism		x				x					
Manual Overhead and Horizontal Doors	Track	Check for damage or wear		x				x					
		Inspect seals and rollers		x				x					
	Door to Counterweight Balance	Examine for rust and cracks. Adjust and lube as needed		x				x					
		Make sure counter does not spin while door is going up and down		x				x					
Power Units- Sliding Doors	Reversing Edge	Depress to reverse travel				x							
	Drive Chain	Check lube, tautness and for evidence of rust						x					
	Manual Release	Check for adequate lube, evidence of rust or damage						x					
	V" belts	Frayed or worn?						x					
	Gear Box	Check oil level; is operation noisy and/or rough?						x					
	Brake & Solenoid	Check for slipping or evidence of worn discs						x					
	Reversing Contactor & Relays	Check for lack of contact, sparks and/or wear						x					
	Limit Switches	Check for smooth operation, evidence of wear						x					
	Leaf Power Cords	Are they frayed or broken?						x					
Roll Up Doors	Door Fabric & Frame	Check for any visible damage or unusual wear		x		x							
	Actuators	Check for automatic operation of the door		x				x					
	Hardware	Check for proper tightness		x				x					
	Limits	Observe both open and close door limits; ensure that a proper floor seal is intact when door is fully closed – no visible light seen between reversing edge and floor		x				x					
	Cables and Pulleys	Ensure that cable is not slack, misaligned or fraying		x				x					
Fire Prevention													
	Control Panel	Is the panel accessible without evidence of mechanical or water damage?			x	x	x	x	x	x			
		Alarm, supervisory and trouble signal (inputs) are properly functioning								x			
		Evacuation signals and auxiliary signal (outputs) are properly functioning								x			
		Circuit supervision, including ground fault and power supply supervision are functioning properly								x			
		Fuses – supervised and rating is correct								x			
		Interfaced equipment – Circuit integrity verified								x			
		Lamps and LEDs are illuminated								x			
		Primary power supply is properly functioning								x			
		Disconnect switches- intended function verified								x			
	Batteries	No evidence of corrosion or leakage								x			
		Connections checked and ensured								x			
		Batteries are within acceptable date range								x			
		Battery charger is operating properly								x			
		Load test is acceptable								x			
		Voltage level is acceptable								x			
	Transient Suppressors	Transient suppressors are in good condition and functioning properly								x			

Component	Sub Component	Related Equipment/ Task	Not Applicable (N/A)	Walk Through	Daily	Weekly	Monthly	Quarterly	Semi Annual	Annual	3 year	5 year	Other
Fire Alarm System - All Types	Remote Annunciators	Accessible, no mechanical damage and operates properly								x			
	Alarm Notification Devices	No obstructions to impair effectiveness								x			
		No physical damage								x			
		No changes in building conditions that render the appliance ineffective								x			
		Viewing paths to visible notification devices clear								x			
		Devices operate as intended								x			
		Emergency Contact List updated with Security Company								x			
	Initiating & Supervisory Devices	No evidence of mechanical or water damage								x			
		Heat detectors not painted								x			
		Devices operate as intended								x			
		Radiant energy detectors not obstructed, lenses clear and unit directed toward intended hazard								x			
		Smoke detectors have no covers, bags or tape								x			
		Emergency communications equipment								x			
		Correct operation verified								x			
		Interface equipment								x			
		Signals required to be transmitting, receiving, and verifying at control unit								x			
		AHU shutdown verified								x			
		Access control interface verified								x			
		Aux power supply, etc. verified								x			
		Special hazard systems								x			
		Detection circuits operate per original design verified								x			
		Releasing circuit operation verified								x			
		Supervision of devices and circuits verified								x			
		Supervising station monitoring								x			
		Alarm signal and restoration verified								x			
		Trouble signal and restoration verified								x			
		Supervisory signal and restoration verified								x			
Fire Extinguisher	Inspection	Location in designated place			x	x	x	x	x	x			
		No obstruction to access or visibility			x	x	x	x	x	x			
		Operating instructions on nameplate legible and facing outward				x	x	x	x	x			
		No safety seals and tamper indicators missing or broken				x	x	x	x	x			
		Fullness confirmed by weighing or "hefting"								x			
		No obvious physical damage, corrosion, leakage or clogged nozzle				x	x	x	x	x			
		Pressure gauge in normal range				x	x	x	x	x			
		HMIS label in place								x			
	Maintenance	Examination of mechanical parts								x			
Warehouse Floors													
Warehouse Concrete Floors	Joints/Joint Filler	Monitor joint filler condition for material separation/tearing		x				x					
	Joints	Monitor joint edge condition for deterioration/break down		x				x					
	Cracks	Monitor crack edge condition for deterioration/break down		x									
	Repairs	Monitor condition of any previously performed repairs		x				x					
	Surface Damage	Monitor floor for pop-outs, defects, deep scratches, new cracks		x					x				
	Surface Wearing	Monitor for signs of dusting, delamination, surface wearing		x					x				

Component	Sub Component	Related Equipment/ Task	Not Applicable (N/A)	Walk Through	Daily	Weekly	Monthly	Quarterly	Semi Annual	Annual	3 year	5 year	Other
	Joints at Building Transitions	Monitor for signs of deterioration/break down/frost		x				x					
	General Condition	Monitor overall condition; plan/budget annual maintenance		x						x			
Lighting													
Lighting Fixtures		During lamp replacement cleaning fixture lenses and reflectors								x			
		Relamping program									x		
		During lamp replacement inspect electrical connections								x			
Racking Systems													
All Racking	All steel racking components including cross bracing, pallet stops, rack anchors and nuts and bolts of the racking system	Inspect per facility and/or rack manufacturers' rack repair inspection program. Consult ANSI MH16.1 for further information.		x			x						
Refrigeration Systems													
See separate IARW/WFLO guidelines													
Roofs													
Cap Flashings		Inspect for missing fasteners, missing expansion clips between sections, wind damage, etc.							x				
Edge Metal		Inspect for missing or loose fasteners, cracks in sealant or flashing, corroded metal, wind damage, etc.							x				
		Leaks in this area can cause serious structural component damage							x				
Base Flashing		Inspect top terminations to ensure they are secure and sealed, wall flashings to ensure they are totally adhered (Note: some systems are designed for loose wall flashings), base termination for loose or backed out fasteners, seam edge and vertical seams for open areas, deteriorated flashing membrane, etc.							x				
Penetrations		Inspect drains for proper termination of clamping rings and strainer, ensure that drains are not clogged by debris, pipe boots for flanges for tight seal, top of pipe boots for proper sealing, etc.							x				
Field Membrane		Inspect for deficiencies and worn spots, check for voids in field seams (Note: removal of ballast or pavers are not possible in routine inspections), ballast or paver termination of field membrane is properly distributed and not displaced, be aware of change in substrate firmness under foot, that equipment leaks have not damaged the membrane, if coated check for peeled or worn coating, etc.							x				
Drainage		Ensure that all gutters, downspouts and drains are clear of debris, note any consistently ponded water larger than the size of a tire, etc. NOTE: Large areas of ponded water can add substantial weight to a roof system which can cause structural damage.							x				

2.3 Refrigerated Warehouse Checklist

This sample refrigerated warehouse checklist was previously published in the 2008 Maintenance and Modernization Manual. It is a combination of several lists in use by different warehouses and should be considered as a general guide.

Refrigerated Warehouse Checklist

Revised:
Rick L. Stromberg, Henningsen Cold Storage Company, Richland, WA, December 1987
James C Marrella, United States Cold Storage, Inc. Cherry Hill, NJ, July 2000

The following refrigerated warehouse checklist has been developed in response to requests from members for such a list. It is a combination of several lists in use by different warehouses to which have been added items suggested by the IARW Warehouse Operations Committee. This list should be considered as a "General Guide" to our industry, thus some items may not pertain to your operation. In these situations use the "Not Applicable" (NA) column. It is recommended that the auditor(s) do not leave a box unchecked.

Annual use of this list and the Training Matrix will help the user(s) to maintain a safe and efficient facility. Please note that the Training Matrix was developed during the first half of 2000 and based on current OSHA, EPA, USDA and FDA requirements. Thus, there may have been additional requirements added after the published date. It is understood that the user of this section is required to determine current federal, state and local requirements for their facility.

At the end of this checklist and training matrix are areas reserved so that the user may add items to cover situations peculiar to his/her facility.

Suggestions for additions or other revisions will be appreciated so that they can be included in future editions. Please contact the reviewer or the IARW with your comments and suggestions.

OFFICE:	**Yes**	**No**	**NA**
General layout of offices and office area conducive to efficient flow of work?	[ ]	[ ]	[ ]
Office/computer equipment conducive to requirements of the job?	[ ]	[ ]	[ ]
Proper lighting layout and appropriate light levels conducive to employee workstation?	[ ]	[ ]	[ ]
Proper ventilation, heating, and cooling in all areas?	[ ]	[ ]	[ ]
Appropriate storage area for old records?	[ ]	[ ]	[ ]
Are appropriate type of fire extinguishers located throughout the area?	[ ]	[ ]	[ ]
Are all fire extinguishers cleaned, and inspected monthly?	[ ]	[ ]	[ ]
Emergency lighting working and checked monthly?	[ ]	[ ]	[ ]
Fire sprinkler system, are sprinkler heads unobstructed?	[ ]	[ ]	[ ]
Fire sprinkler system "Major" valve(s) identified and labeled?	[ ]	[ ]	[ ]
All fire alarms in proper working order and tested per facility's schedule?	[ ]	[ ]	[ ]
Trip hazards, such as electrical extension cords, computer cable floor mats, etc?	[ ]	[ ]	[ ]
Electrical hazards, such as overloaded outlets, frayed electrical extension cords?	[ ]	[ ]	[ ]
Bulletin boards — conspicuous location, posted with current material and all legally mandated notifications?	[ ]	[ ]	[ ]

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Signage:			
Exit door?	[ ]	[ ]	[ ]
Non-exit doors?	[ ]	[ ]	[ ]
Restricted areas?	[ ]	[ ]	[ ]
Specific caution areas?	[ ]	[ ]	[ ]

DOCK AREAS:	**Yes**	**No**	**NA**
Clean and free of obstructions?	[ ]	[ ]	[ ]
Floor surface smooth, free of ruts, holes, bumps, etc?	[ ]	[ ]	[ ]
Aisle clearly marked?	[ ]	[ ]	[ ]
Unused pallets neatly stored?	[ ]	[ ]	[ ]
Is protection against damage by forklift provided and in proper condition?	[ ]	[ ]	[ ]
Proper lighting layout and appropriate light levels conducive to employee work area?	[ ]	[ ]	[ ]
Dock plates in proper working condition?	[ ]	[ ]	[ ]
Dock bridge plates properly stowed and in good working condition?	[ ]	[ ]	[ ]
Appropriate type of fire extinguishers located throughout the area and properly guarded?	[ ]	[ ]	[ ]
Are all fire extinguishers cleaned, and inspected monthly for proper working condition?	[ ]	[ ]	[ ]
Emergency lighting working and checked monthly?	[ ]	[ ]	[ ]
Fire hose(s) connected to standpipe and in good condition?	[ ]	[ ]	[ ]
Exposed extinguishers that could freeze protected against freezing?	[ ]	[ ]	[ ]
Fire sprinkler system, are sprinkler heads unobstructed?	[ ]	[ ]	[ ]
Fire sprinkler system "Major" valve(s) identified and labeled?	[ ]	[ ]	[ ]
All fire alarms in proper working order and tested per facility's schedule?	[ ]	[ ]	[ ]
Signage:			
Exit door?	[ ]	[ ]	[ ]
Non-exit doors?	[ ]	[ ]	[ ]
Restricted areas?	[ ]	[ ]	[ ]
Specific caution areas?	[ ]	[ ]	[ ]
Specific requirements, e.g. Wheel chocks?	[ ]	[ ]	[ ]

REFRIGERATED STORAGE ROOMS:	**Yes**	**No**	**NA**
Cleanliness, swept and vacuumed per facility sanitation schedule?	[ ]	[ ]	[ ]
Floor surface smooth, free of ruts, holes, bumps, etc?	[ ]	[ ]	[ ]
Racking in proper condition, all damaged racks reported and repaired in a timely manner?	[ ]	[ ]	[ ]
All racking systems marked with maximum pallet weight?	[ ]	[ ]	[ ]
Product stacked in an orderly and stable (no overhead hazards) condition?	[ ]	[ ]	[ ]
Required product stacked and stored per facility's HACCP program?	[ ]	[ ]	[ ]
Unused pallets neatly stored?	[ ]	[ ]	[ ]
Temperature and humidity for commodities maintained and recorded on a regular schedule?	[ ]	[ ]	[ ]
Proper lighting layout and appropriate light levels conducive to employee work area?	[ ]	[ ]	[ ]
Lots clearly identified?	[ ]	[ ]	[ ]
Customer's "Re-call" procedures up-to-date?	[ ]	[ ]	[ ]
Appropriate type of fire extinguishers located throughout the area and properly guarded and charged?	[ ]	[ ]	[ ]
Are all fire extinguishers cleaned, and inspected monthly for proper working condition?	[ ]	[ ]	[ ]
Emergency lighting working and checked monthly?	[ ]	[ ]	[ ]
Fire sprinkler system "Major" valve(s) identified and labeled?	[ ]	[ ]	[ ]
Fire sprinkler system, in-rack system free of damage and in working order?	[ ]	[ ]	[ ]
Fire sprinkler system, are sprinkler heads unobstructed?	[ ]	[ ]	[ ]

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All fire alarms in proper working order and tested per facility's schedule?	[ ]	[ ]	[ ]
Floor surface smooth, free of ruts, holes, bumps, etc?	[ ]	[ ]	[ ]
Are the aisles clearly marked?	[ ]	[ ]	[ ]
Are the aisles clear, free of slippery areas?	[ ]	[ ]	[ ]
Is protection against damage by forklift provided and in proper condition?	[ ]	[ ]	[ ]
Freezer doors in proper working order?	[ ]	[ ]	[ ]
Are the evaporators inspected per facility's maintenance schedule?	[ ]	[ ]	[ ]
Signage:			
Exit door?	[ ]	[ ]	[ ]
Non-exit doors?	[ ]	[ ]	[ ]
Restricted areas?	[ ]	[ ]	[ ]
Specific caution areas?	[ ]	[ ]	[ ]
Specific requirements, e.g. blast freezer?	[ ]	[ ]	[ ]

USDA AREA:	**Yes**	**No**	**NA**
Cleanliness, swept, vacuumed and washed down per facility sanitation schedule?	[ ]	[ ]	[ ]
Floor surface smooth, free of ruts, holes, bumps, etc?	[ ]	[ ]	[ ]
Proper lighting layout and appropriate light levels conducive to work area?	[ ]	[ ]	[ ]
Wall surface smooth, free of holes, etc?	[ ]	[ ]	[ ]
Is there appropriate hot water supply for clean up?	[ ]	[ ]	[ ]
Is there a mixing valve or separate hot water supply for washing hands?	[ ]	[ ]	[ ]
Are all required equipment USDA approved?	[ ]	[ ]	[ ]
All cleaning supplies have a USDA approved label or met local USDA approval?	[ ]	[ ]	[ ]
Appropriate type of fire extinguishers located throughout the area and properly guarded?	[ ]	[ ]	[ ]
Are all fire extinguishers cleaned, and inspected monthly for proper working condition?	[ ]	[ ]	[ ]
Emergency lighting working and checked monthly?	[ ]	[ ]	[ ]
Fire hose(s) connected to standpipe and in good condition?	[ ]	[ ]	[ ]
Exposed extinguishers that could freeze protected against freezing?	[ ]	[ ]	[ ]
Fire sprinkler system, are sprinkler heads unobstructed?	[ ]	[ ]	[ ]
Fire sprinkler system "Major" valve(s) identified and labeled?	[ ]	[ ]	[ ]
All fire alarms in proper working order and tested per facility's schedule?	[ ]	[ ]	[ ]
Signage:			
Exit door?	[ ]	[ ]	[ ]
Non-exit doors?	[ ]	[ ]	[ ]
Restricted areas?	[ ]	[ ]	[ ]
Specific caution areas, e.g., High Voltage?	[ ]	[ ]	[ ]
Specific requirements, e.g. blast freezer?	[ ]	[ ]	[ ]

EMPLOYEES' WELFARE AREA:	**Yes**	**No**	**NA**
Cleanliness, swept and mopped per facility sanitation schedule?	[ ]	[ ]	[ ]
Are all trash cans emptied daily?	[ ]	[ ]	[ ]
Are all employees' lockers cleaned on a regular schedule?	[ ]	[ ]	[ ]
Proper lighting layout and appropriate light levels conducive to the area?	[ ]	[ ]	[ ]
Are the walls surface clean, smooth, free of holes, etc?	[ ]	[ ]	[ ]
Is there appropriate hot water supply?	[ ]	[ ]	[ ]
Is there proper ventilation, heating, and cooling in all areas?	[ ]	[ ]	[ ]
Is there a non-smoking area?	[ ]	[ ]	[ ]
Is there an appropriate locked storage area for janitor's supplies?	[ ]	[ ]	[ ]

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Bulletin boards — conspicuous location, posted with current material and all legally mandated notifications?	[ ]	[ ]	[ ]
Are appropriate type of fire extinguishers located throughout the area?	[ ]	[ ]	[ ]
Are all fire extinguishers cleaned, and inspected monthly for proper working condition?	[ ]	[ ]	[ ]
Emergency lighting working and checked monthly?	[ ]	[ ]	[ ]
Fire hose(s) connected to standpipe and in good condition?	[ ]	[ ]	[ ]
Fire sprinkler system, are sprinkler heads unobstructed?	[ ]	[ ]	[ ]
Fire sprinkler system "Major" valve(s) identified and labeled?	[ ]	[ ]	[ ]
All fire alarms in proper working order and tested per facility's schedule?	[ ]	[ ]	[ ]
Signage:			
Exit door?	[ ]	[ ]	[ ]
Non-exit doors?	[ ]	[ ]	[ ]
Restricted areas?	[ ]	[ ]	[ ]
Specific caution areas, e.g., High Voltage?	[ ]	[ ]	[ ]
Specific requirements, e.g. Wash Hands?	[ ]	[ ]	[ ]

ENGINE ROOM:	**Yes**	**No**	**NA**
Is the type of refrigerant and system charge conspicuously posted?	[ ]	[ ]	[ ]
Is a daily engine room log maintained?	[ ]	[ ]	[ ]
Is the daily engine room log reviewed by all Department Heads?	[ ]	[ ]	[ ]
Are all valves, pipes, switches, etc., clearly identified or color coded?	[ ]	[ ]	[ ]
Bulletin boards — conspicuous location, posted with current material and all legally mandated notifications?	[ ]	[ ]	[ ]
Is a prescribed maintenance program regularly followed and maintenance log books kept?	[ ]	[ ]	[ ]
Is the area cleaned on a regular schedule?	[ ]	[ ]	[ ]
Proper lighting layout and appropriate light levels conducive to employee work area?	[ ]	[ ]	[ ]
Proper self-closing container provided for oil, rags, combustibles, etc?	[ ]	[ ]	[ ]
Are all guards in place on all exposed machinery?	[ ]	[ ]	[ ]
Switchboard handles and switches properly identified?	[ ]	[ ]	[ ]
Non-grounding mats or platforms by all switchboards?	[ ]	[ ]	[ ]
High voltage warning signs properly placed?	[ ]	[ ]	[ ]
Proper clearance maintained around switchboard?	[ ]	[ ]	[ ]
Refrigerant leak detectors operational with regular calibration, testing and are maintenance log book kept?	[ ]	[ ]	[ ]
Emergency refrigerant ventilation equipment clearly marked, accessible, and in proper working order?	[ ]	[ ]	[ ]
Have the local fire department been invited for their annual walk-through?	[ ]	[ ]	[ ]
Appropriate type of fire extinguishers located throughout the area and properly guarded?	[ ]	[ ]	[ ]
Are all fire extinguishers cleaned, and inspected monthly for proper working condition?	[ ]	[ ]	[ ]
Emergency lighting working and checked monthly?	[ ]	[ ]	[ ]
Fire hose(s) connected to standpipe and in good condition?	[ ]	[ ]	[ ]
Exposed extinguishers that could freeze protected against freezing?	[ ]	[ ]	[ ]
Fire sprinkler system, are sprinkler heads unobstructed?	[ ]	[ ]	[ ]
Fire sprinkler system "Major" valve(s) identified and labeled?	[ ]	[ ]	[ ]
All fire alarms in proper working order and tested per facility's schedule?	[ ]	[ ]	[ ]
If your emergency response plan requires the use of your employees have they had their schedule drills?	[ ]	[ ]	[ ]
Are all exterior valves for the refrigeration system properly locked and monitored?	[ ]	[ ]	[ ]
Are all overhead lifting devices clearly marked with lifting capacity?	[ ]	[ ]	[ ]

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Signage:

Exit door?	[ ]	[ ]	[ ]
Non-exit doors?	[ ]	[ ]	[ ]
Restricted areas?	[ ]	[ ]	[ ]
Specific caution areas, e.g., High Voltage?	[ ]	[ ]	[ ]
Specific requirements, e.g. Hearing Protection?	[ ]	[ ]	[ ]

REPAIR SHOP:	**Yes**	**No**	**NA**
Convenient, safe stowage for all tools and supplies?	[ ]	[ ]	[ ]
Convenient, safe stowage for all Personnel Protective Equipment?	[ ]	[ ]	[ ]
Condition of handtools — check for mushroom heads, loose handles, dullness, etc?	[ ]	[ ]	[ ]
Are all ground fault outlets working properly?	[ ]	[ ]	[ ]
Grounding provided for all power tools?	[ ]	[ ]	[ ]
Is the area cleaned on a regular schedule?	[ ]	[ ]	[ ]
Proper lighting layout and appropriate light levels conducive to employee work area?	[ ]	[ ]	[ ]
Proper self-closing container provided for oil, rags, combustibles, etc?	[ ]	[ ]	[ ]
Are all fire extinguishers cleaned, and inspected monthly for proper working condition?	[ ]	[ ]	[ ]
Emergency lighting working and checked monthly?	[ ]	[ ]	[ ]
All flammable material(s) stored only in Underwriters approved container(s) complete with flash screens and self-closing lids?	[ ]	[ ]	[ ]
Are all guards in place on all exposed machinery?	[ ]	[ ]	[ ]
Are all overhead lifting devices clearly marked with lifting capacity?	[ ]	[ ]	[ ]

Signage:

Exit door?	[ ]	[ ]	[ ]
Non-exit doors?	[ ]	[ ]	[ ]
Restricted areas?	[ ]	[ ]	[ ]
Specific caution areas, e.g., High Voltage?	[ ]	[ ]	[ ]
Specific requirements, e.g. Eye Protection?	[ ]	[ ]	[ ]

MATERIALS HANDLING:	**Yes**	**No**	**NA**
Pallets kept in good repair?	[ ]	[ ]	[ ]
Does all handling equipment have data plates, listing capacity and height?	[ ]	[ ]	[ ]
Is the "Pre-operating" checklist used routinely for all handling equipment?	[ ]	[ ]	[ ]
Lift trucks equipped with overhead guards?	[ ]	[ ]	[ ]
All mechanical equipment regularly maintained and logs kept?	[ ]	[ ]	[ ]
Elevators routinely inspected?	[ ]	[ ]	[ ]
Elevators in good condition, cables, gates, safety devices operating properly?	[ ]	[ ]	[ ]
Elevator shafts safely enclosed?	[ ]	[ ]	[ ]
Extinguishers on all fork trucks; where required?	[ ]	[ ]	[ ]
Batteries and battery charging equipment properly maintained?	[ ]	[ ]	[ ]

BUILDING:	**Yes**	**No**	**NA**
Overall appearance, condition of building maintained properly?	[ ]	[ ]	[ ]
Building insulation?	[ ]	[ ]	[ ]
Doors?	[ ]	[ ]	[ ]
Windows?	[ ]	[ ]	[ ]
Paint?	[ ]	[ ]	[ ]
Gutters and downspouts, etc?	[ ]	[ ]	[ ]

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Building approaches?	[ ]	[ ]	[ ]
Entrances?	[ ]	[ ]	[ ]
Yards?	[ ]	[ ]	[ ]
Walks?	[ ]	[ ]	[ ]
Driveways?	[ ]	[ ]	[ ]
Blind spots properly marked?	[ ]	[ ]	[ ]
Stairways?	[ ]	[ ]	[ ]
Condition of treads?	[ ]	[ ]	[ ]
Hand rails?	[ ]	[ ]	[ ]
Lighting in good condition?	[ ]	[ ]	[ ]
Use of paint to emphasize potential hazard/no traffic areas?	[ ]	[ ]	[ ]
Adequate and safe parking spaces?	[ ]	[ ]	[ ]
Electrical:			
All electrical equipment properly identified?	[ ]	[ ]	[ ]
All wiring properly supported and tightly connected at junction and outlet boxes?	[ ]	[ ]	[ ]
All wiring, BX cables, etc. in good condition?	[ ]	[ ]	[ ]
Motors, transformers, etc., properly grounded?	[ ]	[ ]	[ ]
All fuses/circuit breakers right size and type and properly maintained?	[ ]	[ ]	[ ]
Transformer enclosure in proper location and in good repair?	[ ]	[ ]	[ ]
High voltage warning signs properly placed?	[ ]	[ ]	[ ]
Non-grounding mats or platforms by all open switchboards?	[ ]	[ ]	[ ]
Heating Equipment:			
Safety pilots and automatic fuel shutoffs on oil or gas furnaces chimneys, flues, etc., clean?	[ ]	[ ]	[ ]
Insulation on steam pipes in good condition, especially where pipes penetrate walls?	[ ]	[ ]	[ ]
Safety valves, pressure gauges working properly?	[ ]	[ ]	[ ]
Miscellaneous:			
All company owned vehicles in proper working order?	[ ]	[ ]	[ ]
Have all public liability hazards in and around facility been identified?	[ ]	[ ]	[ ]
First Aid Kits convenient locations, properly stocked, etc?	[ ]	[ ]	[ ]
Are the following Personal Protective Equipment (PPE) used at your facility?			
Safety shoes?	[ ]	[ ]	[ ]
Hard hats?	[ ]	[ ]	[ ]
Eye Protection ?	[ ]	[ ]	[ ]
Eye wash stations?	[ ]	[ ]	[ ]
Hearing protection (High noise area)?	[ ]	[ ]	[ ]
Gloves, for chemical protection?	[ ]	[ ]	[ ]
Rubber aprons, for chemical protection?	[ ]	[ ]	[ ]

EMPLOYEE TRAINING:	**Yes**	**No**	**NA**
Have all appropriate employees been trained in the following:			
Manual lifting Facility Back-care Program?	[ ]	[ ]	[ ]
Facility's House Rules?	[ ]	[ ]	[ ]
Employee Emergency Action Plan?	[ ]	[ ]	[ ]
Employee Fire Protection Plan?	[ ]	[ ]	[ ]
Facility's Emergency Response Plan?	[ ]	[ ]	[ ]
Employee Alarm System?	[ ]	[ ]	[ ]
Portable Fire Extinguisher?	[ ]	[ ]	[ ]
Personal Protective Equipment?	[ ]	[ ]	[ ]
Respiratory Protection?	[ ]	[ ]	[ ]

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Occupational Noise Exposure?	[ ]	[ ]	[ ]
Access to Employee Exposure & Medical Records?	[ ]	[ ]	[ ]
Medical Services and First Aid?	[ ]	[ ]	[ ]
Regular safety meetings?	[ ]	[ ]	[ ]
Bloodborne Pathogens?	[ ]	[ ]	[ ]
Asbestos Awareness?	[ ]	[ ]	[ ]
Lockout Tagout of Hazards Energy?	[ ]	[ ]	[ ]
Permit Required Confined Spaces?	[ ]	[ ]	[ ]
Power Industrial Trucks?	[ ]	[ ]	[ ]
Hazard Communication?	[ ]	[ ]	[ ]
Accident Prevention, Signs and Tags?	[ ]	[ ]	[ ]
Hot Work Permits?	[ ]	[ ]	[ ]
Oxygen-fuel gas welding and cutting?	[ ]	[ ]	[ ]
Resistance Welding?	[ ]	[ ]	[ ]
Process Safety Management?	[ ]	[ ]	[ ]
Risk Management Program?	[ ]	[ ]	[ ]
Hand and Portable Power Tools?	[ ]	[ ]	[ ]
Guarding of Portable Powered Tools?	[ ]	[ ]	[ ]
Other Portable Tools and Equipment?	[ ]	[ ]	[ ]

SITE SPECIFIC:	**Yes**	**No**	**NA**
_____	[ ]	[ ]	[ ]
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Comments:

Inspector Signature

Date

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2.4 Sanitation

For information on general environmental controls related to sanitation, please refer to OSHA standard 1910.141, avaialble at www.osha.gov. The full link is below:

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9790

Chapter 3: Structural

Acknowledgements

Anthony D. Ooten, Primus Design Services, LLC, Woodstock, Georgia, USA

Joseph Bove, PE Stellar, Jacksonville, Florida USA

3.1 Design

3.1.1 Introduction

The primary goal of any structural design is to assure human safety. The secondary goal is to minimize property damage and remain functional if the structure must withstand a critical natural event. Structural design of a cold storage distribution warehouse is straightforward in comparison to many buildings. However, combining all structural elements and considerations specific to cold storage warehouses can become a complex task.

3.1.2 Types of Design Options for Construction

Low rise distribution centers require large open floor spaces and clear heights up to 60' to accommodate storage systems. Therefore, the most suitable structural system is invariably an open space frame consisting of steel columns supporting structural steel and open web steel joists and joist girders. The system allows large bay spacing which provides maximum flexibly for storage rack layout. Options to conventional structural steel buildings do exist, most notably pre-engineered metal buildings (PMB). However, PMBs are most economical when used to provide minimal "shade and shelter" and therefore are not recommended for cold storage buildings. Large lateral flexibility found in many metal buildings can be detrimental to the all-important thermal envelope. The refrigeration system of evaporators, condensers and piping can also impart substantial loads on the structure and be somewhat sensitive to excessive building movement.

Exterior walls in cold storage warehouses are most commonly insulated metal panels which rely on steel members called girts to support the panels against deflection due to thermal bow and wind loads. Exterior steel columns carry the girts and are most efficient to support vertical roof loads and lateral loads from wind. As an option to IMP walls supported by steel framing, insulated precast walls can be considered. However, most distribution warehouses have clear heights that make precast walls impractical without the use of girts and columns to carry wind load. Furthermore, creating a thermal envelope at the interface between concrete panel and roof/underslab insulation is much more problematic.

The structure remains stable against lateral loads through a resisting system consisting of a roof diaphragm and vertical resisting elements which carry lateral loads into the foundations. Steel roof deck serves as a horizontal diaphragm and gains stiffness with fasteners into the roof framing system. An alternative to steel deck diaphragm is a horizontal truss system which consists of steel tension members – often angles- attached below the roof framing system and forming a truss to transfer loads to the vertical resisting element. Steel deck is most often used as the diaphragm in low rise warehouses since it can provide excellent stiffness with a relative small increase in fasteners.

Several options also exist for vertical resisting elements. Concentric steel braced frames are most often chosen over steel moment frames and concrete shear walls. Concentric cross-braced frames provide excellent stiffness against building drift and are more economical than moment frames especially considering the height of most warehouses. Concrete shear walls are a good option for economics and stiffness, but as mentioned above, concrete walls are not good structural choices for exterior walls on distribution warehouses due to lateral forces acting perpendicular to the wall.

Although there are options, the preferred structural system for cold storage warehouses remains structural steel space frames, steel deck diaphragms and vertical cross braced frames.

3.1.2.1 Foundation Systems

A geotechnical exploration and evaluation must be performed at each site to determine a suitable foundation system to support the building structure. The two most common foundation systems for low rise distribution center building structures are shallow support systems and deep support systems.

Shallow systems consist of independent spread footings to support building columns, reinforced grade beams spanning between spread footings to support perimeter wall loads, and shallow retaining walls to support unbalanced grades such as found a dock face.

Deep support systems can be in several forms. Drilled piers with under-reamed bells are generally larger diameter reinforced underground columns. They are on the order of 24 to 60 inches and extend to depths ranging from 12 feet to 25 feet below the ground surface. These systems are often used in areas where expansive soil is prevalent and the depth is as required to penetrate the expansive layer. Under reamed bells are required to increase bearing area and to provide an anchor against expansive soils attempting to lift the pier by means of skin friction on the straight sides.

Auger cast piles are slender underground cast-in-place concrete columns with minimal reinforcing - normally one bar. They are of smaller diameter on the order of 12 inches, much deeper on the order to 60 feet or more. Steel or precast driven piles are similar to auger cast piles in size and depth. They are pre-manufactured and are installed by driving, or “hammering” into the ground. Groups of piles are required to support

concentrated loads such as at building columns. Pile groups are always encased at the top with pile caps and or grades beams to equally distribute the loads and provide lateral support.

Storage rack systems within the structure are supported by mat foundations most notably concrete slabs on grade. Sub-base preparation is all important in the performance of a slab on grade. If a strong base can be prepared, the mat slab on grade can be designed as unreinforced. Otherwise, a structural slab supported by piles, a post-tensioned slab, or a ribbed waffle slab must be used.

3.1.2.2 Seismic Zone Consideration

Until recently, the United States was divided into seismic zones 0 through 4 which was relative to potential ground motion during a seismic event. Two new systems of classification have been developed replacing the old "seismic zones". They are Seismic Performance Category (SPC) and Seismic Design Category (SDC).

SPC considers not only the site seismicity but also the occupancy of the structure. The development of SDCs resulted from recognition that forces imparted to a building during an earthquake result not only from sub-surface rock motion, but also the site-specific type of soil upon which the structure is directly founded. Local and national building code requirements for seismic detailing are based upon the new classification of SDC.

There is an economic impact resulting from assigned SDC. SDC "A" is the least restrictive and SDC "E" (or even "F" in extreme cases) is the most restrictive. Buildings in SDCs D and higher are required to be detailed using an additional national steel code and some structural systems are not permitted in the higher SDC categories. Furthermore mechanical, electrical, and architectural components are all effected by increasing seismic design categories.

While the West Coast is known as a hot bed for seismic activity, geographic areas centered near Memphis, TN and Charleston, SC can have building sites situated in high SDCs.

3.1.2.3 Clear Heights

Building clear height requirements are a function of the owners planned storage requirements. Almost all building elements are effected as the structure grows taller. Longer columns require more stiffness to carry the same weight. Wind loads are greater at higher elevations therefore the lateral stiffness of the roof diaphragm and vertical cross-braces needs to be increased. Wind uplift (suction) on the roof is greater requiring stiffer roof elements and larger footings to anchor the roof structure against wind uplift. Perimeter columns are deeper to resist wind loads against the walls. Seismic loads are effected as the majority of the building weight is raised higher above the base.

Storage and distribution facilities have been growing taller and taller. Not many years ago, 40 feet clear was considered a tall building. Recently 40 feet clear has become

the norm and heights as tall as 60 feet are more common for structural steel buildings. Above 60 feet, the economics of an open space frame are reduced more rapidly and rack-supported structures become an attractive alternative.

3.1.2.4 Pallet Weights

Pallet weights in storage systems range from 1500 pounds to 3500 pounds per pallet as a common range. The weights effect the rack structure and can also effect the building structure most notably the slab on grade. The slab must be thickened or reinforced to support heavier rack leg loads due to heavier pallet weights. Heavier pallet weights also mean higher seismic loads must be considered. In the case of self-supporting racks inside an open space frame structure, separation of the racks and building columns must be addressed to prevent damage in a seismic event.

3.1.3 Checklist of Items to Consider

- Governing building codes and local amendments
- Special design loads required by the owner or insurance underwriters
- Effect of all equipment on the structure
- Areas of intended future expansion
- Geotechnical recommendations
- Availability of materials
- Thermal conducting through steel elements into the sub-slab and warmer rooms
- Roof slope and drainage
- Rain ponding stability
- Roof deflection
- Wall support and girt detection
- Building frame drift
- Building expansion joints.
- Slab on grade control joints
- Building expansion joints
- Vibration of elevated equipment and mezzanines
- Corrosion and moisture control

3.2 Structural Design of a Warehouse Building

Industrial warehouse buildings are facilities designed to accommodate the durable goods intended to be stored. Generally, the overall facility complex includes receiving and shipping docks, warehouse areas, and infra-structure support spaces to service the operation such as maintenance shop, refrigeration engine room, electrical, etc. and a welfare area for the employed staff. Some warehouse spaces are designed for specific temperatures while others are convertible, or have the ability to alter the operating temperature based on the perishable product requirements. The building structures and

associated materials of construction are selected for performance and longevity, availability, speed of construction and economics.

The four most common superstructures are:

1. Conventional Steel
2. Rack Supported
3. Pre-engineered
4. Pre-cast Concrete

3.3 Conventional Steel Warehouse Building Overview

Conventional warehouse building structures are characterized by their use of steel frames comprised of standardized structural steel members that support the building envelope's roof, walls, and utility equipment at the superstructure level, and use of cast in place concrete foundation elements at the substructure level. These conventional buildings generally do not exceed heights above 60' and achieve additional storage space by expanding horizontally. When building floor space accommodates multiple types of operations and uses such as production lines, cold and dry warehousing, distribution docking, and office space, conventional buildings become an attractive option due to their flexibility in usage. It is advantageous to space the interior building columns anywhere from 40' to 60' away from each other in order to maximize unobstructed floor area. This unobstructed floor area could accommodate freestanding racking systems that are independent of the building framing.

3.3.1 Roof Framing

Working from the top down, the roof of a conventional building serves two primary structural purposes, the first of which is the vertical support of sustained dead loads such as roof membranes, insulation, and the deck, and the support of transient live loads, such as snow and human traffic. The second primary purpose of a roof is the horizontal transmission of lateral wind and seismic forces through diaphragm action. Corrugated metal roof deck attached to the roof framing system with screw fasteners, powder actuated fasteners, or puddle welds is a common deck system, and can serve as rigid diaphragm with a concrete topping and studs, or as a flexible/pseudo flexible diaphragm as is. The metal deck and fastening system is an example of an element within the roofing system that contains the structural shear capacity necessary to transmit these forces to the vertical braces and/or moment frames.

The roof system and rooftop utilities are supported by framing members such as open web K-type and LH-type joists and standard AISC wide flange sections. Generally, for large open bays on the order of 1600 to 3600 sq. ft., primary joist girder and secondary joist members are most economical for vertical gravity load support. In some instances, wide flange girder primary members and wide flange beam secondary members are used for their resisting capacity of inconsistent and heavily concentrated loading patterns. A

common rule of thumb for wide flange beam design, assuming moderate uniform loading, is the depth of the beam in inches should be roughly the span of the beam in feet divided by two.

3.3.2 Columns

Columns are used to support the roof and roof framing systems and are generally hollow structural steel (HSS) or wide flange (WF) sections, with HSS columns generally being the more economical choice. In addition, exterior columns also serve as the support system for the vertical building envelope. The vertical building envelope of a conventional building is generally comprised of a skin such as an insulated metal panel, and a secondary horizontal spanning member supporting the skin called a girt. Girts can be wide flange or channel sections, and are generally oriented with the strong axis facing the exterior of the building to provide maximum resisting capacity to out of plane wind loads and other lateral loads the building envelope may be exposed to.

3.3.3 Lateral Bracing

Designated columns and roof members in addition to bracing members and/or specially designed moment connections can be utilized as lateral frames for the purpose of resisting wind and seismic lateral forces. The bracing members can be angle, rod, or HSS members, and effectively serve as web members in vertical truss systems that transmit tension and compression forces to the foundation system. Various configurations of bracing systems exist, such as concentrically braced, x-bracing as an example, and eccentrically braced, k-bracing or v-bracing as examples. Depending on the bracing configuration, the lateral forces can travel through the frame in different load paths. The ideal bracing configuration is the x-brace, which is due to its high stiffness and corresponding deflection resistance. In addition, the x-brace has the ability to yield more economical brace sections due to possible tension only bracing load paths.

In the case that there is limited room for bracing members within a frame, utilizing moment frame connections is recommended. However, when possible, the use of moment connections is usually avoided due to their limited resistance to lateral deflection and labor intensiveness. These connections consist of an arrangement of plates, bolts and/or welds. The strategic placement of these elements achieves a fixed type of member fixity, which transmits lateral forces to the foundation through the development of moment, or torque, in frame members.

3.3.4 Foundations

When soil conditions are optimum, conventional building columns are generally supported on shallow spread footings, and building walls on continuous footings. For interior building elements such as floor mounted equipment and storage racking, a slab on grade or structural slab generally serves as a foundation. When overturning forces and/or high concentrated forces are applied to slab foundations, top and bottom reinforcement is generally provided to assist in resolving the tension component of flexural bending. For many applications with moderate and uniform loading, a simple slab on grade with minimum temperature and shrinkage reinforcement will be sufficient.

Different racking systems and arrangement patterns may be used for warehouse operations; therefore, a thorough slab analysis is required to determine which system is necessary.

3.3.5 Geotechnical Implications and Considerations

When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, advanced foundation systems such as drilled piers, helical auger piles, micropyles, and rammed aggregate piers are often utilized. These alternative foundation solutions enable the superstructure loads to be transmitted to competent soil strata, or spread the loads out over a larger surface area. In some cases, when shallow spread footing and continuous footing foundations bear on clayey and silty fine grained soils, differential settlement, hydrostatic uplift and frost heaving, and in extreme cases liquefaction may occur leading to structural failure. In cases where unsuitable soils exist in isolated areas, it is possible to economically remove and replace localized portions of the deficient subsurface soil with compacted structural fill of acceptable soil properties. Project site subsurface characterization information is obtained from a geotechnical report, and is crucial for the determination of applicable and feasible foundation systems.

3.4 Rack Supported Warehouse Building Overview

Rack supported buildings are very efficient when it comes to the utilization of space for the purposes of storage and retrieval operations. Often, these buildings utilize an automated storage and retrieval system (AS/RS), characterized by its use of automated cranes, elevators, carts, product racking, and software control systems. Rack supported warehouses can be constructed as high as 140 feet, and in many cases, accommodate over 20 vertical pallet levels. This type of technology enables the building footprint to be condensed into a smaller area, which is highly beneficial in areas where land is expensive. On the other hand, the possibility of multiple operation types is unavailable due to the highly-specialized nature of this building type. Possibly the most unique element of a rack supported building is its use of the rack system to support not only itself, but the building envelope's walls and roof. Because the building structure and racking system in a rack supported building are integrated, the possibility of depreciating the combined system as equipment, as opposed to a building, exists. If this potential tax benefit is utilized, the rate of depreciation could be much steeper, making this building type an attractive option for warehousing applications.

3.4.1 Roof Framing

The structural roof system of a rack supported building is generally the same as that of a conventional building, utilizing corrugated metal deck as a diaphragm, and open web trusses or standard AISC sections as roof framing members. One distinct characteristic of rack supported buildings is the large number and short unbraced lengths of framing members. As the unbraced length, defined to be the greatest distance between

points of buckling resistance in a member with compressive forces either by flexural bending or axial compression, of a structural member increases, the section properties, such as linear self-weight and cross-sectional area, necessary to prevent failure tend to increase as well. Because of the close proximity of rack columns to each other, the horizontal primary and secondary framing members can achieve light and condensed section dimensions.

3.4.2 Columns

The columns in a rack supported building can vary between being hot rolled or cold formed, standard tubular or built-up sections, and simple gravity members or as part of a tower braced frame. In addition, columns are generally spaced closely together, which distributes superstructure loads much more evenly across the foundation system, as compared with other building types. Because of the numerous pallet levels these buildings accommodate, the columns are laterally braced against buckling very frequently, thus allowing the sections to be light and condensed. This is in stark contrast to columns of a conventional building which are generally only braced at the foundation and roof levels, yielding heavy and broad sections.

3.4.3 Lateral Bracing

The lateral bracing system of a rack supported building is characterized by the use of tall and slender bracing towers, comprised of many light and condensed members. Generally, angle members are utilized as both tension and compression diagonal braces, as well as struts to transfer load and engage adjacent braces. With the many pallet loading configurations possible, the analysis complexity can be extensive. For this reason, far more load combinations may apply in contrast to other building types, in particular in high seismicity zones where the product mass magnitude, configuration, and proximity to bracing towers can be highly variable.

3.4.4 Foundations

In the construction phase of a rack supported building project, high wind uplift forces may be generated and imposed on foundation elements, as pallet loads may not present to counteract overturning forces. Generally, a structural slab on grade with top and bottom reinforcing bars is utilized to resist these types of concentrated overturning forces. Rack / building columns generally do not have their own dedicated foundation system, such as shallow footings, because of the high number of column locations as well as relatively uniform spreading of loads. In cases where an automated storage and retrieval system is used, slab levelness is critical, as these systems are very sensitive and may derive their precision from laser systems referenced to the finished slab elevation.

3.4.5 Geotechnical Implications and Construction

When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, advanced foundation systems such as matt or raft foundations, drilled piers, and rammed aggregate piers are often utilized. These alternative foundation solutions enable the superstructure loads to spread

the loads out over a larger surface area. Note that subsurface characterization information is obtained from a geotechnical report, and is crucial for the determination of applicable and feasible foundation systems.

3.5 Pre-Engineering Metal Warehouse Building Overview

A pre-engineering metal building (PEMB) is generally characterized by its use of light gauge metal roof and wall cladding members, low cost of materials, fast erection times, and large clear spans between columns. PEMBs typically utilize moment frames as the primary lateral load resisting system; therefore, these types of buildings are relatively flexible and can have significant lateral drift. This inherent lateral flexibility can have detrimental implications for sensitive finishes and/or equipment if not carefully addressed. In addition, due to marginal designs, resulting in the potential cost effectiveness that is typically sought after, PEMBs are generally inflexible for future modification and/or expansion.

3.5.1 Roof Framing

The roof framing and roofing system dead loads of a PEMB are very light, on the order of 3 PSF, in comparison to other warehousing building types. This lightweight nature can be attributed to the marginal overdesign of roof framing members, often containing just a few percentage points of additional stress capacity beyond the minimum loading requirements. Standing seam metal deck is commonly used, which utilizes a horizontal bracing system to transfer lateral loads to the vertical bracing system. In addition, standard corrugated metal deck can also be used as a flexible diaphragm as an alternative to standing seam and horizontal bracing roof systems.

Secondary roof framing members are usually light gauge cold formed c- or z-section purlins, and are generally spaced closely, at 5' on center, due to their relatively small flexural capacities. In addition, primary roof framing members are commonly constructed out of steel plates, forming custom or built-up I-sections. As mentioned earlier, these members are designed very near their required minimum capacity, and contain multiple tapers along their span in order to conform specifically to shear and moment envelope demands.

3.5.2 Columns

PEMB columns are typically built-up sections, similar to the primary roof framing members, or standard AISC wide flange sections. Frequently, columns will have a haunch and stiffener plates at the beam connection point in order to eliminate buckling failure points and develop shear and moment forces through the connection. Because of the light nature of these buildings, there can be high net uplift forces transmitted through the columns and into the foundation system. A robust column anchorage system, consisting of a base plate, anchor bolts, and possibly tension and shear reinforcing bars, is often required to resist the high concentrated wind and/or seismic forces at the column base.

3.5.3 Lateral Bracing

As mentioned earlier, the lateral bracing system in a PEMB often consists of moment frames, but can also include x-bracing or shear walls to form a hybrid system if lateral deflections become excessive with just moment frames. In general, as the clear span of a PEMB increases, roof framing and column members increase in size due to higher gravity flexural stresses. This increase in member sizes is directly proportional to an increase in frame stiffness, which ultimately translates into a reduction in lateral building drift. On the other hand, as frame member spans decrease, they become more flexible and produce higher deflections.

In addition to resisting lateral forces such as those developed during wind and seismic events, the bracing system also needs to resist the horizontal component of the roof gravity loads. This is due to the fact that common gabled roof configurations impose a lateral thrust force. A common lateral drift consideration when dealing with PEMBs, is the interaction between the framing and wall systems. In cases where masonry walls are utilized as the building's vertical envelope, it is imperative that lateral drifts are even further minimized, so as to eliminate failure at wall corners.

3.5.4 Foundations

PEMB foundation systems can effectively utilize a structural slab on grade system with thickened edges at column locations, or a slab on grade with minimum shrinkage and temperature reinforcement and dedicated column footings. Because superstructure dead loads can be very small, large net uplift forces must be counteracted by the foundation system self-weight. In many cases, the design of the foundation system is controlled by the counteracting weight requirement over soil limitations. In addition to vertical superstructure loads generated by overturning forces, horizontal shear reactions generated by lateral wind, seismic, and gravity thrust forces also need to be resisted by the foundation system. In order to resist these lateral shears, a combination of hair-pin reinforcing bars and the slab on grade act as tension members to resist the shear in the direction where concrete edge distances are the shallowest. Hair-pin bars are typically bent around the anchor bolt group, and develop the shear forces imposed at the column base into the slab on grade along their lengths. Further, a thickened slab or grade beam may be necessary to transfer shear forces along braced sections. Coordination and care must be taken to ensure continuity of the slab system.

3.5.5 Geotechnical Implications and Considerations

When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, advanced foundation systems such as matt or raft foundation, drilled piers are often utilized. These alternative foundation solutions enable the superstructure loads to be transmitted to competent soil strata, or spread the loads out over a larger surface area. In some cases, when shallow spread footing and continuous footing foundations bear on clayey and silty fine grained soils, differential settlement, hydrostatic uplift and frost heaving, and in extreme cases liquefaction may occur leading to structural failure. In cases where unsuitable soils exist

in isolated areas, it is possible to economically remove and replace localized portions of the deficient subsurface soil with compacted structural fill of acceptable soil properties. Project site subsurface characterization information is obtained from a geotechnical report, and is crucial for the determination of applicable and feasible foundation systems.

3.6 Precast Concrete Warehouse Building Overview

Precast / prestressed structural elements typically utilize high tensile strength prestressed reinforcing strands, which increase load carrying capacities, and enable longer clear spans that may not be possible and/or feasible with sections utilizing just conventional reinforcing bars. Because of the strict manufacturing and quality control procedures typically utilized in plant casting of precast concrete products and the durable nature of the constituent elements, these buildings can reduce maintenance costs and achieve long service lives. Further, local material sourcing and manufacturing, high thermal mass and insulation properties, use of recycled materials, such as fly ash and silica fume, and ability to be recycled, once crushed, into road base and construction fill, enable precast concrete to be a sustainable and environmentally friendly alternative to other warehouse building types.

Construction times for precast concrete buildings can be short, as superstructure members can be fabricated while foundation work is being performed. In addition, the manufacture of precast components in factory-controlled conditions enables uninhibited production, regardless of weather conditions or site staging requirements. An inter Wythe consisting of ridged insulation can be cast into the elements along with a vapor barrier for the purposes of developing a thermal wall element. Lastly, aesthetic features such as embedded stone, brick, or tile veneers, texturing and profiling, and coloration can be integrated into precast / prestressed structural elements. This type of flexibility may generate economical and effective ways of achieving architectural function and appeal for a building.

3.6.1 Roof Framing

The roof framing system in precast concrete warehouse structures is generally comprised of double-T beams and inverted-T girders. The double-T beams serve as both the secondary framing members, as well as the roof deck itself. Stitching the flange portion of double-T sections together creates a rigid diaphragm, capable of transferring high shear loads to the vertical bracing system. The roof insulation and membrane can simply be adhered to the top of the double-T flange, creating a simple yet effective roofing system. Depending on the clear span of the framing members, beam camber could pose an issue at the beam to girder connection, where a significant valley might form. In these cases, it might be necessary to provide a cast in place concrete topping in order to maintain a continuous slope of proper proportions for drainage.

Secondary double-T beams are generally supported by primary inverted-T girders, where the stems of the double-T bear on the flange ends of the inverted-T. Clear spans on the order of 60’ to 80’ are possible due to the prestressed effect of the high tensile

strength reinforcing tendons on the surrounding concrete. Specifically, prestressing induces a larger and stronger compressive stress zone within the member section, which serves to overcome higher tensile stresses developed through flexural bending. This revolutionary technology enables concrete to overcome its inherent weakness to tensile stress.

3.6.2 Columns

Precast concrete building columns are typically square in section, and utilize vertical and horizontal reinforcing bars to resist horizontal shear and bending moment. Typically, a cage of reinforcement is utilized within the column profile, comprised of vertical bars, which resist lateral flexural bending, spaced close to the perimeter of the column section, and horizontal ties, which resist horizontal shear, wrapped around the vertical bars. Since columns primarily act as compression members, there generally is not a need for prestressing strands to offset any high tensile stresses. However, prestressing tendons may be used in axial load bearing members along the building perimeter, where high out of plane wind loads may generate tensile stresses as a result of flexural bending. Precast columns are typically cast monolithically with a corbel, which is a short hunched cantilever bracket extending off of the column face. Corbels require precise reinforcement detailing, as significant loads must be transferred, through bearing, from the primary girder members to the column through these elements. Precast concrete columns typically resist very high vertical roof dead loads on the order of 60-70 PSF. By contrast, conventional steel framed building roof dead loads generally do not exceed 20-30 PSF. As a result, precast concrete column sections are generally no smaller than 18 inch or 24-inch square.

3.6.3 Lateral Bracing

Precast concrete buildings typically utilize shear walls as their lateral resisting system. Shear walls effectively serve as vertical cantilever beams, transferring superstructure lateral forces down to the foundation system. Because the roof diaphragm is rigid, non-uniform loading will generate torsional forces, therefore it is recommended that two shear walls, at each extreme of the diaphragm be provided, with their principal axes perpendicular to the lateral loads they are designed to resist. Further, designing shear walls as load bearing is highly advantageous, as vertical gravity loads assist in resisting uplift and overturning forces. Shear walls can come in many forms, such as insulated sandwich wall panels, litewalls, or solid wall panels. In addition, a hybrid lateral bracing system, comprised of both steel x-braces and shear walls is also an effective option. Precast concrete buildings are generally subject to significantly higher seismic demands, as member weights are considerable higher than those in other building types. As a result, more robust lateral resisting systems are typically required in high seismicity zones.

Insulated sandwich panels are an effective option for cold storage warehouse applications due to their high thermal insulation properties. These panels are generally constructed out of one layer of high-performance insulation, sandwiched in between two

layers of concrete. The composite section yields a highly energy efficient system, and is a popular alternative, even in non-precast warehouse projects.

3.6.4 Foundations

As with other building types, columns are typically supported on cast in place spread footings, and bearing walls on cast in place continuous footings or grade beams. Because superstructure loads are generally significantly higher than those of other building types, larger foundation members are usually necessary to distribute loads out over more soil surface area. For moderate and uniform equipment and racking loads, a slab on grade with minimum shrinkage and temperature reinforcement will generally be sufficient.

3.6.5 Geotechnical Implications and Considerations

When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, advanced foundation systems such as drilled piers, helical auger piles, driven piles and rammed aggregate piers are often utilized. These alternative foundation solutions enable the superstructure loads to be transmitted to competent soil strata. Project site subsurface characterization information is obtained from a geotechnical report, and is crucial for the determination of applicable and feasible foundation systems.

Building Type vs. Typical Structural System Matrix

		Building Type			
		Conventional	Rack Supported	Pre-Engineered Metal Building	Precast
Typical Structural System	Roof Diaphragm	Corrugated Mt'l Deck	Corrugated Mt'l Deck	Standing Seam & Horiz. Bracing or Corrugated Mt'l Deck	Double-T Beam Flange w/ or w/o Concrete Topping
	Roof Framing	WF Section and/or Joist / Joist Girder	Open Web Steel Truss or Standard AISC Section	Light Gauge C- or Z-Purlin, Built-Up I-Section, or Open Web Joist / Joist Girder	Double-T Beam & Inverted-T Girder
	Lateral Bracing	Braced Frame, Moment Frame, and/or Shear Wall	Braced Frame and/or Moment Frame	Moment Frame, Braced Frame, and/or Shear Wall	Shear Wall and/or Braced Frame
	Vertical Gravity Framing	WF, HSS Column, and/or Wall Panel	Rack Post / Column	WF, HSS, and/or Built-Up Section	Concrete Column and/or Wall Panel
	Foundation	Shallow & Continuous Footing w/ Slab-on-Grade	Structural Slab-on-Grade	Structural Slab-on-Grade and/or Shallow & Continuous Footing	Shallow & Continuous Footing w/ Slab-on-Grade

3.7 Rack Supported Building Versus Conventional Building

Rack supported buildings have become a popular approach to modern warehousing techniques. Emphasis is placed on the advantages of this concept, which is relatively new to refrigerated warehouses.

3.7.1 Discussion

There are quite a few similarities between rack supported buildings and conventional constructed buildings. They can both utilize any style of racking. Both can also be serviced by any type of material handling equipment. The method of refrigeration can be the same for either concept. The use of standard insulation and roof construction can be used on either.

Rack supported buildings offer a better utilization of the cube than does conventional construction. This is accomplished by eliminating the duplication of building steel. Elimination of the steel reflects a reduction in square footage required. This

reduction in square footage reduces both time required to construct the facility and the overall cost of construction.

Foundation loads are greatly reduced due to the dispersion of wind and roof loads over many rack columns. Distribution of floor loads will reduce the foundation design and minimize site work. Not only does this reduce the cost of the foundation but also the time required to do the site work.

Roof trusses are also affected by the dispersal of load over all of the rack columns, reducing the depth required to carry the roof. This will reflect in vertical space reduction, thus requiring a shorter building than conventional, with a reduction in the cost of building steel.

The design of the rack supported building is the responsibility of the engineering staff of the rack manufacturer and not the responsibility of the customer's architect.

Numerous styles of storage systems can be incorporated into a rack supported building. Any type of outer material can be applied to the building. It is suggested that height be dictated by the design of refrigeration offered to avoid the stratification that can be a problem in high-rise systems and in compliance with local building codes. Expansion of a rack supported building is economical in comparison to a conventional building.

Although there have been numerous installations to form a procedure to offer incentives, to date, the Internal Revenue Service has not formally adopted a standard for rack supported buildings. A rack supported building is generally considered capital equipment and the cost of the structure can have an accelerated write off, unlike conventional buildings.

Conventional construction, unlike rack supported buildings, offers flexibility in allowing the owner to re-arrange the racking system after the facility is constructed. This single source concept of a rack supported building makes the financing of a rack supported building more difficult than a conventional structure.

3.7.2 Conclusion

There are many advantages for public refrigerated warehousemen to seriously consider rack supported facilities for their future plans. In public refrigerated warehousing, the maximum utilization of the cube is the major concern. A rack supported structure will offer better utilization of the cube than a conventional structure offers. There is a large misconception that rack supported buildings are used solely with high-rise applications. As you see, any racking concept can be offered in a rack supported building.

Chapter 4: Walls

Acknowledgements

Steven Mauro, Kingspan Insulated Panels, Deland, Florida, USA

4.1 Introduction

Insulated panel systems are ideally suited for thermally controlled environments such as cold storage freezers and coolers and food processing and packing facilities. Equally, insulated panel systems can be applied to atmospheric controlled environments where, in virtually all cases, finished product protection and hygienic control is of utmost importance. While not the only type of building insulation wall system in use today, insulated panel systems are by far the most common, and the subject of this section of the manual.

An Insulated Metal Panel (IMP) is a strong single unit constructed of a rigid foam core, most commonly polyurethane, sandwiched between two sheets of coated metal that provides an exceptionally strong building enclosure.

The durable metal panel facings resist damage and create a vapor barrier which offers long-term thermal stability. The metal skins also come in a multitude of colors and textures. When compared to other exterior finish options such as stucco, masonry or pre-cast concrete, the IMP provides a unique combination of water and vapor impermeability, excellent thermal performance and visual appeal.

The IMP offers high insulation values and built-in thermal breaks that significantly improve the energy efficiency of buildings, thus reducing heating and cooling costs for building owners. These built in thermal breaks prevent heat conductance from the metal exterior to metal interior skin.

The IMP is a single building enclosure element, so it speeds up project completion and can be installed in almost any kind of weather without risk to system integrity. IMPs are installed using a complete concealed fastener system that typically includes the vapor barrier, air barrier, and water barrier along with a high efficiency insulation system, thereby reducing the need for a large number of components to be installed. The lightweight nature of IMPs also provides framing and foundation savings. They are designed to meet the most demanding performance requirements, which, when combined with the inherent benefits of metal facings, requires less maintenance than most other exterior building systems.

Structures such as cold storage facilities, manufacturing plants, food processing facilities and office buildings are proven to be excellent applications for the IMP. Architecturally, the IMP offers many design options because it is available in various joint

sizes, curved and formed panels, and with a variety of high performance coatings or surface textures. Interior coatings also provide easy cleaning and sanitizing, as well as high light reflectivity.

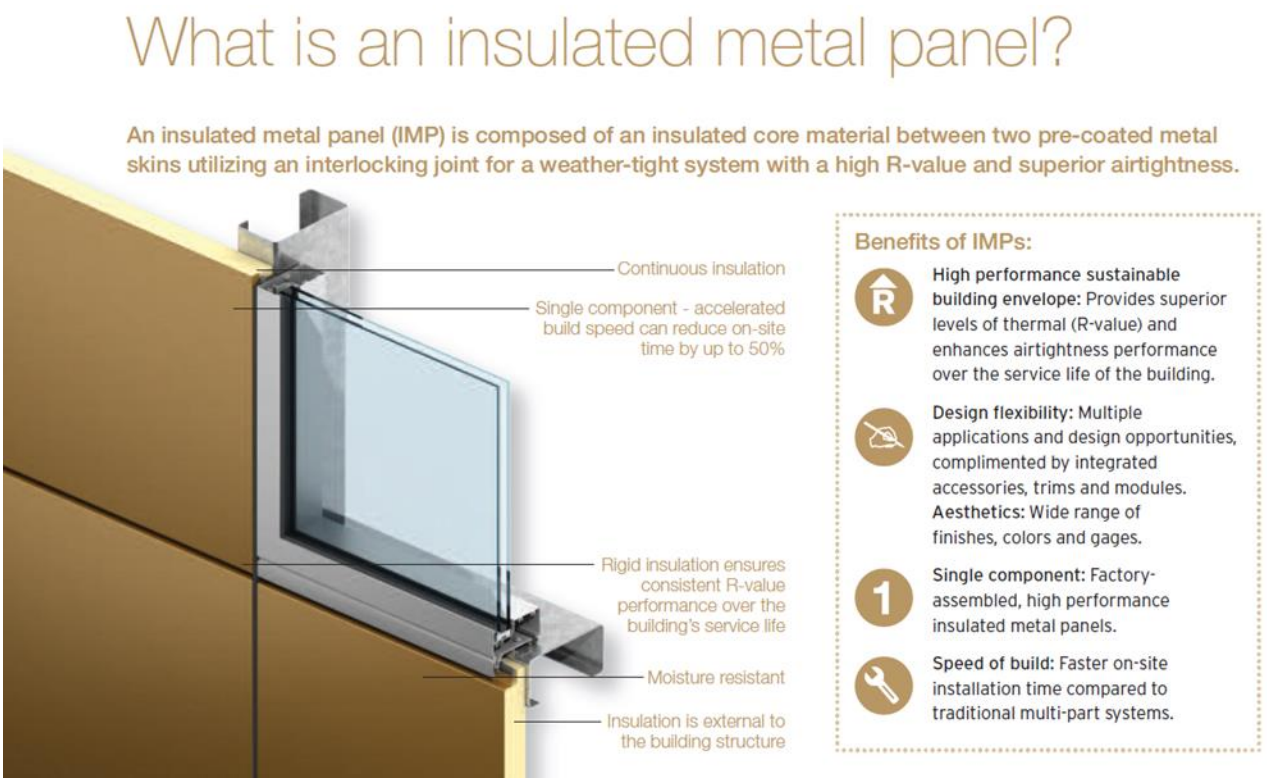
Energy consumption by buildings accounts for 39% of the energy consumed in the United States (EIA 2010). With current concerns over global warming and the associated impacts of energy consumption, energy efficiency has become dramatically more important as a design goal in buildings. Leadership in Energy Efficient Design (LEED) certification is providing a marketing benefit to energy efficient, sustainable designs. Possible future imposition of carbon taxes on energy consumption, and otherwise increasing energy costs are making the economics of energy efficient buildings increasingly favorable.

IMPs offer a variety of core material types with insulation values from R-25 to R49 for walls and insulation values of up to R-49 are available for roofs in addition to a ceiling system of R-25 to R-49. For the purpose of this guide, IMPs constructed of Modified Polyisocyanurate (PIR) were used as a baseline for cold storage wall and ceiling panels.

4.2 Design

The choice of envelope construction is based on sturdiness to endure harsh environments and a material that requires minimal maintenance. Choices are built up masonry, tilt concrete, and insulated panels, as well as various insulating materials. Factors that determine insulation choice are durability, cost, fire performance, and most importantly, thermal performance and vapor tightness. IMPs provide a highly efficient perimeter for temperature extremes from blast freezers as cold as -50°F to food manufacturing to extremes up to 180°F due to the high insulation characteristics and stability of the insulating material in the panel.

Figure 4. 1



Insulation Thickness

The R-Value of insulation required varies with the temperature held in the refrigerated space and the conditions surrounding that space. However, local code and adopted energy codes should be referenced. The range in R-Value requirements can differ due to variations in energy cost, insulation materials and climate conditions. For exact values consult a qualified Insulated Panel Manufacturer and or an Engineer of Record for the proposed use. As a baseline for current design practices and the use of current and available PIR foam panels the following values has been provided.

Thickness recommendations / R Values based on a mean insulation temperature of 35°F and ASTM C518 R = 8.25 per inch of material. As cited in the 2010 ASHRAE Refrigeration Guide, the following table identifies the recommended R-Values for various cold storage facilities and temperatures.

Recommended R-Values

Panel Thickness	Minimum R-Value	Temperature Range
3”	R-25	40 to 50°F
4”	R-33	25 to 35°F
5”	R-41	10 to -20°F

6”	R-49	-40 to -50°F

4.2.1 Specifications and Selection Criteria

Pre-insulated metal panel cladding system with insulating foam core (non fire rated use) are used for the exterior walls, partitions, liners and ceilings; including flashings, trim and other accessories to make the system complete, as indicated on the drawings and specified herein.

Metal Wall and Ceiling Panel Assembly: Metal wall and ceiling panels, attachment system components, miscellaneous metal framing, thermal insulation, sealants, and accessories are necessary for a complete a vapor tight, thermally broken system.

Performance Requirements

Test	Procedure	Description
Fire	FM-4880	Class 1 classification rating of insulated wall or wall and roof/ceiling panels, interior finish materials or coatings, and exterior wall systems to unlimited height without sprinkler protection
	ASTM E84	Flame spread <25, smoke developed <450
	CAN/ULC-S101	Standard Methods of Fire Endurance Tests of Building Construction and Materials
	CAN/ULC-S102	Standard Method of Test for Surface Building Characteristics of Building Materials and Assemblies
	ULC/ORD-C376	Fire growth of foamed plastic insulated building panels in a full scale room configuration
	CAN/ULC-S126	Standard method of test for fire spread under roof deck assemblies
	CAN/ULC-S134	Standard method of fire test of exterior wall assemblies
	UBC 26-4/NFPA 285	Intermediate multi-story fire test
	NFPA 259	Test method for potential heat of building materials
	NFPA 268	Standard test method for determining ignitability of exterior wall assemblies using a radiant heat energy source

	NFPA 286 (UBC 26-3)	Enclosed Room Corner Test
Weather & Vapor Barrier	ASTM E283	Air leakage <0.001 CFM/sq ft
	ASTM E331	No uncontrolled water penetration
	AAMA 501-94	Panel wall assembly meets air and water tightness criteria
Structural	FM-4881	Class 1 exterior wall systems
	FM-4471	Class 1 panel roofs
	ASTM E72	Standard test methods of conducting strength tests of panels for building construction
Fatigue Tests	Cyclic test to positive and negative wind loading to ± L/180 deflection	The panels exceeded 2 million alternate cycles without failure or damage
Bond Strength	ASTM D1623	Panels tested for tensile bond strength of the metal to foam interference

Structural Tests: The design load/deflection criteria shall be verified from tests per ASTM E 72 "Chamber Method" using a 20 psf simulated wind load. A deflection limit of L/180 for exterior wall panels, L/120 for partition walls and L/240 for ceiling panels shall apply. Walk On Ceilings Panel specification and support spans to be specified to support a minimum 20 psf design load. The achieved walk on ceiling psf rating depends upon the joist/purlin spacing and panel thickness.

Thermal Transmission: When tested in accordance with ASTM C 177, Steady-State heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus, the panels shall provide a K-factor of .117 btu/sf/hr/deg F at a 40°F mean temperature.

Water Penetration: There shall be no uncontrolled water penetration through the panel joints at a static pressure of 12 psf when tested per ASTM E331.

Water Absorption: Maximum 1.0 percent absorption rate by volume when tested according to ASTM C 209

Air Infiltration: Air infiltration shall not exceed .06 cfm per square foot of wall area when tested per ASTM E 283 at a static pressure of 12 psf.

Surface Burning Characteristics: The insulated core shall have been tested in accordance with ASTM E 84 for surface burning characteristics. The core shall have a flame spread of not more than 20 and a smoke developed rating of not more than 145.

Factory Mutual Research Corporation (FMRC): Standard 4880, 50' (15.24 m) High Corner Test for Unlimited Height Structures: The panel assembly shall not support a self-propagating fire which reaches any limits of the 50 foot (15.24 m) high corner test structure as evidenced by flaming or material damage of the ceiling of the assembly.

Thermal Performance: Provide insulated metal wall and ceiling panel assemblies with thermal-resistance value (R-value) indicated when tested according to ASTM C 1363 or ASTM C 518. Cold storage panels of 3", 4",5",and 6". R-Value can be tested and reported at 35° mean and 75° temperature. However for cold storage facilities most will all retain a 35° mean temperature.

Bond Strength (Fatigue Test): The panel shall withstand deflection cycling at L/180 to two million alternated cycles with no evidence of delamination, core cracking or permanent bowing.

Freeze/Heat Cycling: The panel shall exhibit no delamination, surface blistering or permanent bowing when subjected to cycle temperature extremes of -20°F (-28°C) to +180° (+82°C) for twenty-one (21) eight hour cycles.

Panel Analysis: Most manufacturers are now staffed and equipped to provide panel calculations to verify panels will withstand the design wind loads indicated without detrimental effects or deflection exceeding L/180. Include effects of thermal differential between the exterior and interior panel facings and resistance to fastener pullout. Published span charts are established for standard applications. Consult a qualified engineer or technical resource from the manufacturer for specific project requirements regarding wind and thermal loading and panel span performance.

General: Install metal wall and ceiling panels in orientation, sizes, and locations indicated on Drawings. Install panels per Insulated Metal Panel Installation Guide. Typical cold storage installations require the sealant to be applied on the warm side of the panel for a complete vapor seal. However, use of sealant is recommended in the female vertical joint on any side of the panel that is exposed to wash down. Surface caulking all exposed junctures panel junctures may also be incorporated. The combination of field applied foam; vapor tapes and sealant are common practices and should be used to fill voids behind the trims. Seal the entire edge of the trim to the walls and/or ceiling. Simply caulking the seam on the exterior is unacceptable, although a project may require this in addition to the concealed sealant on the warm side.

Expansion Provisions: Provide for thermal expansion of exposed flashing and trim. Space movement joints at a maximum of 10 feet with no joints allowed within 24 inches of corner or intersection. Where lapped or bayonet-type expansion provisions cannot be used or would not be sufficiently weather resistant and waterproof, form expansion joints of intermeshing hooked flanges, not less than 1 inch deep, filled with mastic sealant (concealed within joints).

Warranty: Most manufacturers provide a standard (2) two year warranty providing panels to be free from defects in materials and workmanship, beginning from the date of shipment of panels, excluding coil coating (paint finishes) that are covered under a separate warranty.

Finish Warranties: Paint manufacturers' finish warranties range from five (5) to twenty (20) year limited warranty on paint finish against cracking, peeling, blistering, chalk and color change. NOTE: Please consult the panel manufacturer for warranties the interior painted surface of the panel. This is particularly important in food processing environments where the rate and application and concentration of chemicals used in wash down applications can't be controlled or monitored by the panel manufacturer. Consult your manufacturer for applicable non-painted surfaces in these environments.

Installation: Always consult a company specializing in the management and installation of Low Temperature or Controlled Environment work with documented experience or approved and trained by the manufacturer.

Manufacturers: The following manufacturers are recognized by the GCCA, IARW and CEBA as acceptable IMP manufacturers of continuous line foam-in-place insulated PIR/PUR foam panels for the cold storage industry

- Kingspan Insulated Panels – Deland Florida
- Metl-Span an NCI Company – Lewiston, Texas
- All Weather Insulated Panels / Vicwest – Vacaville, California
- GreenSpan Panels - Waller, Texas

PANEL MATERIALS

The following is provided as a summarized specification and further demonstrated by specifications and technical product information from each manufacturer. For the basis of this document, the physical properties of Kingspan Panels are being utilized.

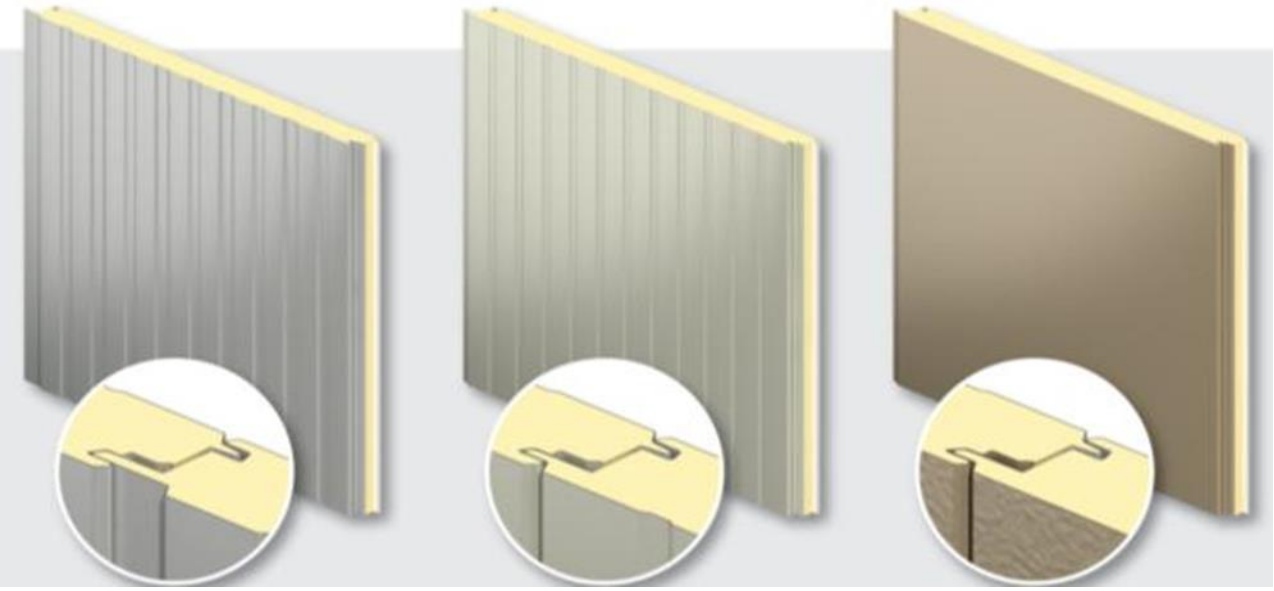
Wall System	Minor Rib/Shadowline/Mesa
Panel Thickness	3", 4", 5" and 6" per the requirements of the project
Core	Modified polyisocyanurate density of 2.0-2.6 lbs. / cu.ft.
Panel Width	40" -45" wide X Length up to 50'-66'
Facing	Hot dipped, commercial quality pre-coated 26-gauge galvanized steel conforming to ASTM A755/A755M, ASTM A446/A446M, Grade D, Coating Designation G-90. Or A653: Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) 26 ga. AZ50 Grade CS-B Embossed
Finish	Exterior: Standard 1.0 mil. Modified Polyester; Siliconized Modified Polyester or 70% PVDF Kynar – Energy Star SRI compliant
Warranty	Manufacturers 2yr – Panel Warranty

Finish Warranty	20 year finish warranty for exterior; 10 year finish warranty for interior sheet materials

4.2.2 Wall Types

Exterior Profiles: Typically referred to as Mesa, Fluted, or Inverted Rib Exteriors. Also available in a heavy embossed non-profiled panel. They are typically 40”-42” wide.

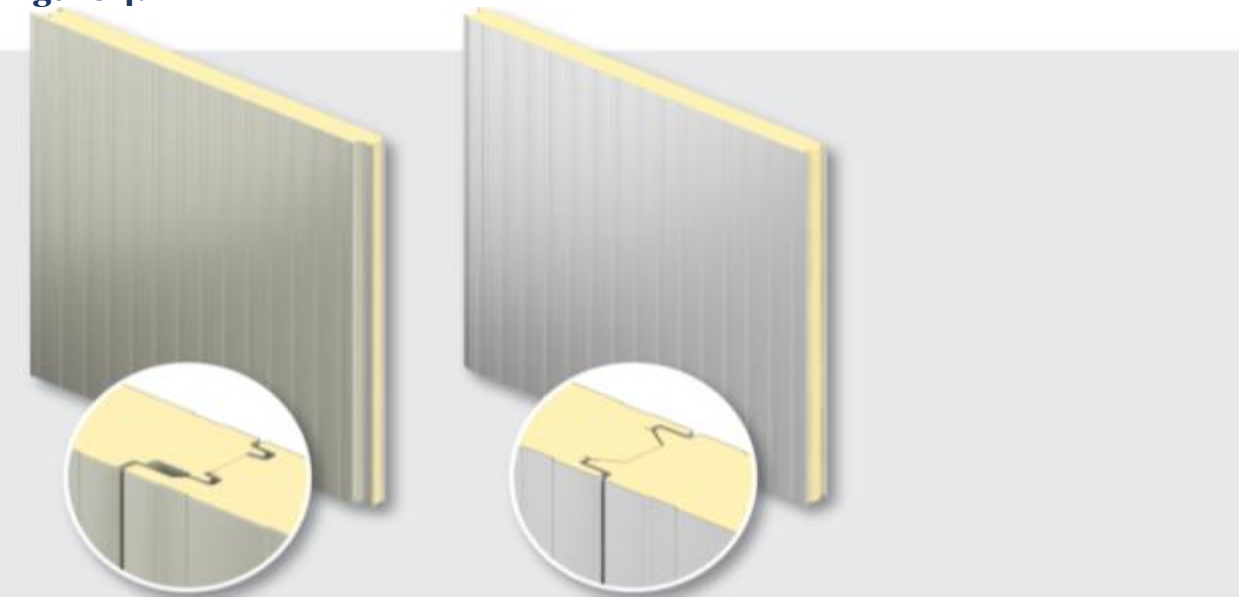
Figure 4.2



Source: Kingspan Insulated Panels 2012

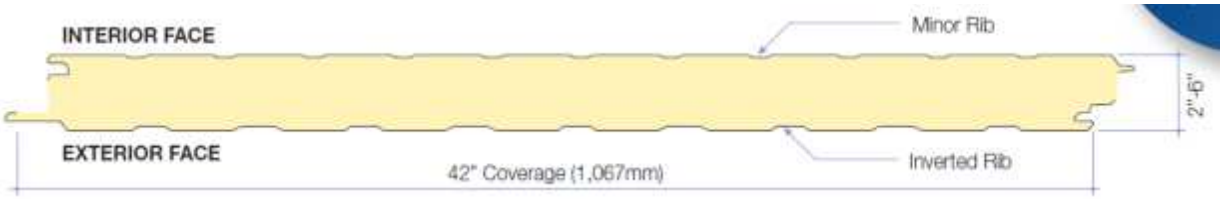
Interior Partition Panels and profiles: Typically referred to as Shadowline, Minor Rib, Light Mesa. They are typically 42”-45” wide.

Figure 4.2



Source: Kingspan Insulated Panels 2012

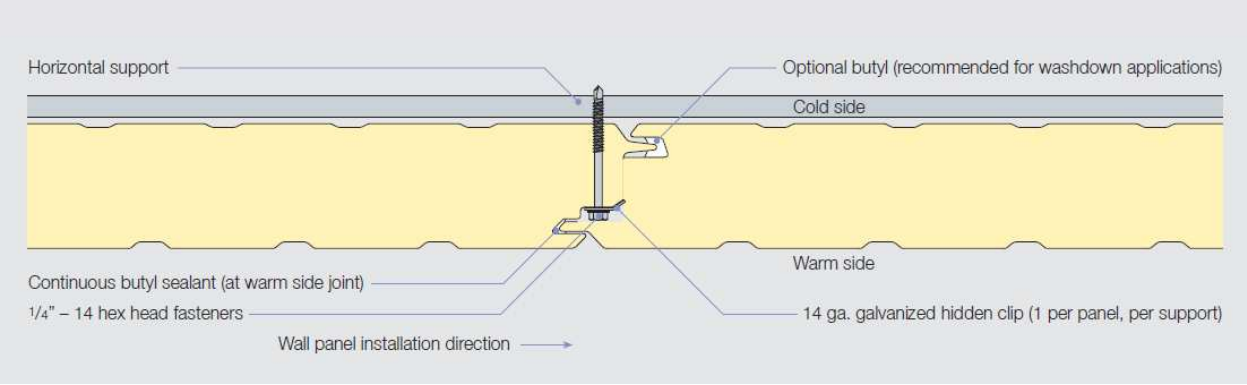
Figure 4.4



Source: Kingspan Insulated Panels 2012

Wall Panel Joints: Typically offset or parallel interlocking double tongue and groove with concealed fastener attachment and vapor seal on the warm side of the joint. Panel fasteners attach both faces of the panel at the connections of the panel ends to the support framing to conform to the requirements of the wall panel's fire resistance rating. The side joint of the wall panel shall have flush double tongue and groove joinery of the metal faces and foam to foam contact for uninterrupted continuity of the Polyisocyanurate core.

Figure 4.5



Source: Kingspan Insulated Panels 2012

4.2.3 Manufacturing Processes

Current panel manufacturing processes include de-continuous and continuous foam in place panel construction. Many of the past practices of structurally laminated panels for the warehouse and distribution market have gone by the way side as efficiencies in production and equipment improved on the continuous line process.

There are three main chemical components needed to make polyurethane insulation for continuous line panels:

- MDI/Isocyanate
- Polyol
- Blowing agent

Polyols provide the opportunity for proprietary performance:

- Catalysts; Flame retardants;Surfactants; Processing additives/aids to a base polyol

Polyurethane foam classification can be broken down to two different types of products:

- PUR (Polyurethane)
- PIR (Polyisocyanurate)

Most manufacturers fall under one or the other acceptable processes to promote and allow for the manufacture of PIR or PUR foam:

- Blowing agents are required to be environmentally compliant. The blowing agents are non-CFC HCFC used have zero ODP (Ozone Depletion Potential) and negligible GWP (Global Warming Potential).

- With closed cell content of the foam measured as high as 98%, this traps the gasses which allows for the insulation property of the product to work.

The following images represent an example of a continuous foam manufacturing process as seen in today's factories:

Figure 4.6 Full Continuous Line



Source: Kingspan Insulated Panels 2012

Figure 4.7: Double Coil Feed Up Station



Source: Kingspan Insulated Panels 2012

Figure 4.8: Profiling Mill



Source: Kingspan Insulated Panels 2012

Figure 4.9: Cooling Rack



Source: Kingspan Insulated Panels 2012

Figure 4.10: Stacker and Packaging



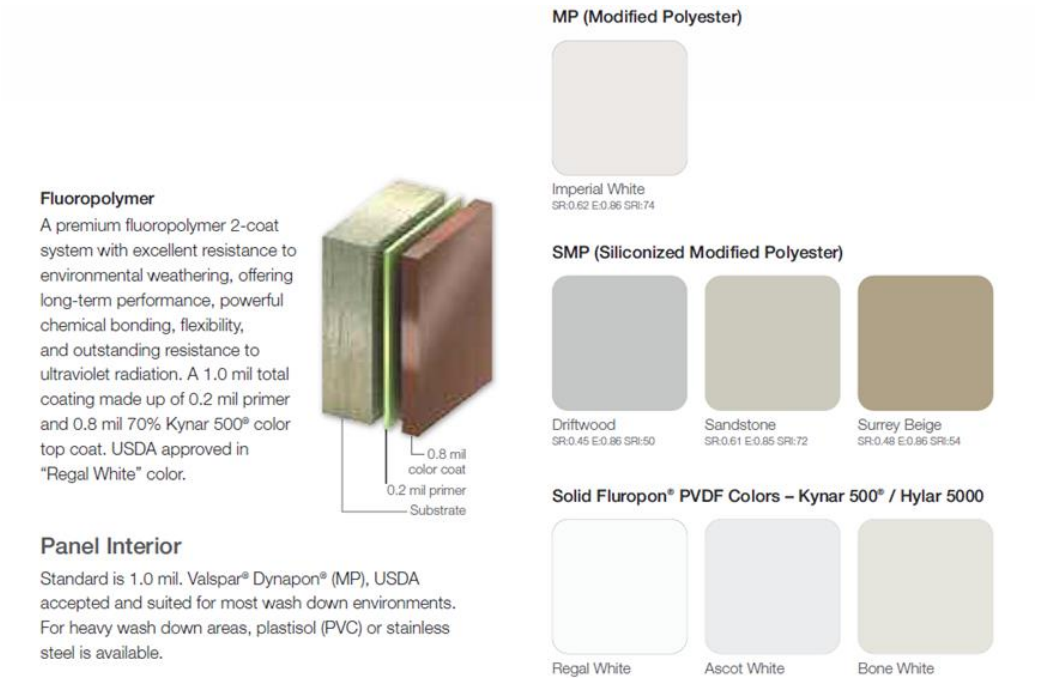
Source: Kingspan Insulated Panels 2012

4.2.4 Coatings

Figure 4.11: Exterior/Interior Facing Options



Figure 4.12: Panel Finishes



Exterior face sheet shall be treated with 0.2 mil (5 microns) base primer, followed by a nominal 0.7 mil (17.5 microns) full strength 70% PVF2 fluoropolymer (Kynar) coating in USDA accepted Imperial White or Sandstone. If Sandstone finish is used, it may be necessary to increase the steel thickness to prevent thermal bow and compression buckling. Panel supplier will determine to what extent this is necessary.

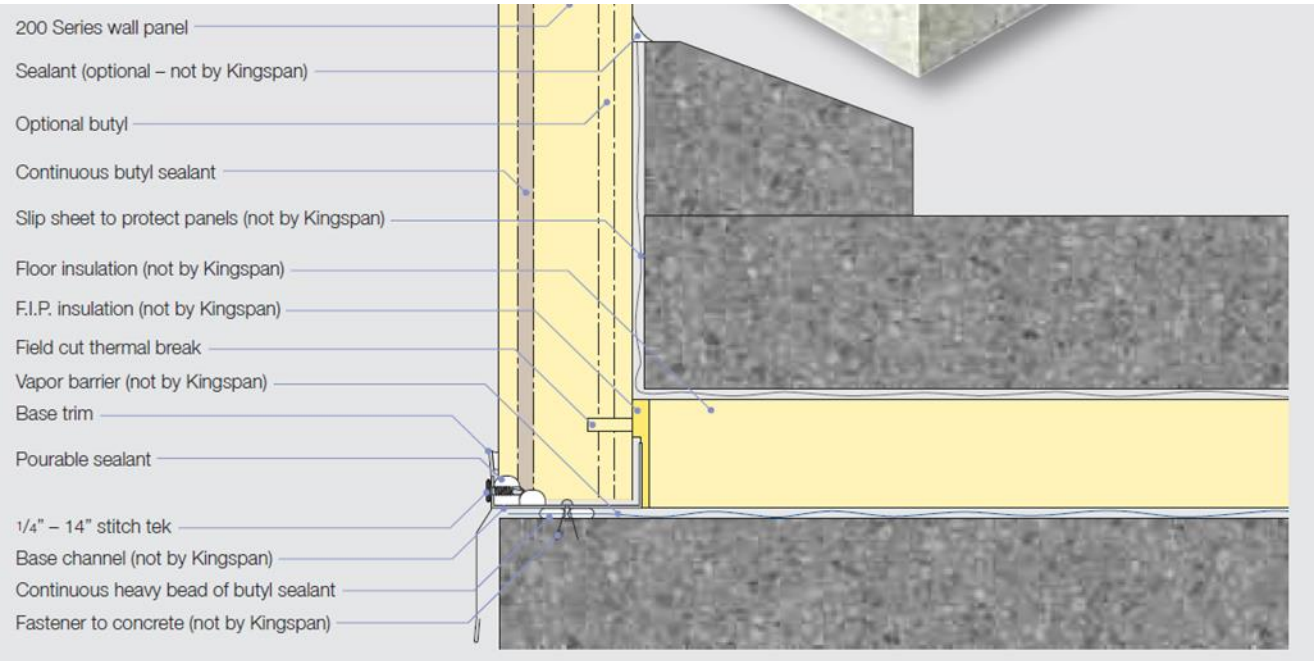
Interior sheet shall be 0.2 mil (5 microns) primer and a nominal 0.7 (17.5 microns) full strength 70% PVF2 fluoropolymer (Kynar) finish in USDA accepted White or USDA accepted Modified Polyester White.

Cooler/Freezer	Imperial White – Embossed Kynar
Processing/High Wash Down	Imperial White – Embossed Kynar or 3042B SS / 316 SS

Finish guideline shall be used to determine Modified Polyester (MP); Siliconized Modified Polyester (SMP); Kynar (KN); Vinyl Plastisol (PVC) or Stainless Steel(SS).

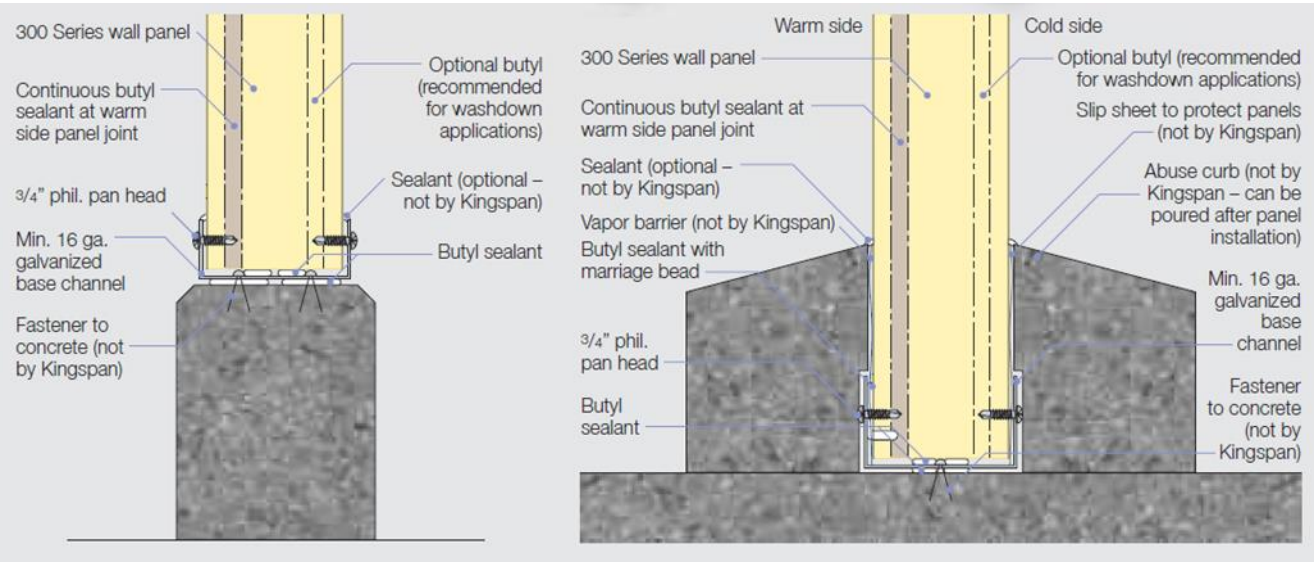
4.2.5 Critical Requirements and Details of Walls

Figure 4.13: Exterior Base Detail



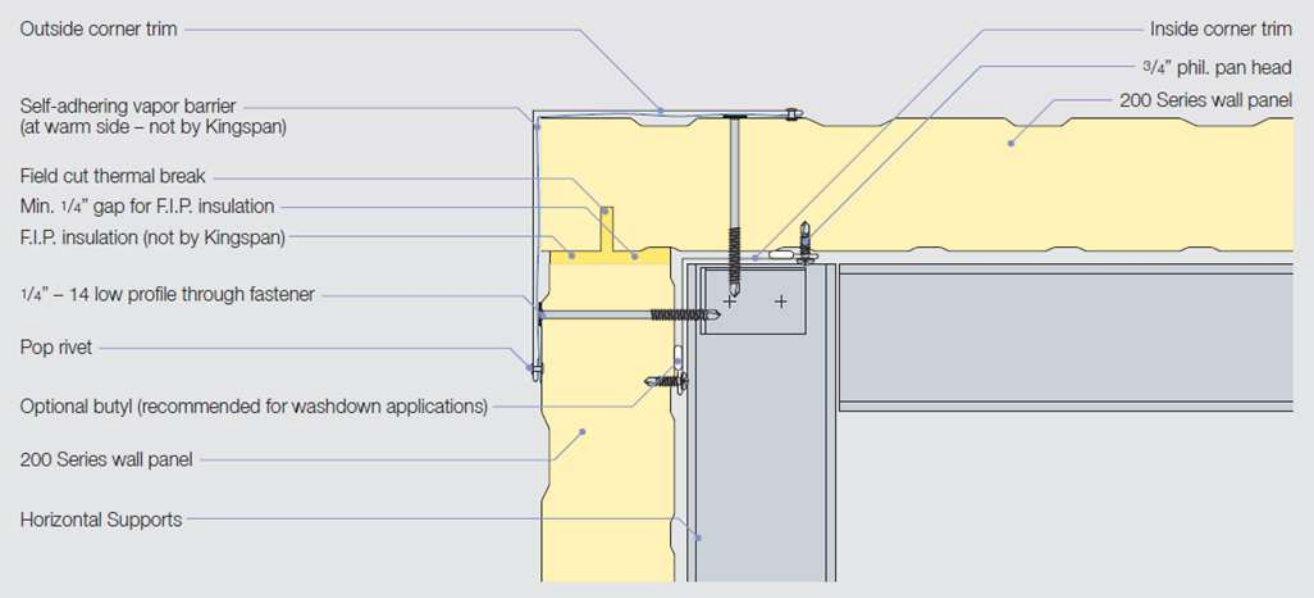
Source: Kingspan Insulated Panels 2012

Figure 4.14: Interior Partition Base Detail



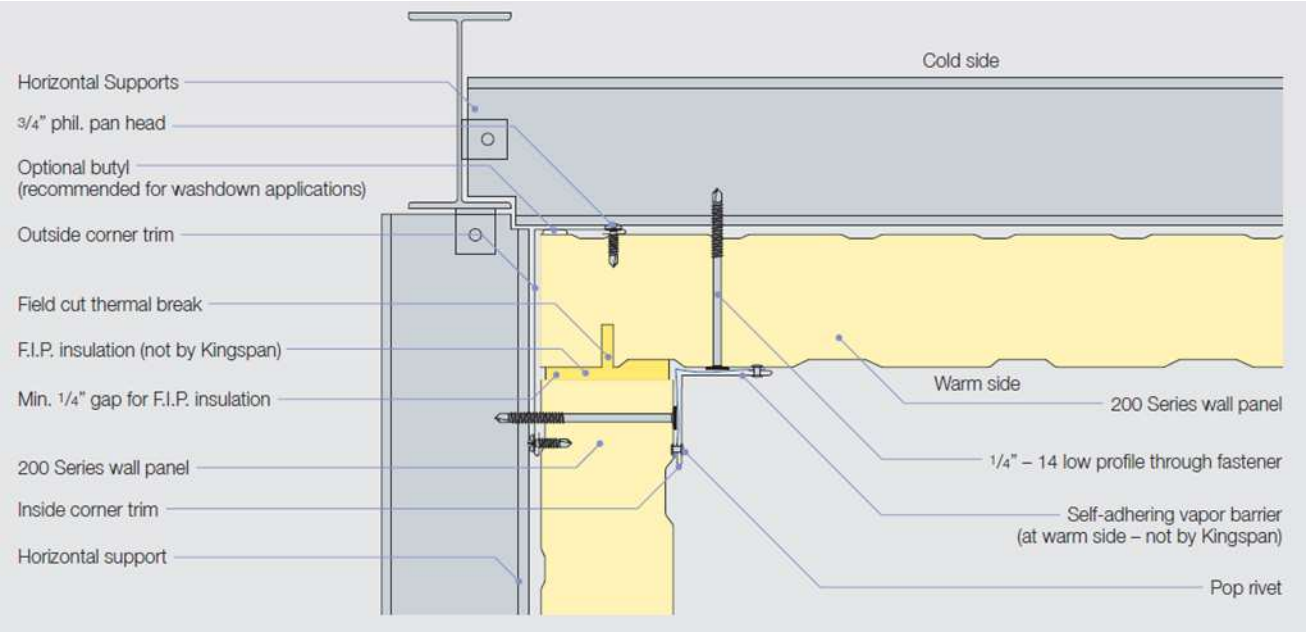
Source: Kingspan Insulated Panels 2012

Figure 4.15: Outside Corner Trim



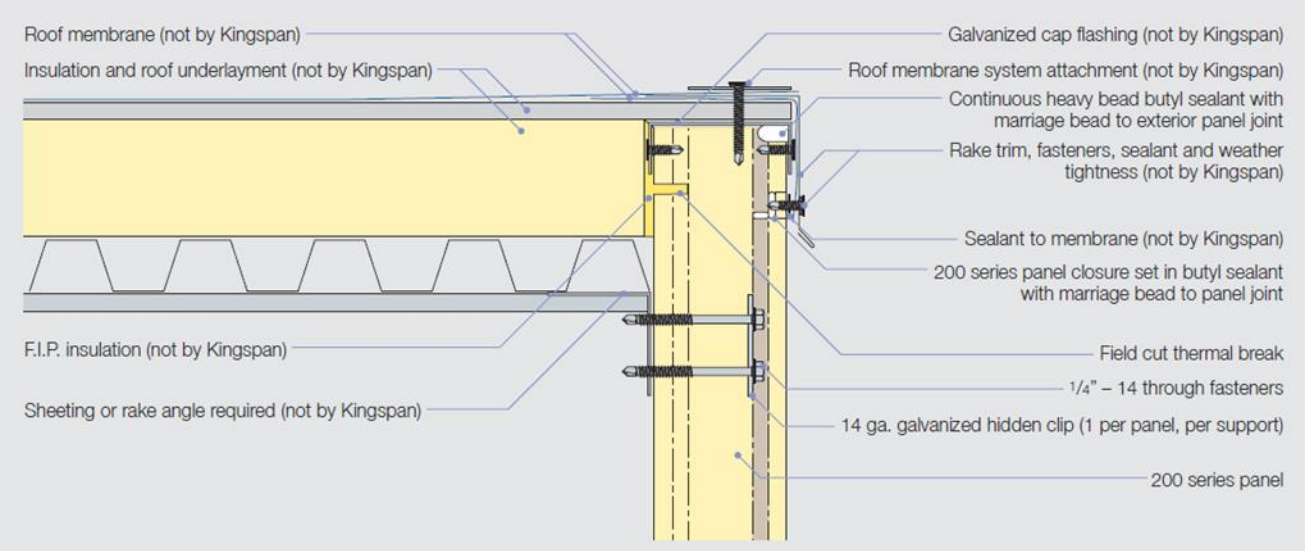
Source: Kingspan Insulated Panels 2012

Figure 4.16: Inside Corner Trim



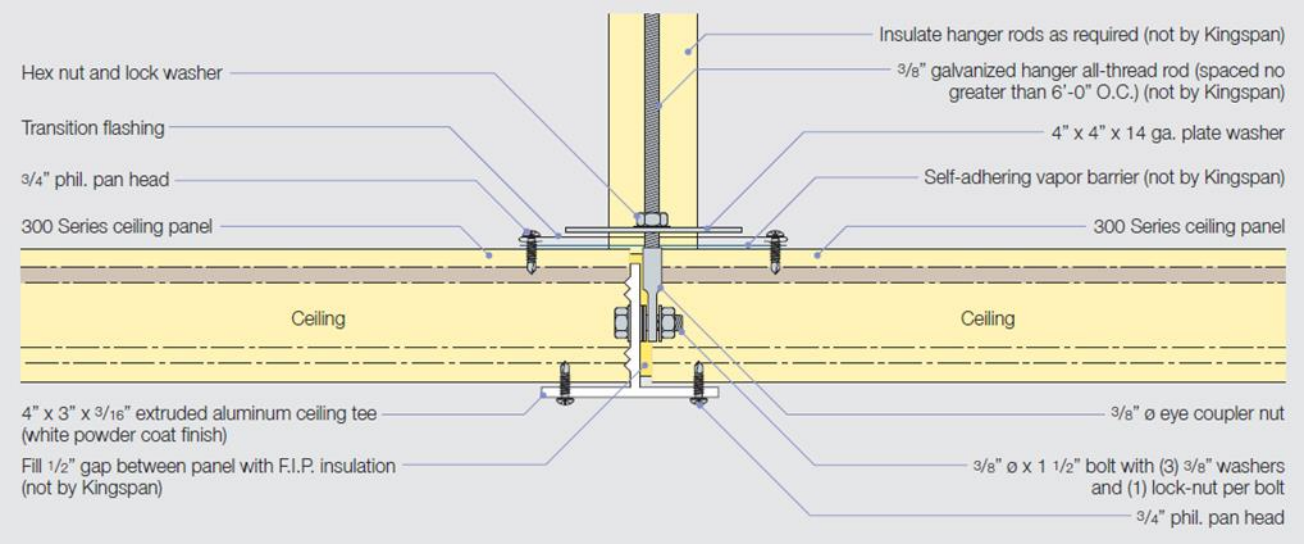
Source: Kingspan Insulated Panels 2012

Figure 4.16: Roof Wall Transition



Source: Kingspan Insulated Panels 2012

Figure 4.17: Ceiling Tee Detail



Source: Kingspan Insulated Panels 2012

4.2.6 Desired R-Value and ROI for Additional Thickness

The following is a exercise to determine the return on investment.

Summary:

Identify the Return on Investment (ROI) based on an analysis of the energy efficiency impact of constructing a typical refrigerated warehouse with high performance IMP wall systems, an insulated built up roof system, and the additional steps necessary to achieve a simple payback by utilizing different types and thicknesses of insulation materials in a freezer warehouse in three climates.

The Locations:

- Sacramento
- Chicago
- Boston

The Warehouse:

A 100,000 ft² refrigerated warehouse: The warehouse is a single story, rectangular building, modeled as a single freezer zone.

A Baseline Warehouse building in various climate locations which is compliant with ASHRAE Standard 90.1-2004 and 90.1-2007 was developed. The envelope will then be improved with varying insulated metal panel wall and roof systems. Though a series of inputs, simulate and evaluate the ROI for incremental changes in the insulation values of walls, roofs and floors, while also demonstrating the energy reduction in BTU's for a typical refrigerated warehouse. The baseline was determined in developing the simulation using the minimum requirements of ASHRAE 2010 Standards for Refrigerated Warehouses.

The goal was that measurable energy savings for incremental insulation increases in walls, roofs and floors should be realized in certain locations and climates. However, are these upgrades necessary and does the savings in energy provide a reasonable return on initial investment?

Regardless of the outcome, a well-insulated, low leakage envelope provides a foundation for all other energy efficiency strategies. As reduced cooling and energy loads are achieved through efficiency upgrades, the cost of making those systems more efficient is decreased. Installing efficient building systems by starting with the "Envelope First" is an ideal approach.

4.3 Maintenance

This section is a reproduction of content printed in the 2008 Guidelines for the Design, Specification, Construction, Maintenance and Fire Management of Insulated Envelopes for Temperature Controlled Environments published by the Controlled

Environment Building Association (European Division). It has been provided as a courtesy to members of IARW and CEBA.

Without a proper and considered program of regular maintenance any insulated envelope is likely to deteriorate to the point of losing thermal efficiency and potentially to the point of sustaining significant damage to the envelope itself. A proper management regime supported by a system of active maintenance will ensure that damage and defects in the envelope are recognized at an early stage and that the appropriate corrective action is taken before any serious deterioration may occur. Failure to do this may result in the following:

- The vapor barrier of the outer facings to the insulated envelope may be breached allowing vapor to penetrate the insulant core and condense to form ice.
- Contamination of the enclosed environment and stored product with particles of insulant from damaged panels. This is particularly acute for mineral wool.
- The insulant core, which may be combustible, may be dangerously exposed and encourage fire and smoke spread.
- The thermal insulating capacity of the envelope may be compromised.
- Vermin may be provided with access/egress from/to the store.

4.4 Modernization

IMP manufacturers work closely with government and industry associations to promote the use of IMPs as energy efficient and economical building construction methodology. The MCA and IMP manufacturers are currently spearheading a campaign to define IMPs within the ASHRAE 90.1 and IECC standards by including IMP assemblies as a standard construction type.

The Federal Energy Policy Act of 2005 established a tax deduction for energy-efficient commercial/industrial buildings applicable to qualifying systems and buildings through 2013. Section 303 of the Federal Energy Improvement and Extension Act of 2008 (H.R. 1424, Division B) was enacted in October 2008. A tax deduction of $1.80 per square foot is available to owners of new or existing buildings. Deductions of $0.60 per square foot are available to owners of buildings in which individual lighting, building envelope, or heating and cooling systems meet target levels that would reasonably contribute to an overall building savings of 50% if additional systems were installed. This would actually put some urgency of getting the projects (new or retrofit) funded and completed. These deductions can apply to architects and owners.

Energy Analysis for Credit (EA): Demonstrating percentage of performance improvement compared with the baseline building performance rating. Based on the LEED Rating System, the following pertains to IMPs.

- Material and Resources (MR) Product Certificates for credit for products having recycled content, documentation indicating percentages by weight of postconsumer and pre-consumer recycled content.

- Product Certificates for credit for products and materials required to comply with requirements for regionally manufactured materials. Include statement indicating cost, location of manufacturer, and distance to project for each regionally manufactured material.
- Indoor Environmental Quality (IEQ) Product Data for credit for sealants, including printed statement of VOC content. Product Data for credit for paints and coatings, including printed statement of VOC content.
- Pilot Credit 43: Certified Products. Provide a UL Certified EPD Qualification.
- Submit documentation that products have been certified in accordance with ISO 14025.

Chapter 5: Floors

Acknowledgements

Original Narrative By:

Patrick Buenbrazo, Coldbox Builders, Vaughan, Ontario, Canada
Paul D'Agostino, Coldbox Builders, Vaughan, Ontario, Canada
Marko Dzeletovich, Coldbox Builders, Vaughan, Ontario, Canada
Barry Foreman, Providence Engineering Corporation, Lancaster, Pennsylvania, USA
James C. Marrella, United States Cold Storage, Inc., Cherry Hill, New Jersey, USA
Scott Metzger, Metzger/McGuire, Bow, New Hampshire, USA
Brian Rosabal, Coldbox Builders, Vaughan, Ontario, Canada

Updated in 2018 By:

Daren Sealover, Graycor Construction Company
Rolands Cepuritis, Primekss North America

5.1 Design and Installation

5.1.1 Introduction

In large warehouse and industrial buildings, the floor surface is probably the most important building component because it can have the greatest impact on the cost of operations in the building. A good floor which has been properly designed and properly installed will be an asset for 30 years or longer.

It is important for everyone on a construction project team to have some basic concrete knowledge. This narrative has been prepared to provide an overview of the subject.

Typically, floors are concrete slabs bearing directly on the earth or a prepared subbase. However, if soil conditions dictate they can be built over enhanced or deep foundations. Concrete slabs are often subject to high point loading (racking) and dynamic vehicular (forklift) loads. The slab is one of the few remaining site built components in a building. As such, a concrete slab is dependent upon appropriate design, quality control, uniform materials, and skilled craftsmanship for placement and finishing.

The construction of a floor slab is outwardly simple. The contractor lays out the area which will become the slab and contains it with forms. Usually a vapor barrier of plastic is installed between the subgrade or earth and the facility floor. Reinforcement

consisting of steel rods wire mesh is installed, then the contractor places the concrete in the slab form work. The concrete is screeded or leveled, usually by a mechanical device. It is then floated using a bull float which resembles a long handled, flat squeegee. Floating opens the surface to allow the excess water in the concrete to migrate to the surface and evaporate. Depending on the abrasion or impact resistance requirement or other requirements (such antistatic properties of the floor) a dry-shake hardener can also be applied on the fresh concrete. Finally, the floor is troweled with a finishing machine usually consisting of rotating flat blades. The concrete is then cured for a number of days. Proper curing is very essential to completing the chemical reaction and the concrete reaching its maximum strength and performance properties.

Concrete is the result of a complex chemical reaction and the variables affecting a concrete floor are equally complex. The design of a concrete slab requires the Engineer of Record to make choices among many alternatives including strength, reinforcement, thickness, materials, cement type, subsurface, curing, placement, tolerances, joints, details and finish. The following discussions summarize the alternatives that must be considered by the owner and the engineer when selecting a concrete slab on grade.

There are four main variables which will play important roles in determining the long-term durability and productivity of any industrial concrete floor:

- Subgrade reliability
- Floor slab design
- Floor slab construction
- Floor slab maintenance

While the slab design is critical many slab problems can be prevented with an excellent subgrade/subbase to support it. The floor slab design and construction teams should communicate regularly with each other and with the building owner throughout the construction process to ensure that potential complications in floor slab construction process and ramifications of various design or construction decisions on the finished floor slabs are well understood by all parties. At a minimum, all three parties and all material vendors whose products will be used in finishing or enhancing the floor slabs should be involved in a pre-construction meeting to discuss the construction process and application of all relevant materials. In an ideal case, the design and construction should be executed by the same party, thus allowing for the best communication and having one single source of responsibility. Where possible, material vendors should be asked to inspect/oversee installation of products at the start of construction, and should be enlisted to discuss or provide guidance on the best ways to maintain the long-term durability of the floor and the installed floor protection products.

5.1.2 Concrete Type

Concrete consists of cement, water and aggregate (various sizes of rock). Many modern concrete mixes include admixures designed to enhance the placement and end-result properties of the concrete. The water and the cement chemically react and form a

paste that bonds to the aggregate and then the entire mass hardens to form concrete. Concrete's hardness comes from the chemical reaction not from the evaporation or drying process.

Two types of concrete for floor slabs are being used today. Conventional portland cement concrete is the most commonly used material. Expansive concrete, also known as shrinkage compensating concrete, is a more specialized material.

Portland cement concrete is the standard type of concrete that uses Type I/II portland cement. Type I/II is used when the special properties of any other type are not required. About 95% of concrete is made with Type I/II cement. One of the inherent features of concrete is that more water is added to the concrete mix than is necessary for it to react with the cement. The excess water is used as a lubricant to make the concrete flow more easily to aid in placing the concrete. However, as this excess water leaves the slab it reduces its volume and results in drying shrinkage. Some limited amount of the shrinkage will occur also during the curing period in terms of the so called chemical shrinkage, which happens when the reaction participants (essentially cement any other binders and water in concrete) occupy slightly higher volume than the reaction products (hardened cement stone). However most of the shrinkage in the form of drying will take place long after the casting (typically at least for 2 years until the moisture equilibrium with the environment is slowly reached). Different types of concrete compositions can have very different drying shrinkage potentials. This is the reason why careful mix design is of a crucial importance for the flooring applications. It is not recommended to use a standard composition from the ready-mix supplier, without allowing a qualified engineer to verify it. The main reason for this is because concrete suppliers are normally designing their mixes in order to guarantee a certain level of concrete compressive strength and workability, without taking into consideration the characteristics that are essential for flooring, such a drying shrinkage potential of the mix or setting time.

As the concrete shrinks, it must slide across the surface of the earth beneath it. Because concrete is inherently weak in tension, and especially weak while it is new ("green"), the restraint in the form of friction against the earth substrate will prevent concrete from sliding and cause concrete cracks as it shrinks. Straight, uniform joints are usually preferable to random cracks. Therefore, joints are located in the slab to induce cracks at the joint in a pattern that is acceptable. All joints need to be designed to support the transfer of loads across the joint. The American Concrete Institute (ACI) provides guidelines for joint spacing based on the slab criterion. If joints are not provided, or if provided, they are not at the correct depth and locations, random cracks will occur, and in most cases, will be unacceptable with respect to subsequent use and maintenance of the floor.

Shrinkage compensating concrete expands while the concrete is curing. Expansion normally is complete in approximately 7 days, but it will stop sooner if curing is inadequate or the expansive cement or the concrete mix is inadequate. After expansion is complete, the concrete shrinks in the same manner as conventional portland cement

concrete. Ideally, the initial expansion of the concrete offsets or compensates for the shrinkage. As expansion occurs in the concrete, in which reinforcing bars, or certain types of steel fibers have been placed, the steel resists the expansion and pre-stresses the concrete. When the concrete shrinks, the amount of pre-stress is reduced and the tensile stresses remaining in the concrete are low enough that the slab does not crack. Thus, it is possible using shrinkage compensation concrete to eliminate many of the contraction or sawed joints in slabs.

The cementitious properties of shrinkage-compensating concrete can be produced by several alternate methods. Historically, in the U.S. substituting Type K cement for portland cement has been the "traditional" method of making shrinkage-compensating concrete. An alternate method uses a powdered admixture which is mixed with portland cement to create an expansive concrete. This admixture is usually cheaper than Type K, but the two methods may not produce exactly the same product. Since the first applications of these materials in the 60s, many other innovative ways of producing shrinkage compensating concrete have also been developed globally.

5.1.3 Slab Pour Width

It is common practice to place conventional portland cement concrete slabs in long lanes or strips because this is the most efficient method. A checkerboard pattern sequence of placement was used in the past, but this method is no longer recommended. The checkerboard is costlier to install and the joint quality is not as good. In racked storage facilities, it is good practice to locate the slab lanes so that construction joints are concealed beneath the rack. This reduces the amount of traffic that must travel over the construction joints.

Determination of the width of the slab pour is influenced by many factors:

- The available concrete placing equipment
- The column bay spacing
- The desired joint spacing
- The required floor flatness
- The type of concrete being used

Contractors usually use a vibratory screed to strike off the placed concrete to the proper elevation. A vibratory screed is a piece of equipment that incorporates a long straightedge with a motor attached. This motor vibrates the straightedge, thus allowing it to easily level and strike off the placed concrete. Vibratory screeds can range in length from 10 feet up to 80 feet. However, for ease of concrete placement, 40-50 feet is a generally accepted upper limit. Both ends of the screed must be supported on a carefully established edge or temporary rail to control the floor elevation. A laser screed is a mobile version of a vibrating screed that can be used to level wide expanses of concrete.

The Somero Laser Screed is a four-wheel drive vehicle that has a vibrating straightedge mounted on an extended arm that is guided vertically by lasers. This equipment has improved production and allowed much larger pours.

Slab pour width for portland cement concrete should be some fraction of the column bay spacing. Joints are installed primarily to control cracking. Guidelines have been established limiting the distance between joints. For example, if we assume the column bay is 40 feet wide, a joint could be installed at 20 feet, cutting the slab in half. This slab could be poured either 40 feet wide with a joint at 20 feet or the slab could be poured as two (2) 20 foot lanes. Alternatively, a 40-foot bay in a racked storage warehouse might be divided in thirds so the joints occur beneath the racks.

The floor flatness tolerance for a slab can also dictate the width of the slab pour. The narrower a pour, the better the surface flatness. Conversely, the wider a pour, the harder it is to achieve a very flat floor.

Using shrinkage compensating concrete requires different criteria for slab size. As previously stated, conventional portland cement concrete is preferably placed in long, narrow strips. However, for shrinkage compensating concrete, square, or nearly square, slabs are required to provide even expansion and contraction to help eliminate shrinkage cracks. An optimum size pour would be 100 feet x 100 feet, even though some shrinkage compensating systems can allow for even bigger slabs, thus allowing for even faster concreting operations and even fewer joints. It should be noted that the concrete is placed in 20 foot sections, but it is done all in one day, thus avoiding a cold joint between the sections.

The previous paragraphs deal primarily with slabs with shake-on hardener and base slabs under topping. For pouring a topping on a base slab, most of the same guidelines apply. However, from practical experience, a topping pour width from 15 to 20 feet is the optimum.

5.1.4 Floor Joints

There are three main types of joints found in a floor slab:

- Contraction (Control) Joints – Joints which are sawn into the concrete slab surface early in the shrinkage process to control the location of cracking. These joints are typically sawn into the slab at intervals of 12 to 18 feet depending upon slab thickness. Depth of the sawn joint is typically ¼ of the slab thickness. Best practice is to discontinue the reinforcing and include some means of positive load transfer across the joint with reinforcement or dowels. These joint can reach miles in length for a single building. However, they will not be present in the so-called "joint less" flooring solutions.
- Construction (Cold) Joints – Joints which are formed and mark the end of a concrete pour and should be designed to provide positive load transfer. Depth of the joint is the same as the slab thickness. Construction joints are typically sawn at the top after pouring to a nominal depth of ¾"-1" to provide a structurally sound joint for filling and to remove inherently weak edges which can occur during the concrete placement/finishing process. Construction joints are sometimes "armored" to provide additional joint edge protection against deterioration by placing a steel edge or plate along the joint edges during the concrete placement process.

- Isolation Joints – Joints which isolate the concrete slab from other structural building elements such as walls, columns, curbs, etc.

Joint sealant and filler installation timing is very important to ensure proper performance and long term durability of the joints. Because this joint widening occurs gradually, it is important to delay the filling and sealing of joints as long as possible to allow for joint dimension to widen closer to its ultimate width after drying shrinkage is complete. The American Concrete Institute recommends that filling of joints be deferred a minimum of 28 days after slab placement to ensure enough moisture has evaporated to allow for proper joint filler adhesion. ACI further recommends that the filling of contraction and construction joints be deferred 60-90 days or longer after concrete placement to allow for joints to widen closer to their ultimate width prior to filling. Refer to American Concrete Institute's Guide for Concrete Floor and Slab Construction ACI 302.1R-04.

It should be noted that deferring joint sealing or filling 28 days, 60-90 days or even longer will not guarantee that joint dimensional changes will not continue to occur during the life of the concrete floor and impact the installed filler/sealant. Many factors can affect joint dimensional movement including slab thickness, concrete mix design, joint spacing, ambient temperature changes in the building, etc.

Cold Temperature Considerations

Cooler temperatures and reduced humidity affect the rate at which the drying shrinkage process of concrete occurs. Decreases in temperature and ambient humidity will accelerate the concrete shrinkage process and thus accelerate the rate at which joints widen. This temperature drawdown should occur gradually over a period of days (depending on ultimate temperature) to avoid potential cracking or other negative impact to the concrete slabs which can result from rapid drying shrinkage. Consult American Concrete Institute Guide for Concrete Floor and Slab Construction ACI 302.1R-04 for more information.

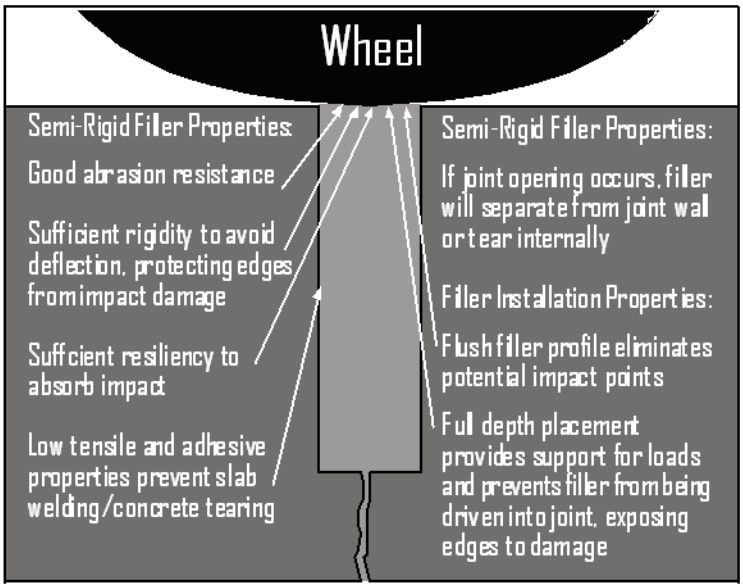
Because of the effects of temperature drawdown on joint dimension the American Concrete Institute recommends that in addition to standard recommended slab cure times joint filling in areas to be temperature controlled should be deferred until such areas are drawn down to ultimate operational temperature and stabilized at those temperatures. For coolers, the recommendation is to stabilize the area for a minimum of five days. For freezers, the recommendation is a minimum of fourteen days. In both cases the longer the filling is deferred after temperature stabilization the better. Installing fillers prior to area temperature drawn down is one of the most common reasons for filler adhesive failure and/or filler-to-concrete separation.

Semi-Rigid Joint Fillers

ACI guidelines call for the use of a semi-rigid joint filler to fill contraction and construction joints and provide joint edge protection in high traffic areas of concrete floors. Such fillers should exhibit a minimum hardness of Shore A 80 as measured using

ASTM D-2240. There are two types of semi-rigid fillers which meet these requirements – epoxies and polyureas.

Figure 5.1



Semi-Rigid Filler Concepts

Epoxy joint fillers are typically two part 100% solids materials which can be hand mixed and placed using a bulk-type caulking gun or two component bulk dispensing pump. Epoxy joint fillers typically take 8-12 hours to cure to sufficient hardness to allow for traffic and cure time can be delayed dramatically as temperatures decline. In general, the installation of epoxy joint fillers is limited to areas in which ambient temperatures exceed 50 degrees F (10 degrees C).

Polyurea joint fillers are typically two part 100% solids materials which due to their short potlife cannot be hand mixed but rather must be dispensed using a dual component bulk pump or dual cartridge set. Polyureas are particularly well suited for installation in lower temperature as temperature does not dramatically affect their chemical cure. Most polyurea fillers can be installed at temperatures as low as -30 degrees F (-35 degrees C) and still exhibit proper cure. Because finishing characteristics may vary, however, it is generally advisable to select a polyurea filler formulated specifically for use in freezer or cooler areas.

Proper Installation of Semi-Rigid Joint Fillers

For a semi-rigid joint filler to provide solid structural joint edge support it must be installed properly. Semi-rigid fillers are designed to be installed to the full depth of the saw cut in sawn joints and/or a minimum depth of 2" (50 mm) in joints where depth exceeds 2" (50 mm). Installation of semi-rigid fillers at depths less than this, over compressible foam rods or inert materials, etc. will not exhibit adequate structural

support under loading and will often result in the filler collapsing or being pushed down below the joint edges, exposing them to impact and ultimately deterioration.

In order for a semi-rigid filler to achieve good adhesion to joint sidewalls and be installed to the proper depth the joints must be cleaned or prepared mechanically, typically using a dustless concrete saw equipped with a diamond or masonry blade. This method cleans the joint face back to bare concrete and ensures the removal of any existing curing compounds, concrete laitance, etc. that could potentially compromise filler to concrete adhesion. Raking or vacuuming joints out is not an acceptable method of joint cleaning.

Additionally, it is important that the finished profile of the installed filler be completely flush (level) with the concrete slab surface. If the filler profile is concave (cupped) or lower than the floor surface joint edges will be exposed to impact damage.

Elastomeric Joint Sealants

Unlike semi-rigid joint fillers, joint sealants exhibit high elongation and lateral movement capabilities and are designed to accommodate great joint expansion and contraction, often up to 35%. Joint sealants are recommended for isolation and other non-traffic joints. Joint sealants can be one or two component materials and are typically either polyurethane or silicone based though there are other chemistries such as polysulfides or acrylics designed specifically for certain properties such as chemical resistance, temperature fluctuations, etc. Expected durability and performance, long term hardening, and other property changes over time can vary tremendously from one product or chemistry to another. Careful consideration should be given to expected service life and replacement costs for joint sealants when selecting products.

Performance, proper curing, and many other characteristics can also be compromised with lower temperatures. Accordingly, it is strongly recommended that a sealant designed specifically for use in temperatures expected to be present in the area be selected.

Proper Installation of Joint Sealants

In order to achieve greater movement capability, joint sealants are mostly installed over a bond breaker such as a compressible foam backer rod to ensure the sealant only has two-point contact, allowing for greater extensibility. It is also very important that concrete substrates be clean, frost free, and free of contaminants and surface tension reducing materials such as water repellents, oils or other coatings.

Joint sealants are designed to be “tooled” or exhibit a concave profile when properly installed. Some sealants may require primers to achieve proper adhesion.

5.1.5 Slab Thickness

The design of concrete floor slabs on grade depends on the types and magnitudes of the service loads. Thickness requirements vary according to the intended use of floors. The American Concrete Institute (ACI) and the Portland Cement Association (PCA)

publish tables and charts for the design of slabs on grade. A structural engineer familiar with the performance characteristics of cold storage floors should be consulted.

The obvious advantage of increasing the slab thickness is that the slab will support additional loads. Increased slab thickness may compensate for minor defects in subgrade or for excessive placement tolerances. Increased slab thickness also reduces a phenomenon called curling, which is similar to wood cupping from uneven moisture. Also, increased slab thickness permits increased joint spacing. Of course, increasing slab thickness results in higher costs and does not by any means guarantee that many of the potential problems, such as cracking, wide joint openings and curling will be prevented. Excellent results can also be achieved through more slender and innovative designs at a more reasonable cost.

5.1.6 Reinforcement

Some concrete slab designs call for steel reinforcement and some do not. The amount and location of the reinforcing can vary from sheets or rolls of gauged wire mesh to a rebar grid. For industrial floor slabs, there is a subtle move away from using gauged wire mesh as reinforcing. However, even slabs with reinforcement are technically considered unreinforced because the amount of reinforcement is less than the minimum needed to qualify the concrete as “reinforced concrete”. The primary purpose of most slab reinforcement is to limit the width of shrinkage cracks. If jointing and sub- grade installation are done properly, reinforcement would theoretically not be needed. However, because this is not a perfect world, many designers recommend using reinforcement. Concrete and cracks in concrete can be somewhat predictable but it requires experienced slab installers reviewing the slab design and constraints (re-entry corners, load transfer, etc....) to minimize cracking. Slab reinforcement has to be designed to work with the concrete floor design.

Shrinkage cracks in concrete slabs are usually widest at the slab surface. In order to keep the crack width as small as possible, the reinforcement must be located near the top of the slab. Reinforcement that is resting on the subgrade is useless insofar as keeping cracks at the surface tightly closed. Reinforcement should be located no more than 2" below the surface of the slab.

Keeping the reinforcement at the correct location is challenging. The preferred method is to use either concrete bricks or metal or plastic chairs for reinforcing support.

The selection of the proper reinforcement can also help keep the reinforcement at the best location. Walking on the reinforcement bars to place the concrete pushes them down from the top surface. By choosing a reinforcing bar spacing that is large, such as 18" x 18", the workers can walk between the bars rather than on the bars.

5.1.7 Fibers

Fiber reinforcement is becoming more commonplace in floor slabs. Fibers are added directly to the concrete truck and then thoroughly mixed into the load of concrete. By using fibers, the construction sequence can be greatly accelerated by the ability to place

concrete as soon as the subgrade is ready, thereby eliminating the time spent laying out reinforcing bars.

There are two types of fibers used: synthetic and steel. Synthetic fibers are typically polypropylene or nylon. These fibers are used to minimize plastic shrinkage cracks in the floors. They typically work only while the concrete is still plastic to help bind the materials together and prevent the so-called plastic shrinkage cracks due to fast drying of the concrete surface while it is still fresh. Typical synthetic fibers (polypropylene and nylon) do not provide any structural reinforcement to the slab and should not be counted on to prevent cracks resulting from slab movement caused by later drying shrinkage or temperature changes.

The use of the correct type of steel fibers will also increase the flexural and shear strength as well as fatigue endurance, impact resistance, toughness and punch-out resistance for pile supported flooring slabs, while low quality fibers are typically used only to minimize shrinkage cracking. The effect of the steel fibers is very much dependent on the quantity used and the steel fiber properties, such as length, diameter, aspect ratio (length/diameter), geometry configuration and steel quality. Typically, steel fibers have to be at least 1.5-2 times longer than the maximum aggregate (stone) size in the concrete, in order to be able to bridge between the cracks that will form in the cement paste between the aggregates. As well, the actual dosage of the fibers should be selected by a qualified engineer because a recommendation of fiber dosage in terms of lbs./ cu yard cannot be universal, it will depend on the given fiber type, subbase properties as well as floor thickness and loading conditions.

5.1.8 Post-Tensioned Concrete

Post-tensioned floors involve installing cables in the slab instead of reinforcing bars. The cables are run from one side of the pour to the opposite side. The day after the concrete is placed, the cables are stretched to put them in tension. Only a small force is applied at first; the final tensioning is done 7-14 days later. Tensioning the cables puts a compressive force on the concrete. When the concrete starts to cure, and shrink, the shrinkage stresses are offset by the compressive force in the slab resulting from the post-tensioned cables. The result is the elimination of shrinkage cracks in the slab. Post tensioning is considerably more expensive than most conventional and steel fiber reinforced slabs. However, in thick slabs, such as those used for rack-supported high-rise structures, this measure can reduce slab thicknesses and reduce costs. Another alternative would be using a system with chemical pre-stressing of the concrete, with the aid of shrinkage compensating concrete and steel fibers. **It should be noted that cutting into a post-tensioned floor made with cables is very dangerous.**

5.1.9 Curing

Evaporation of the water in the mix is not what hardens it. The chemical reaction of the cement mix and water is what hardens or cures the concrete. Doing a great job with mixing, pouring and finishing the concrete is only part of the combination of a good slab. The hardness and durability of the wear surface of the end product is very much

contingent on how well the concrete is cured. It is a best practice to allow the mix to cure under relatively variable environmental conditions for about 7-14 days. However, allowing the curing concrete to freeze or allowing the water to evaporate too quickly can be very detrimental. Keeping the slab covered and damp with a membrane and a water source is a recommended best practice. Alternatively, commercial products are available that can be sprayed on the freshly finished concrete that do a similar job in keeping the moisture from evaporating too quickly.

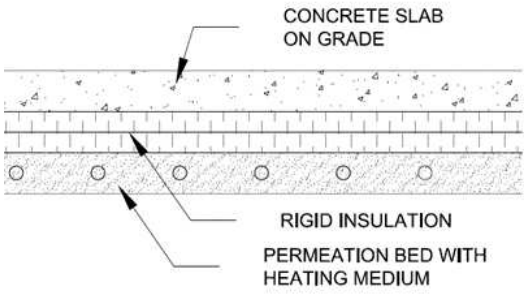
5.1.10 Under Floor Design/Frost Heave Prevention Design

It is important to ensure that a proper underfloor heating system is installed below a low-temperature refrigerated space. If the temperature of the soil beneath the concrete slab drops below freezing temperatures, the moisture it contains will freeze, expand and could cause frost heaving. The ice that forms beneath a building structure will expand and create enormous pressures that are capable of buckling floors and even raising the columns that support the roof. The fundamental solution to prevent this from happening is to keep the soil beneath the refrigerated space above freezing temperatures with a heat source. There are three main conditions that must exist in order for frost heavage to occur are freezing soil temperature, water source, and subsoil that supports capillarity. If any one of the above conditions do not exist, the possibility of floor heavage is reduced.

The higher thermal conductivity (k-factor) you have between the low-temperature refrigerated space and the soil, the easier it is for the heat to be absorbed by the cold temperature. If no heat source is available to replenish this loss, the soil will eventually freeze. Just installing floor insulation underneath the concrete will only lower the thermal conductivity or in other words, only slow down the time for soil to freeze. In rare occasions, if you have a relatively narrow low-temperature box located in consistent hot climates, it is possible that the heat energy in the soil surrounding the area of refrigerated space, is enough to prevent the soil beneath this space from freezing. However, this should always be verified by a geotechnical expert.

The typical construction of an underfloor system is as follows: concrete slab, rigid closed cell insulation, vapor barrier, permeation bed (where your heating source will dissipate) usually sand or a low-quality concrete and your heating source which is embedded in the permeation bed.

Figure 5.2 Cross-section of Typical Underfloor Heat System



5.1.11 Types of Underfloor Heating Systems for Freezer Slabs

Liquid Systems

A liquid underfloor heating system uses the process of recirculating liquids that have been heated to a required temperature. The liquids can be oil or glycol solutions and the pipe lines are placed in a sub-floor material and covered with the remaining floor assembly. The source of heat for the liquids can also vary depending on the requirements of the owner. The two common practices for the liquid heat source are boilers and heat reclaim. A boiler system is much like a traditional hot water heater, the liquid is stored in a boiler and heated up using either a gas or electric power source and then the liquid is circulated through the underfloor piping. A heat reclaim system works in conjunction with the refrigeration equipment. The heat that is being removed from the freezer by the refrigeration system is captured, and with the use of a heat exchanger, it is introduced into the stored liquid in order to bring it up to the required temperature. Once at temperature the liquid is circulated through the underfloor piping.

The draw back to a liquid system are the repair costs, if a blockage or damage to the underfloor piping occurs. When the piping is installed it should always be pressure tested to ensure there were no punctures during installation. This pressure test should continue until after the finished floor slab is installed to verify if punctures have happened during installation of the floor slab. One way to mitigate potential repairs due to blockages and punctures is to minimize spacing between pipes and alternate glycol loops.

Figure 5.3 Glycol Piping



Figure 5.4 Glycol Equipment



Air Systems

There are two types of air systems, gravity and forced air. Each system works with the use of circulating air below the sub-floor.

- Gravity Air Systems (Natural Convection) – A gravity air system uses air vent ducting below the sub-floor. The piping must be placed with a slope to allow air flow as well as drainage for condensation. The drawbacks to the gravity air system are that a consistent temperature is difficult to maintain in certain climates, the amount of heat cannot be controlled. If the pipe ends are not covered with screens, small rodents can get into the piping and cause blockages. Also, if there are any low points condensation will build and could freeze.
- Forced Air Systems (Forced Convection) – A forced air system also uses air vent piping below the sub-floor. Heat is introduced on one end of the piping and forced with blower fans through the pipe. The forced air system allows for consistent air temperatures within the air vent piping. Like the gravity air system, if the ends of the air vent piping are not covered with dampers and screens small rodents can cause blockages in the piping.

Figure 5.5 Gravity Vent Duct



Figure 5.6 Forced Air Unit



Figure 5.7 Electrical Heat Conduit



Electrical underfloor heat tracing is installed inside of conduit below the subfloor. The conduit that the electrical heat tracing is installed in must be placed within the sub-floor. The electrical heat tracing can be installed after the final finished floor slab has been installed by fishing the heat tracing in the conduit. The electrical heat tracing is a self-regulated cable, meaning, the cable is set to a certain temperature. When the temperature drops below the set point the heat tracing is then activated until the temperature set point is met again. The self-regulating electrical cables ensure that only the minimum amount of heat that is required to prevent freezing is used.

Electrical heating cables can also work in conjunction with a thermostat and temperature sensor, the sensor will be placed within the sub-floor and relay the sub-floor temperature. The thermostat will then regulate the heating cables to maintain the desired temperature.

Regardless of the system chosen, monitoring the temperatures in the soil is a necessity. Being proactive and determining early warning signs of frost is the best way to eliminate any chances of ice forming. On a basic level, every underfloor heat system should be installed with a few RTDs (Resistance Temperature Detectors) placed in strategic locations and connected to thermostats for monitoring. However, it is highly recommended to add audible or visual alarms to indicate that the sub-floor temperatures have gone below a specific threshold. In addition to temperature alarms, there should be alarms for failed equipment such as: electrical heat cables losing power and mechanical equipment (pumps, fans etc.) failing. If the system is pressurized with a liquid source, it is recommended that pressure indicators are installed in strategic locations to determine a loss in pressure, which usually means there is a leak, blockage or break in the lines.

Checklist of items that should be considered in the proper design of a subfloor heating system:

- Operating temperatures in the completed structure
- Size of freezer area
- Depth of heating system

- Heat distribution
- Structure of sub-slab
- Proper insulation type
- Sub-floor temperature monitoring
- Relative economics- installed cost and energy consumption
- Maintenance capability of system
- Future expansions
- Ability to replace failed components
- Voltage availability
- Safety of system
- Compliance with all applicable local codes
- Ambient exterior temperatures
- Location and variation in ground water table
- Location of area within facility
- Subsoil classification
- Subsoil sustained temperature
- Drainage

5.2 Maintenance

5.2.1 Introduction

The concrete floor literally serves as the work surface for your entire distribution operation. A well maintained concrete floor, largely free of interruptions in the floor surface, is an important part of ensuring that the floor remains productive. Concrete floor deficiencies, such as deteriorated (spalled) floor joints, pop-outs, divots, random cracks or delaminations in the surface negatively impact operations in many ways, including:

- **Productivity and Cost of Material Handling Operations** - Defects in the floor surface result in material handling vehicle operators slowing down or even taking less productive paths through the facility from Point A to Point B to avoid jarring and impact points. Defects in the floor also increase wear and tear on the material handling vehicles themselves, increasing damage to bearings, wheels, electronics, etc., thereby increasing the costs of maintenance and replacement parts.
- **Reduced Operational Safety** - Defects in the floor and the resulting impact on material handling vehicles can lead to driver fatigue and neck and back strain, as well as tripping hazards for warehouse employees. In extreme cases, sever defects can lead to load tipping or pose other hazards to the safe operation of material handling vehicle.
- **Increased Slab Maintenance Costs** – Given the constant and dynamic loads on slabs, nearly all slab defects will continue to deteriorate in an accelerated fashion unless they are corrected immediately.

- **Food Safety/Sanitation Concerns -** Open cracks and other unsealed/unfilled floor defects create spaces for bacteria or viruses to grow and dirt/debris collection, which can lead to dust settling on packaged products and customer complaints. They also create spaces for insects and other pests to live.

Figure 5.8



5.2.2 Typical Floor Problems

There are many variables involved with providing a poured floor slab. These variables include, but are not limited to the subgrade reliability, the concrete mix, the quality of the labor, environmental conditions during the pour and during the curing period. Given the diversity of the variables it is best to conclude that each floor may have some built-in deficiencies.

A concrete floor's condition can have a direct effect on a facility's productivity. Deteriorated floors lead to increased material handling vehicle maintenance costs, increased sanitation concerns, and driver slowdowns and defect avoidance. As well as, floors in a bad condition would greatly reduced the resale value of the facility.

Additionally, it is important to remember that a concrete floor is not a "static" building component. Concrete floor slabs can experience dynamic changes throughout their service life, especially during the first few years after placement. These changes can be caused by a wide variety of factors, both naturally occurring and operational, which can ultimately affect the condition of a concrete floor.

This outline is intended to provide a basic overview of the most typical floor slab condition issues that should be monitored and maintained or corrected as required. The chart below highlights some potential floor maintenance issues which can occur as a result of both environmental and operational issues.

Potential Issues

Operational Changes	
Change in operating temperature in area	Development of cracks, joint dimensional changes leading to filler separation.
Change in material handling vehicle types, loads, traffic patterns	Increased deterioration of joint edge wear/deterioration resulting from smaller, harder wheels.
Dragging or pushing of pallets	Increase in floor scuffing, surface gouges, surface wear. Surface may exhibit dusting or delamination.
Change in floor scrubbing equipment or chemicals	Chemical or abrasive attack to concrete surface may lead to deterioration of finish, dusting, delamination.
Change in rack loading, locations	Slab may not have been designed for change in loading, could result in additional cracking, slab panel rocking.
Environmental Changes	
Concrete drying shrinkage	Development of cracks, joint dimensional changes leading to filler separation. Slab edge curl, elevation differences at joints, rocking slab panels.
Change in ambient humidity or temperature	Development of cracks, joint dimensional changes leading to filler separation.
Unstable subgrade, improper drainage	Development of unstable concrete panels, development of cracks.

Industrial Concrete Floor Joints

The heavy and dynamic moving loads from the material handling environment make concrete floor joints the most vulnerable parts of a floor. These joints should be designed to smoothly transfer the loads across the joints to minimize potential deterioration and damage.

Maintaining these floor joints is critical to ensure their long-term stability and serviceability. All joints will need periodic maintenance. If left untreated, the joints will chip or "spall" under impact from the wheels and will lead to widening joint edge deterioration, even under nominal material handling vehicle traffic. Smaller diameter or harder wheels will cause more joint edge deterioration in a shorter period of time.

In addition to causing potential floor deterioration, open or poorly maintained joints can also present problems for proper sanitation and can harbor bacteria, insects, etc. Add to these factors the potential vibratory and wheel damage to the material handling vehicles crossing deteriorated joints and it's understandable why floor joints are typically reported as the most typical concrete floor slab issue.

Another contributor to joint damage is slab curl that results in uneven horizontal transitions of slab edges. The condition causes accelerated wear, and under extreme circumstances can become a tripping hazard for the pedestrians. Joint repair at curling conditions require more significant repairs than just filling the joints.

Designing the floor joints with a steel armored joint and/or reducing the number of joints in the slab with "Control Joint Free" concrete floor solutions can greatly reduce potential problems including slab curl.

Floor Joint Issues Potentially Requiring Maintenance/Repair

The need to repair/maintain joints can be the result of many variables, including unfilled joints, improperly filled joints, improper joint filler compound, joint filler separation (resulting from concrete shrinkage related joint opening), concrete floor slab curling or rocking conditions. It's not possible to comprehensively address every potential joint deterioration condition and cause that a facility owner might encounter in this document, but virtually all conditions can be caught and corrected before substantial damage occurs if floor condition is audited regularly.

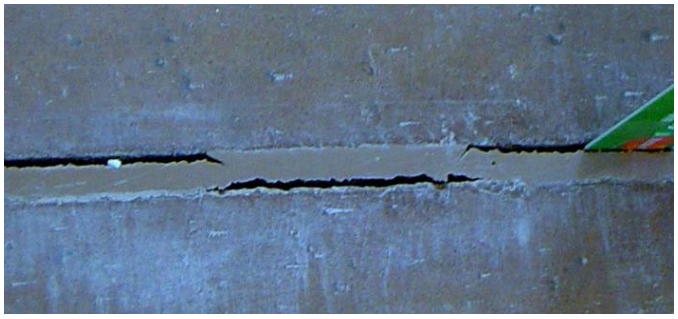
Figure 5.9 Cohesive (internal) joint filler separation



Joint Filler Separation

Concrete shrinkage results in a reduction in the mass of the slab. It should be noted that in addition to normal water evaporation shrinkage thermal shrinkage will occur in cold storage environments as the space temperatures are reduced. Concrete shrinkage affects joint dimensions - as the concrete panel mass shrinks, joint width increases. This applies to both contraction and construction joints, though the widening can be more apparent at construction joints. Because semi-rigid floor joint fillers used to fill industrial floor joints have minimal lateral movement capability (they are structural fillers, rather than sealants), and because they are almost always installed prior to substantial concrete shrinkage occurring, it's likely that the filler will tear, either internally or along the edge of the joint, as filled joints widen. This can result in a void in the filler itself or between the filler and the joint wall.

Figure 5.10 Adhesive (filler-to-sidewall) joint filler separation



Joint Filler Collapse

Sections of joint filler which experience complete adhesion loss in the presence of substantial joint dimension opening can be "punched down" below the joint edge, exposing edges to impact. This would normally occur only in the presence of extreme joint opening (i.e. joint opens wide enough for filler to be driven below base of saw cut) or if there were underlying deficiencies in the original filler installation (i.e. shallow joint filler depth, placement over compressible foam rods or debris, inadequate joint preparation/cleaning, etc.). Joints exhibiting truly depressed filler should be easily identifiable as joint edge deterioration will likely be noted in any area where the filler has dropped in profile, substantially exposing joint edges to impact/damage. Typical repair of joints exhibiting filler collapse involves removing existing filler, re-chasing or saw cutting joint to establish clean, structurally sound edges, and refilling the joint with a semi-rigid epoxy (ambient temperatures) or semi-rigid polyurea (freezer/cooler rooms or for faster access). If deteriorated joint width exceeds 1 ½" (38 mm) structural rebuilding of concrete edges may be desirable for optimal long term durability.

Figure 5.11



Semi-rigid epoxy joint filler installed over compressible backer rod collapses, exposing joint edges to deterioration under material handling vehicle traffic.

Joint Edge Spalling

In addition to the possible cause noted above, joint edge spalling can occur as a result of many factors, including improper saw cut timing at the time of floor construction, concave or low installed joint filler profile, the installation of an improperly soft joint sealant or filler, uncorrected separation voids, and more.

Facility owners should always be on the lookout for any sign of floor joint deterioration and should seek outside assistance if the cause of the joint edge deterioration cannot be readily identified as resulting from one of the above noted conditions or if unusual conditions are noted.

While most joint edge deterioration conditions occur as a result of one of the above conditions, deterioration can also occur as a result of certain poor material handling operational behaviors (i.e. dragging or pushing of pallets, not lifting forks when crossing joints, dropping pallets or other floor impact behaviors, etc.). Deterioration resulting from material handling operations can generally be identified by either its randomness (i.e. isolated chip or spall where a fork impacted a joint edge or where a nail or other hard object was dragged under a wheel) or by its consistency in one general location where a problematic operational behavior has been identified or suspected (i.e. a particular operator drags his pallets and is in charge of loading at Door 8, all the joints at Door 8 show spalling but joints elsewhere look fine).

Figure 5.12



As with any building component, concrete floors require periodic maintenance to ensure optimal performance. Joint edge deterioration (spalling) is one example of a floor condition that can harm operational productivity if left un- maintained.

Slab Edge Curl

Slab edge curling along joints is readily identifiable by a difference in joint edge elevation across two panels. Slab edge curl is to some degree common on virtually every industrial floor, if no special means are taken to avoid it. While the causes of curl are many and still the source of much disagreement within the industry, it occurs as a result of slab panel edges or ends drying faster than the center of the slab panel, leading to a curling or warping effect, similar to the behavior exhibited by a wet sponge when left out to dry. It should be noted that there are proprietary systems available that claim to prevent curling.

Depending upon the degree of curl, it may not present any problem at all or it may be a condition requiring corrective action. Slab edge curl warranting assessment and potential corrective action should be evident as the joint edge will begin to exhibit spalling/deterioration under material handling vehicle traffic (the higher joint edge being impacted and chipped away).

If slab curl conditions are present to the degree that material handling operations are impacted leading to joint edge deterioration, or if panels show evidence of rocking (vertical movement or deflection as material handling vehicles cross the joint) it is important to bring in an engineer, consultant or trusted industrial floor resource to determine potential need for correction and the best long term correction options.

Corrective procedures for this condition would not normally be performed by in-house maintenance staff and vary depending upon conditions, cause and degree of curl and thus will not be addressed within this narrative.

Figure 5.13



Slab edge curling leads to differential elevations between panels at joint locations, creating impact points on the higher side that can lead to joint edge deterioration. tripping risk and risk of wheel-loader accidents.

Floor Surface Issues Potentially Requiring Maintenance/Repair

Potential surface deterioration issues should be readily identifiable visually, the most likely being scratches, gouges, etc. Some surface defects, such as cracks may be related to construction or design issues, while many others tend to result from abuse of the floor directly related to material handling practices, vehicles or housekeeping. Scratches and gouges often result from inadequate cleaning of the floor and the subsequent friction resulting from debris, wood slivers from pallets, nails, etc. being dragged under the wheel of a material handling vehicle across the floor. Improper driver material handling practices such as pallet dragging, pallet pushing, driving with forks dropped, dropping loads too quickly, etc. are all the most likely contributors and causes to any floor surface defects which might become visible. If signs of substantial or abusive surface wear are present on the floor it is recommended that the facility owner work with material handling vehicle operators to identify the potential causes leading to the deterioration and work to change the practices suspected as the most likely cause.

Some degree of general surface wear is inevitable in any distribution operation and does not necessarily pose problems for the long-term serviceability of the floor. Surface defects with the potential to become an issue can typically be identified by monitoring them for one of the following signs:

- Defect creates a substantial interruption in the continuity of the floor surface, creating potential safety concerns (i.e. tripping hazard).

- Defect creates an interruption in the continuity of the floor surface, impacting material handling operations through driver slowdowns, abrasion to material handling vehicle wheels, or impact points for material handling vehicle wheels.
- Defect shows signs of chipping, spalling or other deterioration.
- Defect compromises floor sanitation by creating a space difficult to properly clean and maintain.
- Defect shows signs of dusting, erosion, or other gradual deterioration.
- Defect shows signs of continual growth/degradation.

Among the most typical floor surface defects are the following:

Dusting

Dusting is generally a result of improper hydration of cement paste at the concrete surface at the time of slab curing or finishing procedures. It can also result from contamination of the slab surface by certain environmental sources (i.e. allowing the carbon monoxide from direct fired temporary heaters to buildup on the curing slab). If the floor slab surface is porous, chalky or inherently weak, cement paste or aggregate fines can become airborne under traffic, leading to dust settling on packaged product.

Figure 5.14



Surface Delamination

Delamination occurs when a substantial portion of the concrete paste is lost at the concrete surface, exposing larger aggregates and leading to a rough "washboard" like concrete surface. Delamination is typically related to improper concrete finishing operations during construction but can spread rapidly across the surface due to abrasion and impact of affected areas by material handling vehicle wheels or other material handling practices such as dragging or pushing pallets.

Figure 5.15



Pop-Outs, Potholes, Surface Spalls

Gouges, spalls, or holes in the concrete surface can result from many factors, both construction and operations related. Some may be a result of foreign materials finished into the concrete surface (i.e. wood) or improperly mixed concrete and some result from impact on the floor by the building owner.

Figure 5.16



Bolt-Holes

Bolt holes are holes or pop-outs left in the floor after removal/relocation of racking. In many cases where bolt removal proves challenging, bolts are often cut off in place, leaving potential impact points or tripping hazards behind.

Figure 5.17



Surface Scratches/Gouges

Deep scratches or gouges in the concrete are often caused by material handling operation related activities such as pushing or dragging pallets, having nails caught underneath lift tires, etc. Scratching can also be noted prevalently along the high sides of curled slab edges.

Figure 5.18



Floor Heaving Due to Frost

If floor heave has taken place and has deformed the floor or building, the first step in restoration is to inject heat beneath the floor by whatever means possible. The time or cost to repair damage like this varies on how much ice has formed beneath the building.

5.2.3 Repair of Freezer/Cooler Floors

While the repair methodology for freezer/cooler concrete floors is similar to that of ambient concrete floors, refrigerated areas pose some unique challenges which may require more specialized repair materials or cause the repair area to be out of service for longer periods of time. Since many refrigerated facilities have a short window of opportunity when repair work can be conducted, pre-planning defect preparation time and slower material curing times around operational access limitations is critical.

In freezer/cooler rooms, all work is being done in a closed, controlled environment and that environment typically contains consumer-bound food product. If the food product cannot be removed or isolated from repair areas, caution should be used in selecting the repair material(s). These rooms are a closed environment with minimal air exchange. This increases the potential for contamination of product stored within the room. USDA/FDA/CFIA approval/acceptability of repair products and their relative odors should be considered and established by reviewing product technical data or contacting the manufacturer of the intended repair product(s) to discuss the products in greater detail.

The effectiveness of repair products depends largely on adhesion to clean, dry concrete. Obtaining a clean dry repair area in a 24/7 cooler dock or normally wet area along with potential contamination of the product are very common problems with slab repairs. Special equipment is often required to perform durable, lasting repairs.

Figure 5.19



5.2.4 Basic Repair Recommendations

Who Will Perform the Repairs?

The decision as to who will perform the repairs will require consideration of many factors. If the goal is to self-perform the repairs, an objective analysis of in-house personnel availability and qualification should be made. Proper repair procedures to effect long-term, permanent repairs often require specialty tools and equipment not normally found in the typical maintenance arsenal (i.e. vacuum-equipped dry-cut saws for concrete cutting and crack- chasing, hammer drills, etc.). The costs of renting or purchasing such equipment will need to be factored in to the overall repair costs.

There is no one size fits all answer to whether it is best to use in-house staff or to bring in a contractor. As a rule, it is normally best to bring in a contractor when in-house staff has limited time and capability levels, or when the amount of work to be done is substantial in scope.

But if providing significant areas of work areas at any given time appears impossible, then using in-house personnel may be the only practical option. Under these circumstances, it may be wise to arrange for the proper training of your staff by an outside source with expertise in floor repairs. Some repair material manufacturers may offer low or no cost training or can likely refer you to an appropriate source.

Avoid employing contractors who lack specific knowledge or expertise in performing floor repairs in refrigerated areas. Such work requires a level of expertise that must be attained by experience, rather than by reading manuals or product literature. If the use of an outside contractor appears to be the best option for a repair program, seek out qualified contractors by asking for references from industry associates, specialty consultants, or by contacting manufacturers of the repair products you would like to be used. It is also recommended that any contractor you consider be able to furnish you with a list of successful project references and be willing to perform some example repairs in the facility to demonstrate the skill of their work and its durability.

The use of specialty contractors is almost always mandated for the repair of substantial surface deficiencies. The application of toppings or high-build coatings requires sophisticated equipment to properly clean and/or scarify the surface in order to

achieve proper adhesion. The same applies to the repair of rocking/curled slabs, major structural deficiencies, etc.

Repairs should always be performed at the area's normal operating temperatures. Raising the area temperature for the comfort or convenience of the workers will result in dynamic movement of joints and cracks due to expansion of the concrete. When the temperature is later dropped back to its original level, the joints and cracks will open wider (as the concrete shrinks) and the repair will be compromised. Instead provide workers with proper low-temperature apparel.

Floor scrubbing should be discontinued 24-48 hours prior to the start of any repair to ensure that defects are as dry as possible. Excessive moisture/frost can compromise the adhesion of repair materials or adversely affect their cure.

Preparation of the defect prior to the introduction of the repair product is critical for the success of any repair. All concrete at the defect that is structurally unsound, or contaminated by grease, oil or other foreign materials must be removed. The outer points of all repairs should have a vertical edge; feathered patches are seldom as durable as "notched-in" repairs.

Avoid shallow or tapered repairs. Because the repair can be made to vertical, straight edges, there is no need to "feather" a thin layer of concrete or patching material adjacent to the edge of the repaired area. This thin layer has a tendency to set up faster than the rest of the patching material and poor bonding results. During feathering, fine particles of the patching material are worked to the surface, and consequently, with some material(s) at that surface, where maximum strength is needed, becomes the weakest point. Flaking, spalling or breaking away can start and the result is an even more difficult maintenance problem.

As a general rule cracks should not be routed. If the cracks are not wide enough to accept gravity fed epoxy routing them will do more damage than good. Widening the crack (by sawing, routing) may merely increase their exposure to hard wheeled impact. Cracks that are credit card width (1/32") or greater can often be repaired merely by gravity-flowing the proper repair product into the crevice after blowing/brushing the crevice clear of dirt and debris. Cracks that exhibit edge spalls (deterioration) or "islands" should usually be "chased" (sawn out) before filling.

When outlined first by saw cuts, damaged areas can be chipped out in less time than it takes to do the job using other methods. Cuts are made around the damaged area, to a depth approximately 1/6 the slab thickness. The clearly defined area is then chipped out and the hole refilled with concrete or other flooring material.

Sawing can be done in advance; all areas can be pre-sawed, and actual repair work handled in the course of regular working hours. The water used to cool the blade makes sawing dustless, so machinery in the area is not adversely affected. However, depending on the amount of sawing required and the location of the work area it may be prudent to schedule the work during off hours due to the noise of the sawing and possible tracking "saw mud" throughout the area. This problem is often critical when floor repairs are being made near high traffic areas of operation.

Slab curl can result in an uneven profile at the edges of adjoining slab panels and create an impact point along the edge off the higher elevation slab. This can also result in "slab rocking" when traffic loads are imposed. When repairing joints, it is always a wise to load-test each edge to determine if it deflects under load or is a discernable impact profile exists. If panels elevations vary but no vertical deflection is detected, grinding or leveling of the higher edge may be required prior to repair. If panels do deflect (rock), stabilization of that panel should be considered prior to repairing the joint. Continued rocking will usually cause any repair to deteriorate in short order.

Figure 5.20



Curled panel edges or rocking slabs will require special attention prior to undertaking joint repair.

Some repair material manufacturers provide basic repair advisories that repair personnel can use as guides. Consultants who specialize in floor repairs in refrigerated facilities can also be a valuable resource.

Again, it is recommended that you discuss your floor problems with industry partners who have experienced similar problems and have had them successfully addressed.

Repair Material Selection

There is a vast range of floor repair products available and the list keeps growing., Not all are suitable for use in refrigerated facilities. A careful reading of the literature for each product is necessary. For example, many products cannot be used below 50 degrees F (10 degrees C), while others are formulated specifically for use in lower temperature ranges, including sub-zero applications. Some repair materials have maximum width limitations, are not USDA/ FDA acceptable, or may have other limitations. The selection of a high quality, suitable repair material is an important factor in guaranteeing the long-term success of any repair.

When reading product literature, you should be aware of the product hardness. The American Concrete Institute and the Portland Cement Association have indicated that products having relative hardness's of less than Shore A80 are not sufficient in rigidity to support hard-wheeled traffic without deflecting. Such deflection leaves joint and crack edges subject to hard wheel impact and the resulting edge spalling (deterioration).

On the other hand, some products may have hardness's in excess of Shore A100, which is literally rock-hard. These materials often have adhesive strengths greater than the strength of the concrete itself and if used to repair joints or cracks still experiencing even minimal dynamic movement they may "weld" the defect and "tear" or fracture the concrete in other areas.

Figure 5.21



If using harder "structural" types of repair materials, be certain to understand their adhesive strengths and hardness as well as the original design of the defective area being repaired (i.e. joints are cut or formed to allow movement, etc.).

In general, you should use materials classified as "semi-rigid" to fill joints and cracks, and use "structural" materials to rebuild joint edges (prior to filling), repair surface delamination and gouges, etc.

The most common repair materials for concrete floors are epoxies and polyureas. Epoxies are known for their outstanding durability, but cannot be applied in sub-freezing temperatures since they may not cure. They will generally cure in cooler room environments, but their cure times are slower than at ambient temperatures and will likely require longer traffic access times.

Polyureas have much faster cure rates than epoxies, and many will cure well even at sub- zero temperatures. Both epoxies and polyureas are two component products. Polyureas are more moisture-sensitive, and repair surfaces must be absolutely dry. In most cases the room temperature and traffic-free time available will determine the proper material choice.

Since all refrigerated facilities deal in food and/or pharmaceutical products, it is critical that you avoid any product that might cause contamination of your merchandise. Avoid products that contain solvents if at all possible. When a product's literature states that its solids content is, for example, 90%, this means the product contains 10% solvent. Most solvents leave a residual odor that may remain noticeable for hours, days, even months. More importantly, some solvents have the ability to penetrate packaged goods. Be especially alert to the term "methacrylates." These products release a significant odor that holds a high potential for contamination, and are known to be able to penetrate even polyethylene wraps. There are many suitable 100% solids products on the market from which to choose from when selecting the appropriate repair material.

Your standard practice should be to have any proposed repair product evaluated by the person(s) responsible for your merchandise safety. He/she should not only read the product literature and MSDS, but also perform a physical test to determine problems not identified by printed matter.

Since the early 1990's USDA and FDA no longer test repair/maintenance products and certify them as "approved" for use in regulated facilities. All products are therefore "self-certified" by the manufacturer as meeting federal, state and other criteria. Do not accept the term "USDA/FDA acceptable" on a data sheet as proof-positive that it is fully acceptable for your use in any given application. The final burden for acceptability and merchandise safety falls upon the facility owner.

The Installation

Repair materials should be ground or shaved flush with the floor surface to restore surface continuity.

It is always a good idea to move merchandise as far away as possible from the repair work. Closely follow manufacturer's instructions. The finished profile of all repairs should be flush (level) with the adjacent floor surfaces to facilitate the smooth movement of material handling vehicles. A flush profile with semi-rigid fillers is best achieved by overfilling the defect then razoring off the overfill once the filler has cured into a solid. Structural products must be installed perfectly flush (troweled flush) or ground flush after they cure.

Figure 5.22



5.2.5 Monitoring and Preventative Maintenance

Being a "floor conscious" owner is one of the best ways to help ensure that your distribution operation achieves maximum productivity and that your material handling vehicle maintenance costs remain low. It is recommended that a single person (generally in the operations or maintenance department) be assigned as a "steward" for the floor. An inspection of the floor should be conducted on a periodic basis (monthly or quarterly). During this inspection, any areas noted that show signs of potential deterioration or unusual wear should be mapped out and documented with pictures. This report should then have reviewed by the facility/maintenance director and any areas requiring additional monitoring, maintenance or repair can then be identified and acted upon accordingly.

Key Components of a Good Monitoring and Maintenance Program

- **Potential Corrective Action Areas Should be Prioritized** - Floor areas requiring attention should be prioritized and ranked according to severity, relative impact on operations, and urgency of any necessary corrective action.

- **Guidelines for Corrective Action Should be Standardized -** Develop an internal "Floor Repair and Correction" manual which outlines methods and materials to be used for past or typical floor defect conditions.
- **Responsibility for Corrective Action Assigned; Scheduled -** Determine whether corrective actions and/or ongoing maintenance will be performed with in-house personnel or outsourced and schedule action items.
- **Consistently Scheduled and Performed -** Whether it's weekly, monthly, quarterly, etc. will depend on each individual facility, its conditions and resources.
- **Inspection is Comprehensive -** During the inspection all aspects of the floor should be monitored and any changes in surface or the condition of joints, cracks, or previously performed maintenance/repairs should be observed.
- **Documentation Should be Clear and Consistent -** Areas requiring attention or additional monitoring should be mapped and photographed for easy identification by maintenance personnel or management. Documentation should be available for follow up after corrective action is taken or future monitoring inspections.

Facility owners should monitor joint activity periodically, looking for evidence of the following:

- Separation voids opening between joint filler material and joint edge on one or both sides of joint edge.
- Separation voids or tears within the joint filler material itself.
- Separation voids will generally first be seen as dark hairlines within material or along joint edges. Voids are usually not a concern to the structural integrity of the filler and its ability to protect unless they open to a width of 1/32. (credit card width) or greater. Even when voids do occur to this extent, potential exposure to joint edge damage will be dependent largely on the location and pattern of the voids. Internal separation (tears within filler) require less maintenance as they do not lead to joint edge exposure.
- Separation voids which jump back and forth across the joint or occur dominantly along one edge may require refilling if they exceed credit card or if there is evidence of joint edge deterioration/breakdown occurring at void locations. If evidence of edge deterioration is present, voids should be cleaned and filled with a semi-rigid polyurea filler. Voids showing no evidence of compromising joint edge integrity should be monitored monthly to determine overall activity over a period of time. If voids remain at consistent width over the period of 6 months, refilling activity can be considered. But it is more likely that void dimension will open and close seasonally to some degree. If no signs of joint edge deterioration are present and sanitation issues are not a concern filler separation voids generally will not require maintenance. If either concern is present, refill the voids.
- Separation void at credit card width (1/32") = Maintenance suggested.
- Early minor separation void (<1/32") = No maintenance generally required.

Summary

The repair of your concrete floors can provide an excellent ROI if performed properly. Most facility owners find that their floor repair expenditures are usually recouped within a year or two via increased productivity, fewer worker compensation/injury claims, lower vehicle maintenance costs (bearings, transmissions, etc.) and greatly reduced wheel replacement expenditures, etc. Always remember that your facility's concrete floor is literally the work surface for your entire operation. Anything you do to improve and maintain its condition and productivity will pay dividends in nearly every area operations.

5.3 Modernization

5.3.1 Future Floor Designs and Practices

The future steps in the evolution of sub-floor heating systems are in the controlling, monitoring and maintaining of the underfloor heating system. One key element in underfloor heating is to generate and disperse only enough heat to prevent the subfloor from freezer, while not introducing excess heat into the freezer. The use of a more accurately calibrated and tested equipment (sensors and controls) will allow the end user to achieve the required set points without introducing the excess heat.

Another future component to underfloor heating may be the use of heat reflective materials. By introducing a heat reflective material just above the sub-floor, you will be able to minimize the amount of heat infiltration into the concrete floor slab and lower your heat load on the freezer. Types of heat reflecting materials include ceramic coatings, films, and heat reflecting tarps. Introduction of these items will increase costs to the install of your projects and they may currently be cost prohibitive.

Future floor designs should also include concepts of reducing the maintenance costs and needs for downtime due to repairs of the problems of the traditional concrete floor design. This would involve, considerably reducing amount of the joints in the floor, improved joint design and elimination of curling.

Figure 5.22 Heat Reflecting Tarps



Figure 5.23 Ceramic Coating On Piping



Figure 5.24 Heat Reflecting Film



5.3.2 Food Processing Floor Requirements

To ensure safe food and adequate sanitation programs, the floor requirements within the facility in which food processing and handling operations are conducted must be designed and constructed with consideration of sanitary design principles.

Here are a few key performance requirements for floors within a food processing, handling or storage facility:

- Floors in areas where product is handled or stored should be constructed of durable, easily cleanable materials.
- Floors should have slip resistant surface.
- Floors should be sloped to avoid puddles or depressions where water will stand.
- Floors should be installed and maintained to reduce the likelihood of depressions or other low areas that would accumulate moisture.
- Coved (45 degrees) at the wall to floor joints and sealed.
- Floors should have adequate drainage.

Floor Coating

Due to daily exposure of a variety of chemicals and food products in a food processing and handling facility, the floors should be smooth, impervious, corrosion resistant, cleanable, non-absorbent and in good repair. Many facilities will face the challenge of selecting a floor coating type that will preserve and protect their concrete floors while controlling any kind of cross contamination. Selecting the right type of floor coating will be essential in creating a safe working environment for employees, employers and everyone exposed to the food products within the facility.

Here are some considerations to be made, in addition to the mandatory requirements listed above, when selecting a floor coating:

- Types of chemicals that will be exposed to the floors.
- Temperature of water that will be exposed to the floors.
- Temperature setting of rooms exposed to the floors.

- Can operations shutdown to apply floor coating?
- Schedule and method of floor washing
- Heavy loads on floors.
- Any time restrictions that will require fast cure rate for floor coating.

Always consult a floor coating manufacturer or supplier to assist in providing correct product selection and choose a knowledgeable contractor with experience in the food processing industry to ensure a foundation of success.

Floor Concrete

One of the main objectives of a floor coating is to preserve the concrete floor beneath the coating, although floor coatings cannot protect the concrete against all forces. Food processing floors are subject to very extreme conditions which require a slab design that must consider several elements. The structural floor designer will be able to best select a concrete type, strength, class and composition, although they must be aware of the conditions exposed to the floors.

Some conditions to consider when designing a floor in a food processing and handling facility:

- Will the floor be present in a freeze-thaw environment?
- Will the floors be exposed to hot water wash down or any other moisture?
- Will there be any heavy traffic over the concrete slab?
- Will there be any corrosive or acidic products exposed to concrete slab?
- Will the concrete floor be exposed to thermal shock?

Floor Drains

Within a food processing and handling facility, special attention should be made to the floor drains as they can be a major source of contamination. Floor drains must:

- Be appropriately located so that they are easily accessible and equipped with removable covers that are flush to the floor.
- Have an adequate number and size.
- Be maintained in good repair.
- Be designed and installed so that they are cleanable.
- Have drain lines that are sloped, individually trapped, and properly vented to outside air.
- Be equipped with backflow preventer.

Additionally, the drainage system within the food processing, handling and storage areas should be constructed so that there is no connection to any domestic or other non-food processing drainage.

Here are some considerations to be made, in addition to the mandatory requirements listed above, when designing a drainage system:

- How often are rooms washed, for how long and with what temperature?

- Is there any heavy machinery that will mobilize over sloped floors?
- Do any equipment release water or other liquids into the drains?
- How much solids are anticipated to enter the system?
- What products are being processed that could enter the drainage system?
- Types of chemicals that will enter drainage system.

It is recommended that the drain design be created by a professional engineer with experience in food processing facilities to ensure a proper design that will meet your operation requirements.

Chapter 6: Roofs

Acknowledgements

Jeff Wiersum, 5th Wall Solutions, LLC, Belding, Michigan, USA

6.1 Design

6.1.1 Historical Background of Contemporary Roof Systems

6.1.1.1 Built-up Bituminous Membranes

Today's built-up membranes are the sesquicentennial descendants of the crude prototypical membranes invented in the 1840s, when square sheets of ship's sheathing paper, treated with a mixture of pine tar and pine pitch, served as the felts. The inter-ply bitumen of these early membranes was coal tar, a waste product readily available from the production of coal gas for illumination at plants near the nation's cities. As the next advance, coal tar was substituted for pine tar as a more fluid saturant for the sheathing paper, but square sheets were still dipped manually into the melted saturant and the excess pressed out. Then came the replacement of paper by felt rolls, running through continuously operating saturators. The use of felt rolls accelerated the application process and promoted more uniform membrane quality. Substitution of distilled coal tar pitch for the more expensive pine pitch-coal tar mixture followed.

Asphalt became a competitor of coal tar pitch before the end of the nineteenth century; both as mopping bitumen and as felt saturator. Asphalt was not only more economical than coal tar pitch but also a more versatile material. (Its wide range of viscosities adapts asphalt to much steeper slopes than coal tar pitch.) As a consequence of these advantages, asphalt ultimately replaced coal tar pitch as the most popular bitumen in built-up systems.

More recently, built-up membrane felts have undergone even greater changes. Organic felts containing cellulosic fibers monopolized the market for decades until the introduction of asbestos felts in the 1920s. Today, however, fiberglass felts, introduced soon after World War II, have virtually wiped out the competition. The cellulosic fibers in organic and, to a lesser extent, asbestos felts make them vulnerable to fungus rot, whereas fiberglass felts are virtually immune to this roofing disease. The moisture-absorptive propensity of both organic and asbestos felts makes them vulnerable to blistering. This formerly major problem is virtually eliminated with the porous fiberglass felts. They vent the entrapped air-water vapor mixture that, upon heating, can cause blister growth in poorly applied organic or asbestos-felted built-up membranes. Fiberglass felts also resist

splitting better than organic and asbestos felts, which are drastically weakened by moisture absorption. Moreover, organic and asbestos felts are much weaker in the transverse direction than in the longitudinal direction. The greatly improved modern fiberglass felts have virtually isotropic (i.e., equal in both longitudinal and transverse directions) tensile strength.

In summary, the contemporary built-up membrane is potentially a vast improvement over its predecessors. It still, however, depends upon highly skilled application technique to realize this potential.

6.1.1.2 Single -Ply

EPDM (Ethylene Propylene Diene Monomer)

In the early 1960s the new synthetic single-ply material was introduced into low-slope commercial roofing and was far more expensive than conventional built-up roofing. EPDM was used in Italy before 1960, where Ziegler-Natta catalysis made its polymerization possible. After an incubation period of about ten years in the U.S., big improvements in material quality marked its exponential growth period. By 1975, its growth doubled every year until the mid-1980s. Behind the EPDM revolution is a combination of economic and technological factors:

- Skyrocketing petroleum prices during the energy crises of the 1970s closed the cost gap between more expensive synthetic materials and conventional built-up systems.
- Dissatisfaction with conventional built-up roofing provided a ready market of unhappy building owners and architects eager to try something new.
- The long-term trend toward greater reliance on prefabrication and lesser reliance on heavy field labor favored the generally less labor-intensive field installation of the newer, lighter materials.
- Environmental regulations increasingly limited the heavy polluting installation techniques of conventional built-up roofing, with its smoke-producing hot bitumen kettles.
- The new single-ply systems are generally cleaner and more aesthetically pleasing than built-up systems.
- They are also much better adapted to heat-reflective colors, an energy-conserving feature in warm climates.

EPDM's excellent ozone and ultraviolet resistance, previously exploited by the automotive industry in tires, weather stripping, and trunk-lid gaskets, has now been exploited by roofing material manufacturers. EPDM's capacity for absorbing large quantities of cheaper reinforcing filler materials — notably carbon black, an UV inhibitor — lowers its cost while increasing its tensile strength.

PVC & Blends

The use of PVC sheet material used in roofing in the United States began as a replacement of two-ply bituminous membrane vapor retarders after the famous General

Motors fire in the late 1950s. The fire demonstrated that an internal fire could melt the bituminous material in built-up roofing, which could feed the fire by leaking down roof penetrations. Polyvinyl chloride (PVC) is an inherently fire retardant thermoplastic due to the presence of 57% chlorine in its molecular structure. Because of its fire resistance, it was used as a vapor barrier film layered in ribbons of cold adhesive. This fire-retardant film met the requirements of FM Class I, but did not play a significant part in the early use of single-ply roofing until much later. Its use as a fire-retardant vapor barrier on steel decks resulted in poor adhesion, splitting and lift-off.

In the early 1970s polymer-coated fabrics, originally used as trench tarpaulins, were adapted as roof membranes. Pond and ditch liners made of reinforced polymeric sheets were also elevated to the status of roof membranes. PVC had a major advantage over synthetic rubber material in its weldability, by either heat or solvent welding of field seams.

Early generations of PVC roof membrane had their problems. Some of the thin-mil, unreinforced membranes began to shrink and become brittle due to plasticizer loss from the membrane. In the early 1980s, PVC manufacturers began to introduce reinforcement to the membrane as well as increase the mil-thickness. Improved UV and plasticizer packages also were introduced to make a much more durable membrane. PVC systems are not commonly used in cold storage applications due to their inferior perm rating to other membranes. (See Table I).

TPO (Thermoplastic polyolefin)

The development of a polyolefin thermoplastic material has its roots in the 1930s, when the first high-pressure process was developed for polypropylene. But progress was slow. In the 1960s, scientists succeeded at polypropylene copolymerization, creating EP (Ethylene propylene) polymers. But it wasn't until the 70s that today's TPO really began to take shape. In the 1970s, two significant advancements changed the face of TPO:

- The development of gas phase processes which allowed for more consistent and a greater variety of polyolefins and the successful compounding of polypropylene blends.
- The manufacturers driving these changes in TPO and the polymer technology were in the automotive industry.

The first TPO automotive bumper was developed in Europe by Fiat in 1975. At this time, TPO was used only to replace the metal fascia on the bumper, not to manufacture the complete system itself. But as the decade progressed, auto manufacturers continued to expand their development of TPO components, in part because of its lighter weight and recycling potential.

The 1980s

Science continued to refine polypropylene composites and the production process. TPO use continued to grow in the automotive industry, especially for interior and exterior trim applications. By mid-decade, the technology had also been adopted by the household

appliance industry, which used it for components in dishwashers, clothes washers and other water-based applications.

The technology grew quickly following the introduction of a catalyst system to polymerize the EP and polypropylene materials. In 1986, dynamic vulcanization helped introduce TPO to the roofing industry. However, the roofing membrane as we know it today — a mixture of EP and polypropylene — first came into regular production in 1989.

The 1990s

During this decade, the use of TPO in manufacturing has been rapidly growing globally. Inherent attributes – including chemical resistance — enhance the value of TPO in many demanding industrial environments. Advancements in manufacturing have revolutionized the TPO process.

6.1.1.3 Modified Bitumens

Concurrent with the single-ply elastomers came a more direct attack on conventional built-up membranes: the modified bitumens, pioneered in Italy and other European countries. By reducing the traditional four-ply built-up membrane to two (underlayment plus single-ply sheet), modified-bitumen sheets fulfill the perennial construction goal for reducing heavy field labor. And with their tremendous improvement in material quality (improved flexibility, elasticity, and ductility at subfreezing temperatures) modified-bitumen systems preserve most of the advantages of conventional built-up membranes, their superior puncture resistance and general toughness. In a sense, modified bitumens can be considered more an evolutionary improvement of conventional built-up membranes than a revolutionary alternative.

Like thermosetting and thermoplastic sheets, modified bitumens are a triumph of polymer chemistry. They evolved as an incidental technological by-product of more directly sought advances. One major ingredient in many modified bitumens, atactic polypropylene (APP), is a by-product of isotactic polypropylene (IPP), familiar in tool or hair dryer cases as the integrally molded hinge capable of flexing thousands of times without fatigue failure. The process producing IPP resin yielded a soft, non-crystalline by-product, APP. Seeking markets for this material, manufacturers found that it plasticizes asphalt, endowing it with greatly enhanced physical properties—the previously noted flexibility, elasticity, and ductility down into the subfreezing range (-15 F, -26 C). APP-modified sheets were first used in Italy, where APP polymer was readily available. They were soon imported into the United States.

Because APP-modified sheets have elevated softening points, they proved unsuitable for adhering with hot-mopped asphalt. They required heat fusion by propane torch, operating at temperatures approaching 3,000°F, not only to adhere the modified bitumen sheet to its substrate but also to seal field seams and form flashings.

Another plasticizer, styrene butadiene styrene (SBS) copolymer, produces a modified-bitumen membrane with greater elasticity and low-temperature flexibility than the thermoplastic APP-modified-bitumen membranes. Introduced in France in the

1960s, SBS-modified bitumens exploit the unique ability of SBS to form a polymer dispersion within a mass of asphalt. Even though the polymer represents only 12 percent or so of the mix, the SBS molecules form a net-work. The SBS-modified asphalt behaves something like a water-soaked sponge: despite the much greater weight of the water, the sponge nonetheless behaves like a solid, not a liquid. SBS-modified bitumen thus exhibits truly elastic behavior, recovering its original shape upon removal of deforming stress.

This unique polymer-dispersing property gives SBS a major advantage over APP as a bitumen modifier. Unlike APP-modified-bitumen sheets, SBS-modified-bitumen sheets can be field-adhered with conventional hot-mopped asphalt, because the greatly reduced quantity of SBS polymer elevates the melt point much less than APP does.

6.1.2 Roofing Trends

Conventional Low-Sloped Commercial Roofing Market: 2008 Compared to 2015		
Roof Membrane	Market Share, in %	
	2008	2015
Ethylene Propylene Diene Monomer (EPDM)	22	**19**
Thermoplastic Polyolefin (TPO)	28	**43**
Polyvinyl Chloride (PVC)	10	**13**
Built Up Roofing (BUR Asphalt Roofing)	12	**6**
Single-Layer Asphalt (SBS/APP)	28	**19**
Single-Ply Market Share, 2015		
Roof Membrane	Market Share, in %	
Thermoplastic Polyolefin (TPO)	**55**	
Ethylene Propylene Diene Monomer (EPDM)	**27**	
Polyvinyl Chloride (PVC)	**18**	
Single-Ply Mil. Thickness, 2015		
Mil. Thickness	Market Share, in %	
.080	**3**	
.060	**81**	
.045	**16**	

The trend appears to be toward TPO roofing. The reasons for this are improvements in the formulation of the membranes, hot-air welded seams and the reflectivity of the white membrane particularly in the South and Southwest regions of the United States. The roofing system of choice has been mechanically fastened. Studies have shown that although there may be a thermal drift of 10% to 12% through the roofing fasteners, it only accounts for less than 1% of the entire building envelope. Gaining in popularity is the adhesion of insulation to the deck and fully adhering the membrane to the insulation thus eliminating any fastener penetration in the deck.

In today's cold storage market the predominant roofing systems are TPO and EPDM, due to the flexibility/elongation of the membranes and their excellent perm rating as a vapor barrier material. (See sample testing in Table 6.1).

A roofing material's reflectivity and emissivity are important factors in thermal performance. In fact, the federal government, and many local and state utilities, will provide companies incentive/rebate money to install roof systems and membranes that have a high reflectivity and emissivity rating. These materials are typically relegated to PVC and TPO membranes. The value of these incentives can be up to 40% of the cost of the total project.

Table 1: Water Vapor Transmission

Tested per ASTM E-96 Standard Test Method for Water Vapor Transmission of Material (.045 to 048 mils) Water Method (Method B)

Manufacturer Membrane Samples

Membrane	W. V. T. (grains/hr ft²)	Permeance (perms)	Permeability (perm mils)
TPO	0.005	0.012	**0.49**
EPDM	0.014	0.035	**1.62**
PVC-I	0.115	0.277	**13.30**
PVC-II	0.158	0.253	
PVC-III	0.178	0.285	
PVC-IV	0.094	0.151	
PVC-V		**0.220**	

WVT is tested ASTM E-96, A, B, BW, C, D and E. Generally, the preferred test for cold storage applications is method B or BW. Method B is the water method at 73.4 F and BW is the inverted water method at 73.4 F. The units for WVT are grains/SF x hr. The units for permeance are perms, permeability has units of perm x mil. The key listing here is permeance. The rating for vapor barriers is perms. The cold storage industry standard

indicates that a perm rating of .10 or less is considered a good vapor barrier for cold storage.

6.1.3 Roofing Insulation

A vital component to any refrigerated building is the roof insulation. This is critical to the energy consumption of the facility and the longevity of the roof system. Careful consideration should be taken in the selection of roof insulation.

The majority of the roof insulation installed today is polyisocyanurate (polyiso, ISO). This is due to the thermal retention, higher published R-value per inch – which in turn reduces the insulation thickness and the length of fasteners needed in a mechanically fastened system and relatively low moisture absorption.

It is important to note that wet insulation is 1/65 of its R-value, frozen insulation is 1/100 of its R-value. (See Table 6.3).

R-Value Moisture Absorption (per inch)

Insulation	R-Value	Moisture Absorption
Polyisocyanurate	6.0 (LTTR-180 days) *5.6 (5 year)	1-1.5%
Extruded Polystyrene (XPS)	5.00	0.3%
Expanded Polystyrene (EPS)	3.85	4.0%
Perlite (used mostly in BUR)	2.70	1.5%
Wood Fiber Board	2.00	7.0%
FoamGlas®	3.03	0.2%
Fiberglass	3.60	5.0%
Gypsum Board	0.90	7.7%

***NRCA/ASHRAE recommends 5 year aging**

6.1.4 Roofing Design Considerations

Any roofing system has six design requirements that must be met. The design properties are regulated by criteria set by various testing bodies and associations and are subject to local building codes.

- **Weather Resistance** — The roof assembly must resist entry of water from environmental and other external sources. Other external sources may include condensation and leakage from roof-mounted equipment.
- **External Fire Resistance** — The roof must resist fire from external sources. External sources include sparks and fire brands. Local building codes and/or insurance carriers establish the degree of external fire resistance.

- **Internal Fire Resistance** — The roof assembly must resist fire from internal sources. The degree of internal fire resistance is also established by local building codes and /or insurance carriers.
- **Wind Uplift Resistance** — The components of the roofing system must be attached to the building roof deck in such a manner as to resist uplift pressures caused by wind and/or internal building pressure. Refer to ASCE 7 Wind Uplift Guidelines or Factory Mutual Guidelines if FM Insured.
- **Thermal Performance** — The roofing assembly must have insulating characteristics to provide internal environmental control. The amount of thermal resistance required is usually established by ASHRAE "Recommended R Values for Refrigerated Facilities" (See Table 2). Note: Wet insulation is 1/65 of its original R-Value. Frozen insulation is 1/100 of its original R-Value.
- **Water Vapor Transmission** — A key element to the roofing system selection is the Water Vapor Transmission Rate of the membrane. The cold storage industry standard is that a perm rating of 0.1 or less is usually considered a good vapor barrier for cold storage construction. (See Table I for typical perm ratings on different types of roof systems.)

These criteria must be met by any roofing system considered as a reroofing or recovering option. However, the standards that apply and the exact significance of each vary with the roofing system involved. Checking with individual testing bodies is required to assure which standards are applicable and the requirements for each.

These general specifications may be easier to meet in a situation where the roof is completely stripped to the deck and reroofed. The existence of underlying roof materials may compromise the performance of the new roofing materials applied in a recover situation.

In addition to a loss of performance, a recovered roof may not be insurable. If the plant's insurance carrier requires an Underwriters Laboratory (UL) or Factory Mutual (FM) rated roof (if FM Insured), the recovery may not qualify. FM and UL are based on specific roof assemblies. In order to qualify for the listings, the roof must contain only the materials specified. No listings exist for some recover assemblies. Code violations may result in certain areas from this inability of recovered roofs to be rated.

FM roof ratings may be affected by recovering. Recovering an FM Class II roof does not change its rating. However, using unapproved materials to recover a Class I roof may change its rating to Class II. The Factory Mutual Approval Guide should be consulted, for those insured by FM, for approved materials.

The site-specific information that plays a critical part in the selection process, whether the existing roof is replaced or recovered, must be obtained from many sources. Plant structural drawings, maintenance records, thorough knowledge of plant operations, and local climatic conditions provide the bulk of the information needed.

6.1.5 Building Structure

An analysis of the structural characteristics of the plant building to be reroofed is required. The roof deck must be able to support the weight of the new roof. The original plant structural framing plan contains the live and dead load information from which this determination is made.

Maximum allowable roof loading limits the weight per square foot of the roofing material considered. Any additional weight added to the deck decreases the amount of snow or ponding loads that the deck can support. Ballasted systems and four ply asphalt and gravel roofs are the heaviest roofing option. Fully adhered single ply systems are the lightest.

The amount of lateral, differential, roof-to-wall building movement and structure-borne vibration from plant equipment must be investigated to determine the amount of elasticity and resistance to flexural failure required of the proposed roof material. The service of an architectural firm is helpful in determining the effect of the parameters of roofing choices. Plants that exhibit large structural movement require flexurally compatible systems.

Existing roof slope determines the type of system that is applicable as a reroof choice. Very low slope and dead level roofs can benefit from a retrofit that increases drainage. Lightweight concretes, perlite asphalt, and perlite board can be applied to the deck and sloped to provide drainage in a reroof situation. Tapered insulation systems of various materials are also available for providing an increase in roof slope. Insulation systems also have the advantage of increasing thermal performance of the new roof assembly.

Interior conditions of the plant have an effect on roof choice. The existence of high internal humidity in cold climate areas, hot deck conditions due to in-plant processes, and pressurized interiors require decisions regarding the use of vapor retarders (dry storage), material compatibility, and fastening systems.

6.1.6 Roof Use Considerations

Exhausted materials from plant processes are part of the exterior environment roof systems must handle. Direct contact with these materials is much more acute than with general atmospheric pollutants. Certain chemicals, oils, and fats degrade the performance of some single ply products and asphalt roofs. Hot air above 160°F (57°C) in direct contact on thermoplastics can accelerate failure. Steam contact and debris should be avoided on most roofing materials.

6.1.7 Climatic Considerations

Ultraviolet radiation (UV) is the most important factor in degradation of most roof systems. The addition of carbon black to single ply EPDM materials is effective.

Another climatic factor that affects the choice of a roof system is the presence of ozone, a strong oxidizer. Ozone's effect on single ply systems varies. Thermoplastic Olefin (TPO) and EPDM materials offer the best resistance.

Heat load from sunlight varies greatly depending on plant location. In areas where sun exposure is high, the use of light colors for the roof surface is effective in reducing roof temperatures. On a 95°F day roof temperatures can reach 180°F on a black surface, a white surface may be 110°F making a significant difference.

Frequency and severity of freeze-thaw cycles have an effect on system choice. The roofing membrane must accommodate the change in roof deck dimension from quickly fluctuating temperatures. Most membranes have the ability to meet these changes but material characteristics vary in their ability to withstand the cyclic nature of these tensile forces. Design of the membrane/insulation structure also affects the roof system's ability to handle the effects of any relative motion that may occur between them.

6.1.8 Construction Considerations

According to the Roofing Industry Educational Institute's (RIEI) outline on considerations for selection and use included in their "Reroofing Options" course notes, all reroofing systems are competitive. The tradeoff is lower cost insulations or reduced labor sometimes can compensate for more expensive membrane materials. Based on this assumption, other construction factors gain more importance in the selection process.

Application of all roof systems requires special training and equipment. This factor alone can have a significant impact on selection because the existence of a competent local contractor may limit the type of system available. Proper installation is the most important factor for a satisfactory roofing operation.

The type of system chosen may limit the weather window of opportunity during application. Adhesive bonded systems are best installed when surfaces are dry and at least 5°F above the dew point of the ambient air. Torch and hot air welded systems are capable of vaporizing slightly damp surfaces. Fully adhered systems should be 40° and above for installation. Loose laid systems can tolerate damp surfaces. Wind can make installation of a loose laid and adhered system difficult. Consult roofing manufacturers guidelines.

Onsite plant conditions such as explosive atmospheres, fire hazards, and special fume contamination requirements, may restrict the use of open flames or torches required to install hot bituminous roofing systems.

The amount and type of roof penetrations have an effect on the labor intensity of the system chosen. The flashing requires skill; time attention and sheets in the field of the roof may have to be narrower.

6.1.9 Aesthetic Consideration

Roofs are not usually visible to observers at street level. In the case of sloped roofs, however, a system that provides protection as well as eye appeal is an architectural requirement. Single ply roofs are often chosen originally for these applications because of

their inherent aesthetic appeal. Replacement of roofs in these areas is often in kind to preserve the architectural integrity of the building.

6.2 Maintenance

6.2.1 Inspection and Maintenance Consideration

The choice of a replacement roofing system brings with it inspection pros and cons. Visual inspection, an integral part of roof management, can be complicated by system choice. Heavily ballasted and graveled asphalt roofs make visual inspection difficult. It is critical that seam inspections are made prior to these areas being covered by ballast or gravel. Adhered and mechanically attached membranes are much easier to inspect. Ballasted and graveled roof systems can be very difficult for leak detection.

The patching of aged single ply membrane should be done to the underside of the aged sheet by cutting the hole or cut, large enough to slip a patch underneath and hot air weld or adhere depending on the system.

The Single Ply Roofing Institute publishes an excellent booklet called “Manual of Roof Inspection, Maintenance, and Emergency Repair for Existing Single Ply Roofing Systems”. Some roofing manufacturers also provide similar booklets.

6.2.2 Reconditioning

Another aspect of roof maintenance or modernization a warehouse company should consider is the reconditioning of existing PVC, EPDM and TPO roof membranes. Many times, during the useful life cycle, the roof can be reconditioned using “conditioners and primers” that help recondition the elastomeric properties of the roof membrane. Many times, this can extend both the useful life and warranty of roof membrane at a fraction of the cost of replacing the roof once it reaches the end of its useful life.

6.2.3 Warranties

Roofing warranties require specific criteria be met before they can be issued. Warranties are available for all systems, although their length and scope vary. Most warranties require that the approved materials be applied by approved methods by an approved contractor. In most cases, passing carefully planned inspections by the manufacturer or an outside party representing the manufacturer during and after installation is a requirement.

6.3 Modernization

6.3.1 Roofing Basis-Modernization

The majority of existing flat or low slope roofing is synthetic membrane single-ply. The justification required to implement the reroofing decision is similar for all roof types. The specifics of individual roofing systems alter the importance of some factors in the decision-making process. Age of the roofing unit; general condition of the membrane, insulation and flashings; existence of obvious defects; amount of maintenance time spent fixing leaks; and amount of in-plant damage caused by these leaks may provide the plant engineer with enough evidence that a reroofing operation is on the horizon.

Excessive in-plant damage, roof conditions that pose safety hazards to plant personnel, and catastrophic losses (such as fire, wind blow off, localized failures from excessive ponding of snow loading) typically provided the immediate basis for a roof project.

Reroofing decisions should be based on economic justification. The decision to continue to repair or reroof can depend on the answer to the question: is the total cost of additional roof service life achieved by repair lower than the total annual cost of a new roof system?

An economic comparison based on equivalent annual cost (EAC) is required to fairly compare the two alternatives. For example, a repair program costing $2.00/square foot (psf) is estimated to extend roofing life three years. A tear-off replacement costing $ 5.00 psf is estimated to provide 18 years' service life. Comparing these alternatives to a life cycle (long-term) cost basis requires that each capital cost be reduced to EAC. Assuming an interest rate of 12% compounded annually, the annual cost for repairs is calculated as follows:

EAC = Cost psf debt service constant

= Project Cost psf x [i(1+i) n] / [(1+i) n- 1]

Where i = interest rate, %

n = service life, yr

Thus, the cost for repair is: EAC = $ 2.00 x [0.12 $(1+0.12)^3$] / [$(1+0.12)^3$–1]

= $ 0.83 psf

The cost of tear off replacement is: EAC = $ 5.00 x [0.12 (1+0.1218th power] / [(1+0.12)18th power –1]

= $ 0.69 psf

Based on the EAC, the reroofing cost is $ 0.14 psf less expensive that the repair alternative, and is the obvious choice if the monies for this expenditure are available. Although based on estimated values, the EAC method of comparing expenditure alternatives offers hard figures for action justification. Determining the breakeven point for economic partial replacement versus total tear off and replacement is a unique,

complex and job-dependent question. A rule-of-thumb guideline states that a job requiring the removal of 25% or more of the roof is a candidate for total tear off.

6.3.2 Options for Modernization

Before the plant engineer begins the task of specifying the new roof, an investigation into the present type, general failure mode of the roof, and the condition and type of deck is required.

There are three options available for providing a new roof: recovering, retrofitting, and reroofing. The method of replacement cost may rule out some options for certain roof types.

Recovering refers to placing new roofing material over the existing roof. Major factors to consider are:

- Compatibility of the existing roofing material with the retrofit material.
- Ability of the deck to safely carry the load of the extra roofing material.
- Condition of the insulation and deck below the existing roof.
- Ability of the roof to be recovered.

There may be limitations to how many times a roof can be recovered or will limit the number of roofing systems or materials that can be applied over an existing roof before both systems have to be removed. Operators should check local state codes and regulations.

Retrofit refers to placing a new system over the existing roof, but includes the additional steps of upgrading thermal insulation and in most cases, improving drainage through slight modification of the roof slope.

Reroofing refers to the operation in which the existing roof system is stripped to the deck and new materials (insulation, vapor barriers, and membrane) are installed.

The reroofing option is considerably more expensive than simple recovering. The cost to reroof is always greater than to recover. In many cases, the actual figure is twice that of a recovering operation. Removal of existing roofing materials is labor intensive and controlled by weather conditions. A bare roof deck (especially fabricated types such as wood, metal or precast concrete) affords little protection from water intrusion into the building interior in the event of an unforecasted rainstorm.

With recent bans on landfilling certain types of solid wastes, the disposal cost of removed materials is a factor in the overall expense of a reroofing operation. Worker and environmental safety is also an issue and cost-escalator in the removal of older roofing systems that may contain asbestos. Dirt and dust generated by reroofing can be a problem.

Despite the risks and costs associated with removal of the roof, there are advantages that make this operation attractive:

- Thorough roof inspection of the entire roof deck can be conducted only in a reroof situation
- Deck repairs, when necessary, can easily be accomplished.
- Integrity of the new roof is not compromised by substandard conditions remaining from the old roof.

For example, the effect of trapped moisture in non-removed materials may inhibit thermal performance of the new roof and lead to long-term degradation of both new roofing and existing deck materials. Resistance to wind lift may also be affected. Areas of degraded attachment of the original roof system caused by moisture degradation of membrane bonding planes or fastener corrosion may compromise the wind lift resistance of the new roof.

6.4 Cold Storage Roof Vapor Details

As an additional resource to the Guide to Effective Warehouse Design, Maintenance, and Modernization, CEBA and IARW roofing experts developed sample roof edge details that address a number of scenarios. These construction details are meant as a guide only. Each project is different. Be sure to consult with a specialist during your design process.

Figure 6. 1

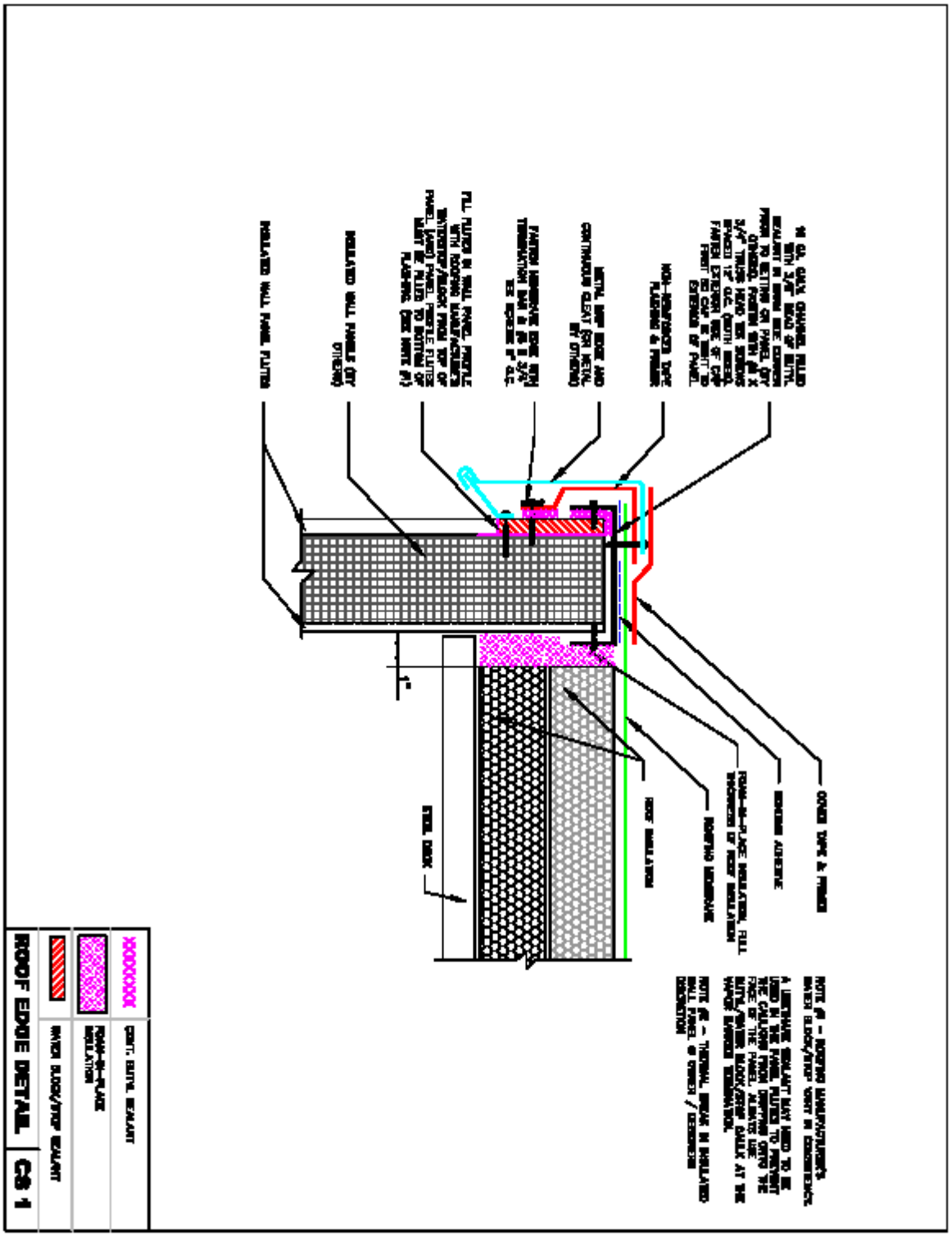


Figure 6.2

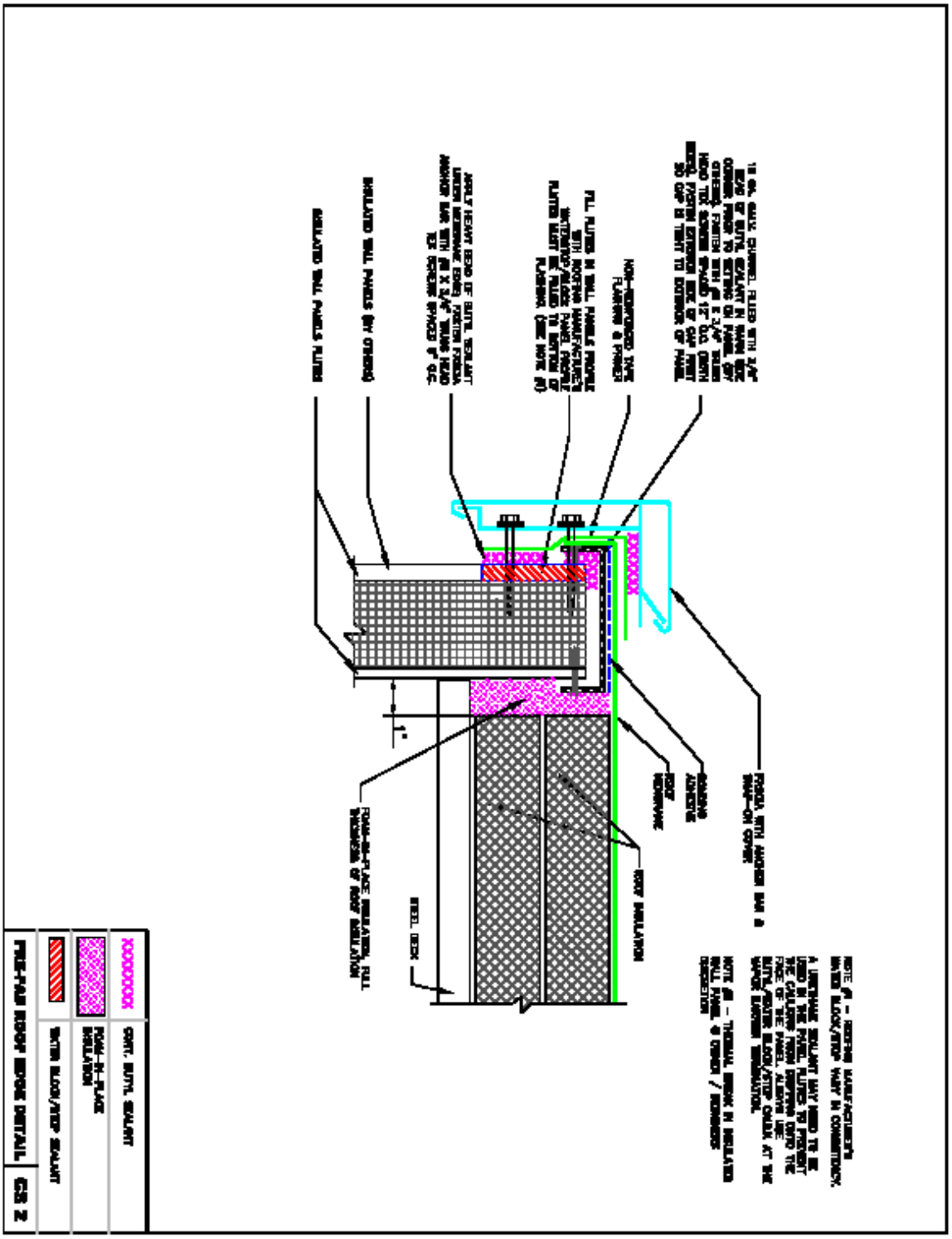

CONT. BUTYL SEALANT
POUR-N-PLACE INSULATION
METAL BLOCK/STOP SEALANT
FREE-FOAM ROOF EDGE DETAIL
CS 2
ROOF INSULATION
ROOF MEMBRANE
ADHESIVE
STEEL DECK

Figure 6.3

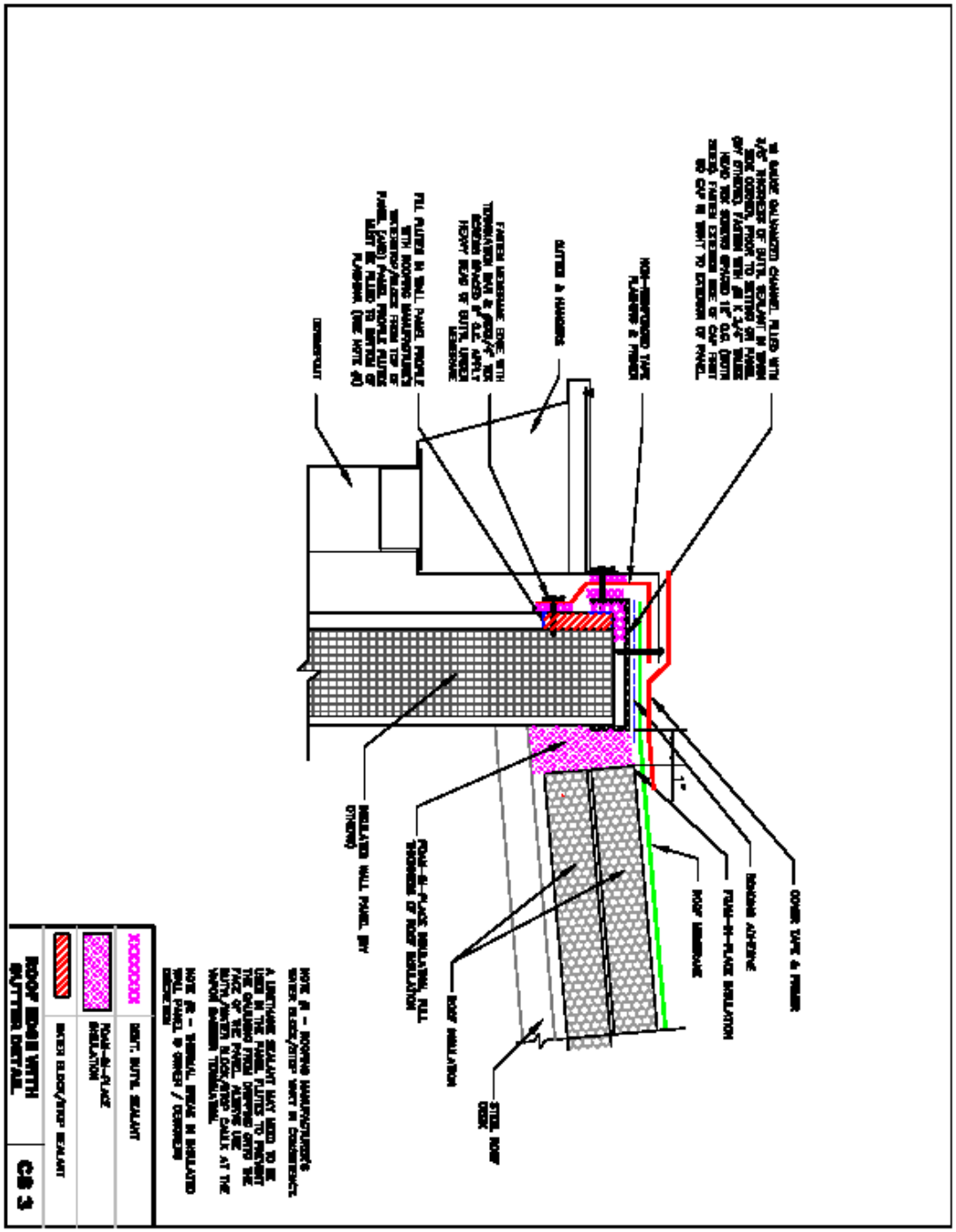

ROOF EDGE WITH GUTTER DETAIL
CS 3
BUTYL SEALANT
FOAM-IN-PLACE INSULATION
WOOD BLOCK/STOP SEALANT
COVER TAPE & FASTENER
FOAM-IN-PLACE INSULATION
ROOF MEMBRANE
ROOF INSULATION
STEEL ROOF DECK
INSULATED WALL PANEL (BY OTHERS)
FOAM-IN-PLACE INSULATION, FULL THICKNESS OF ROOF INSULATION
GUTTER & HANGERS
DOWNSPOUT

Figure 6.4

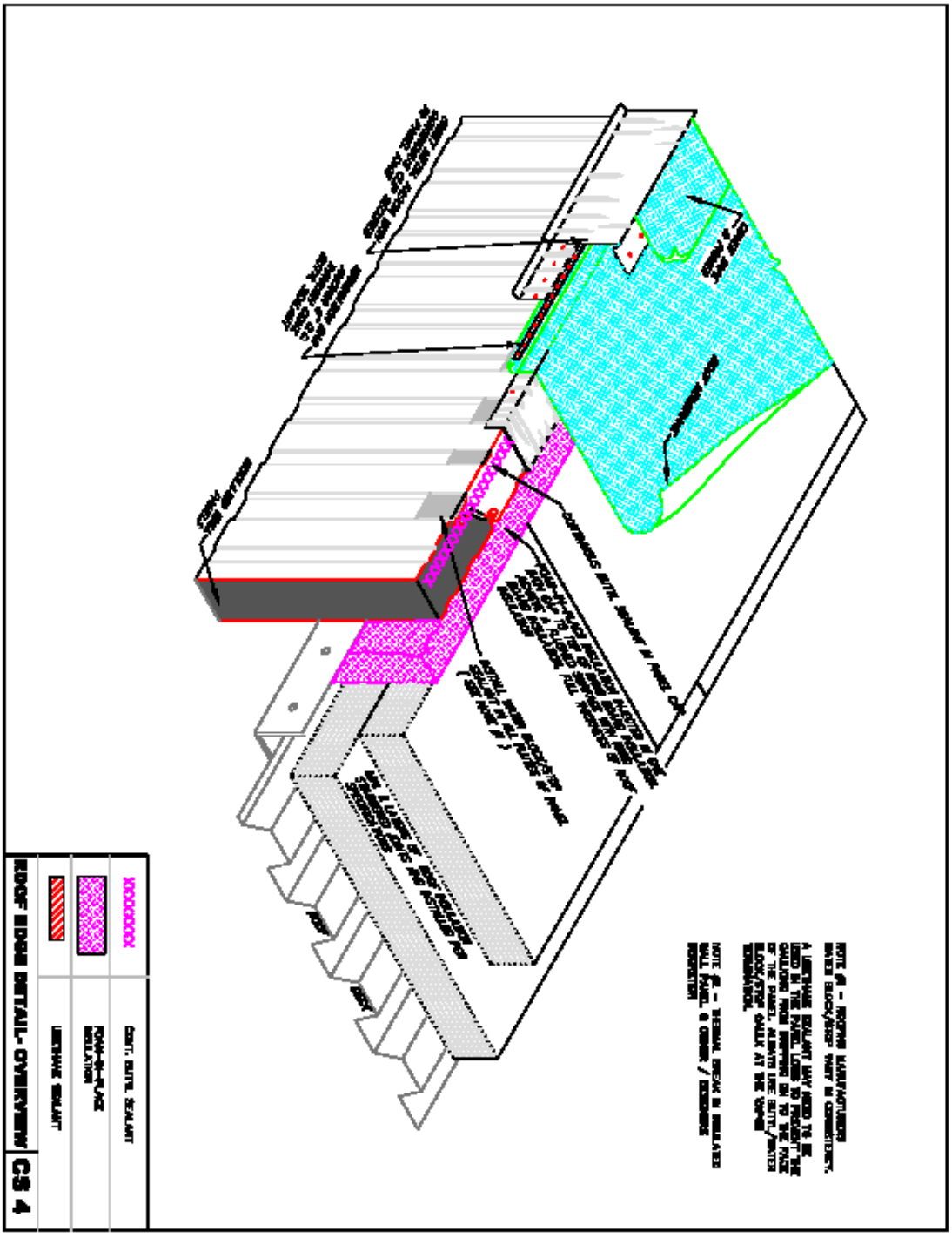


Figure 6.5

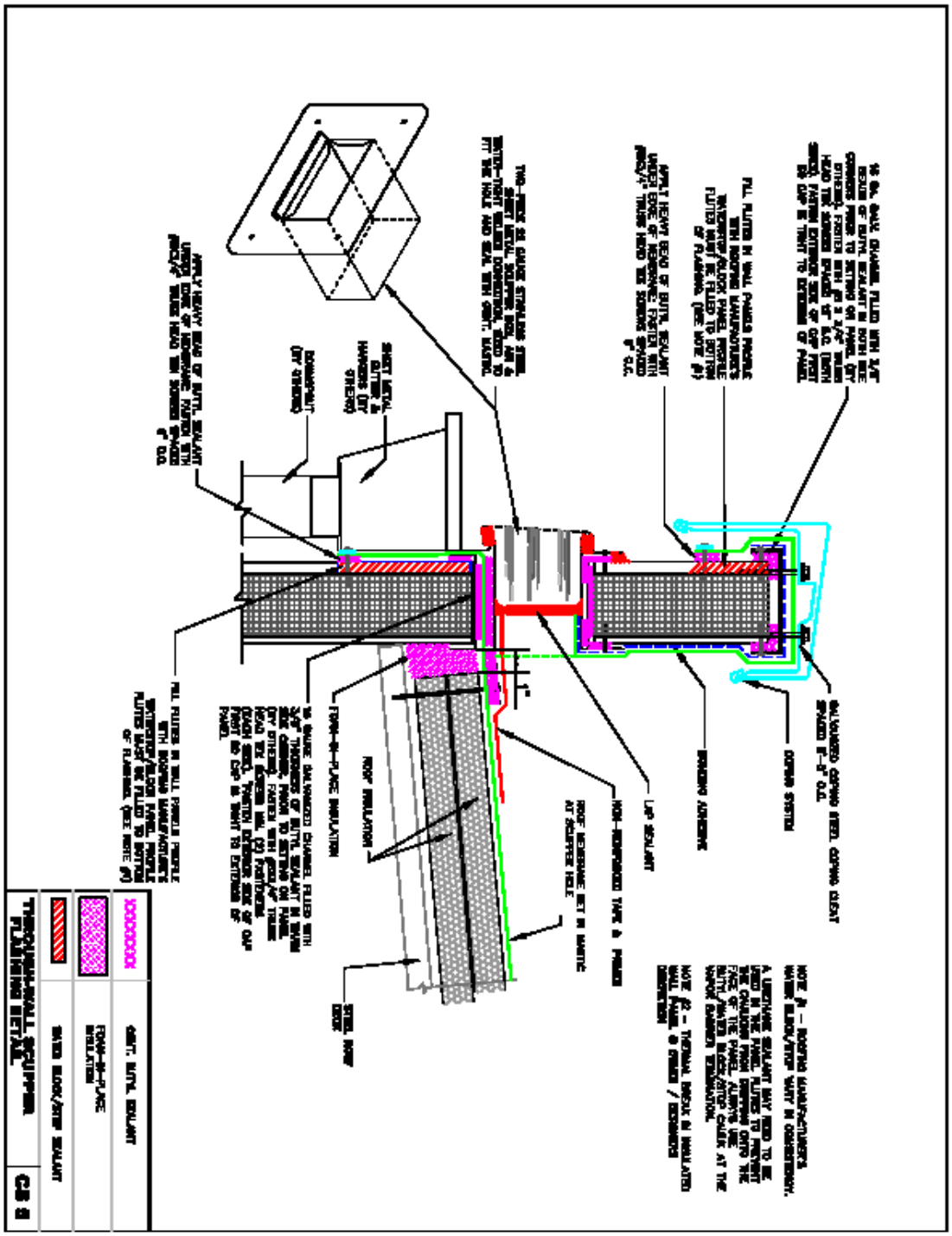


Figure 6.6

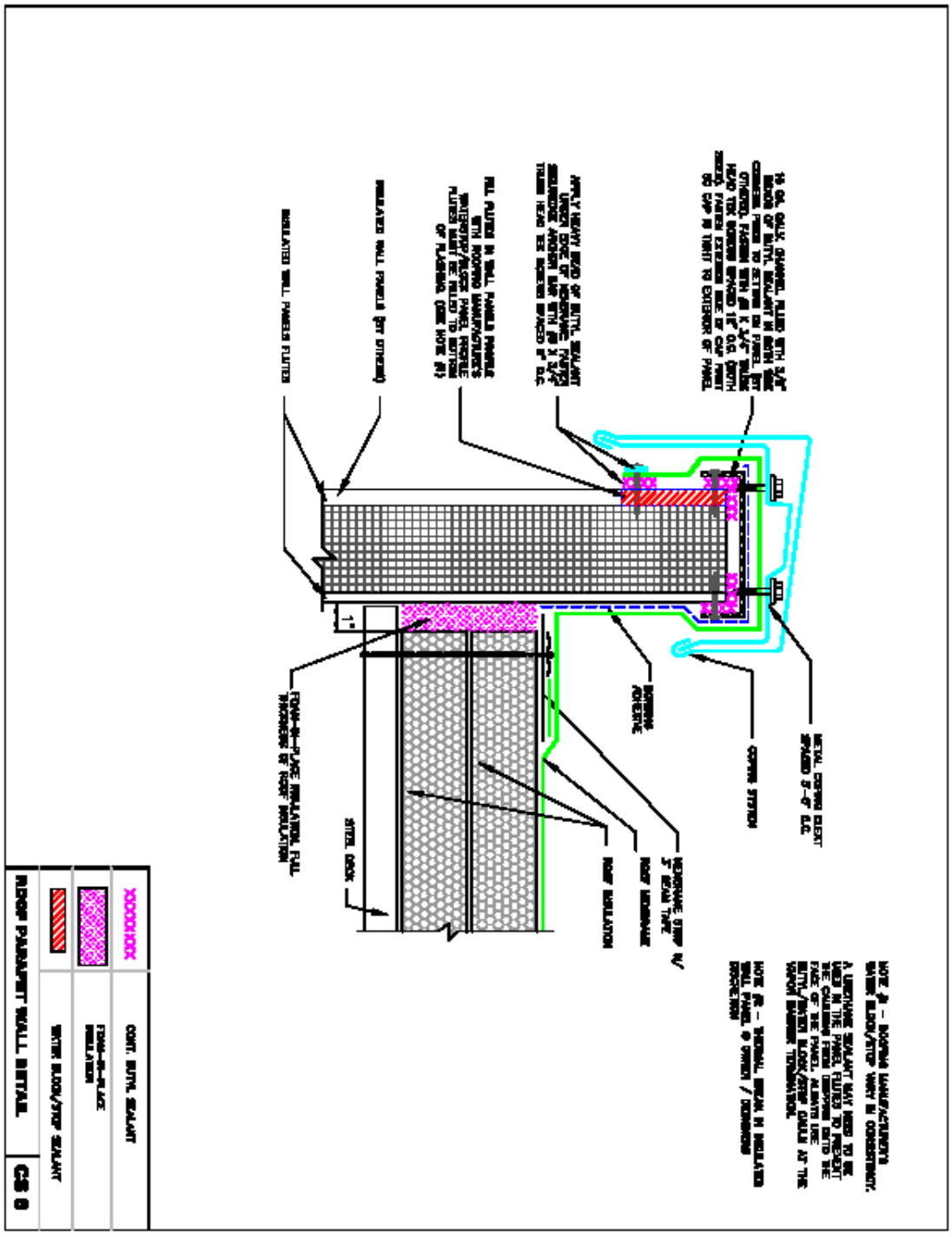

CONT. BUTYL SEALANT
FOAM-IN-PLACE INSULATION
WATER BLOCK/STOP SEALANT
RIDGE PARAPET WALL DETAIL
CS 8
STEEL DECK
ROOF INSULATION
ROOF MEMBRANE
COPING STATION
METAL CEDING CLEAT SPACED 3'-0" O.C.

Figure 6.7

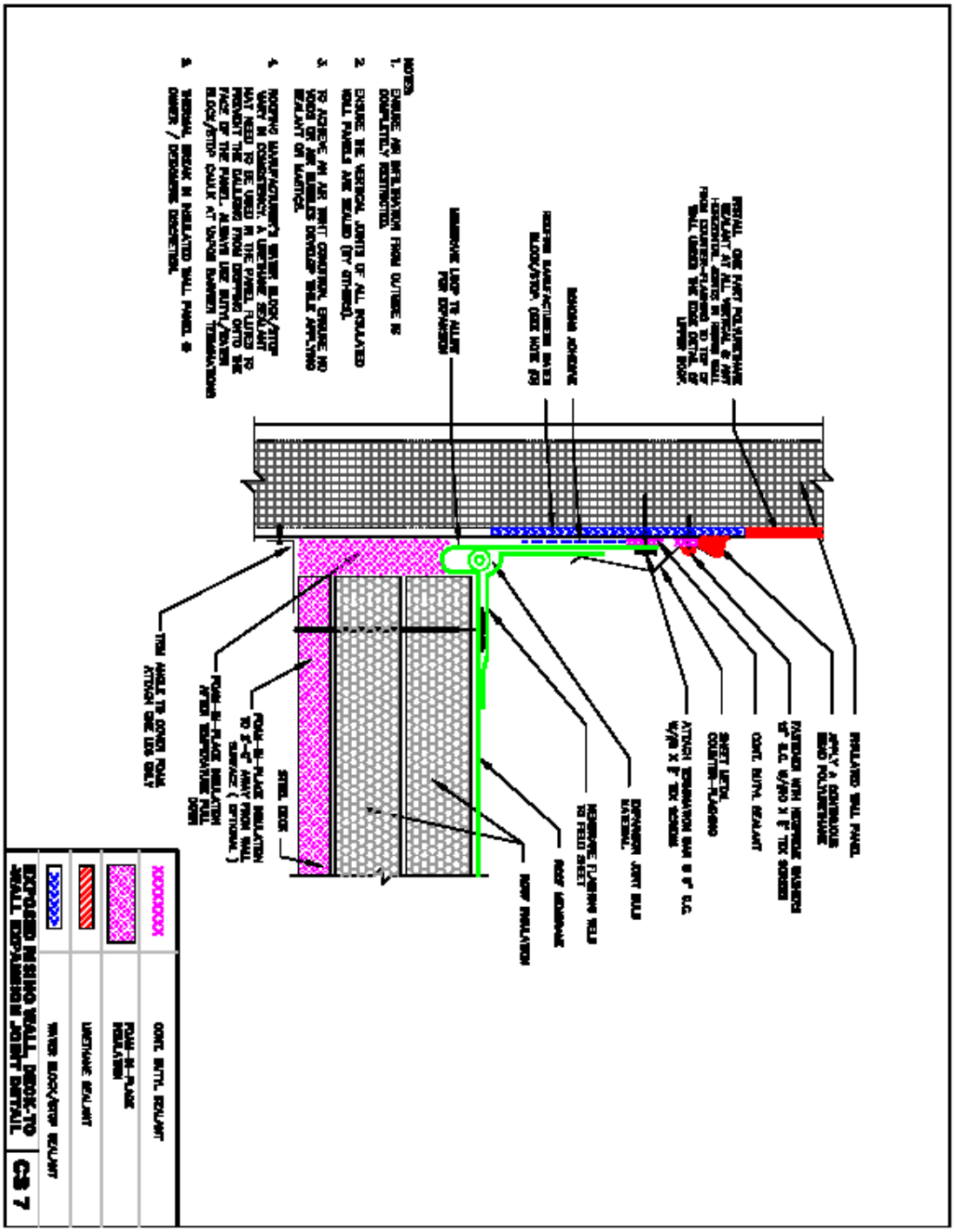


Figure 6.8

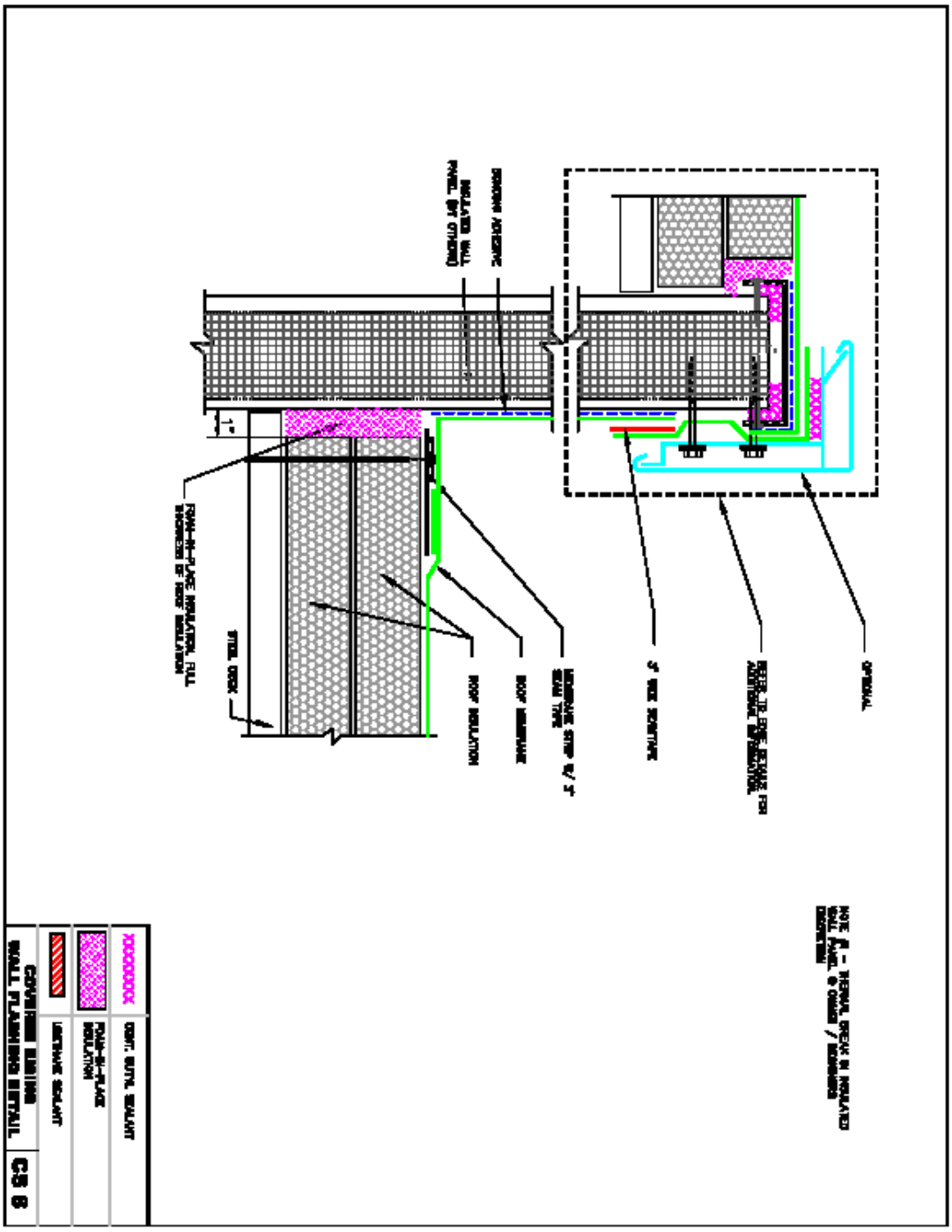

OPTIONAL
3" WIDE SCRIMTAPE
ROOF MEMBRANE
ROOF INSULATION
STEEL DECK
CS 8

Figure 6.9

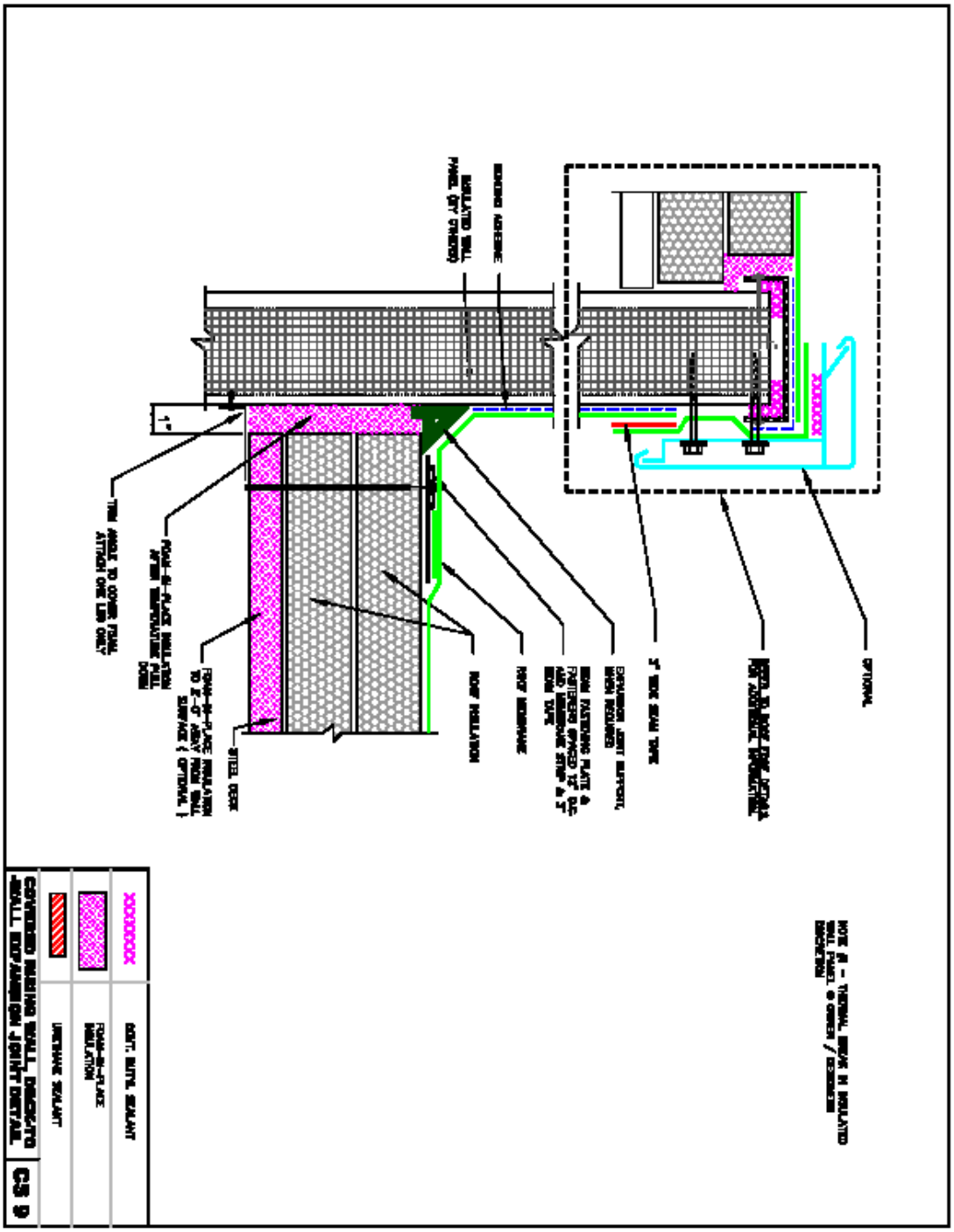

CS 9
CONCRETE RISING WALL, DIAGRATO
SMALL EXPANSION JOINT DETAIL
XXXXXXX
EXIST. BUTYL SEALANT
FOAM-IN-PLACE INSULATION
URETHANE SEALANT
INSULATED WALL PANEL (BY OTHERS)
BONDING ADHESIVE
1"
TRIM ANGLE TO COVER FOAM ATTACH ONE LEG ONLY
FOAM-IN-PLACE INSULATION AFTER TEMPERATURE HAS COME DOWN
FOAM-IN-PLACE INSULATION TO 2'-0" ABOVE FROM WALL SURFACE (OPTIONAL)
STEEL DECK
ROOF INSULATION
ROOF MEMBRANE
BEAM FASTENING PLATE & FASTENERS SPACED 12" O/C AND MEMBRANE STRIP & 3" BEAM TAPE
EXTENSION JOINT SUPPORT BEAM REQUIRED
3" BEAM SEAM TAPE
OPTIONAL

Figure 6.10

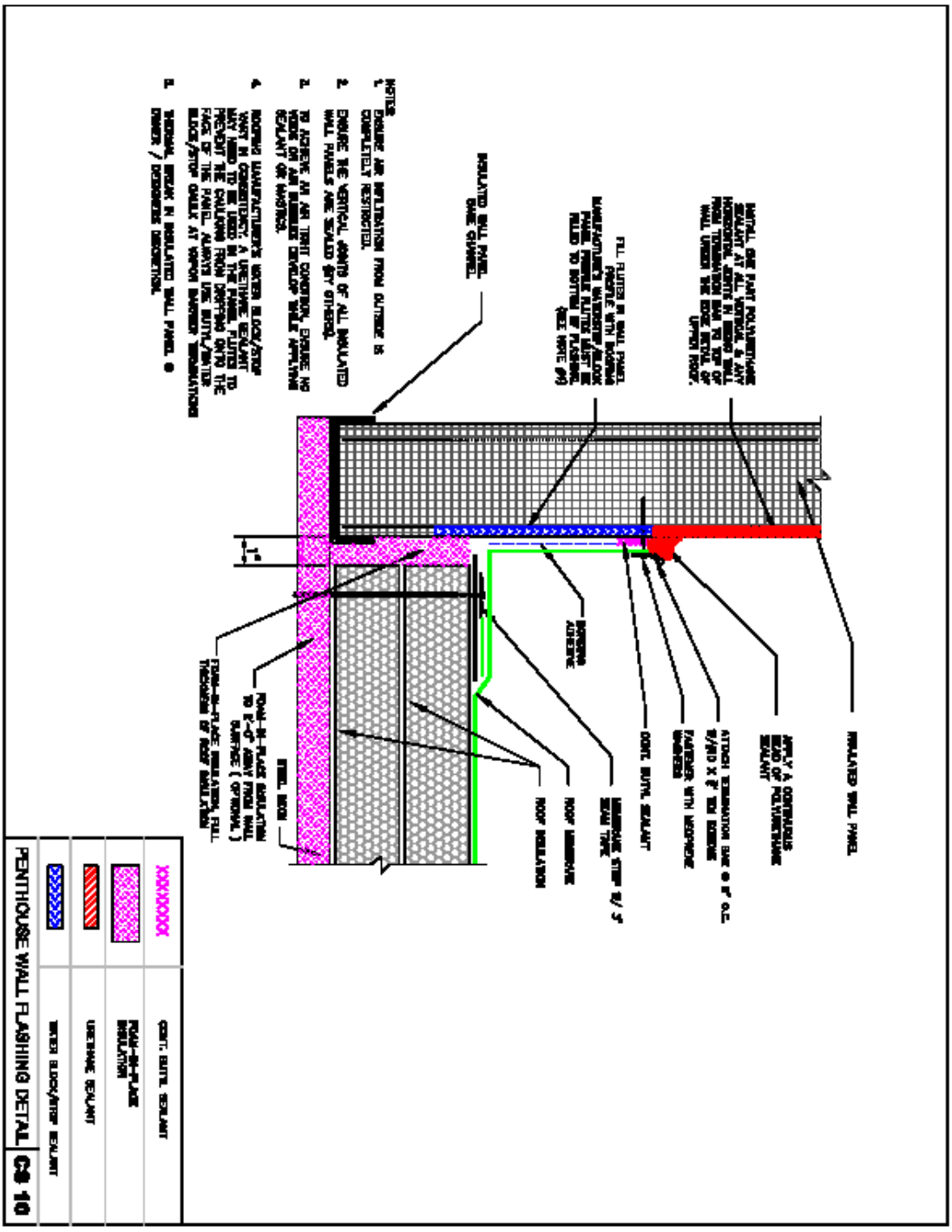

PENTHOUSE WALL FLASHING DETAIL
CS 10
CONT. BUTYL SEALANT
FOAM-IN-PLACE INSULATION
URETHANE SEALANT
WATER BLOCK/STOP SEALANT
INSULATED WALL PANEL
APPLY A CONTINUOUS BEAD OF POLYURETHANE SEALANT
ATTACH TERMINATION BAR @ 8" O.C. W/#10 X 2" TEK SCREWS
FASTENER WITH NEOPRENE WASHER
CONT. BUTYL SEALANT
MEMBRANE STRIP W/ 6" SEAM TAPE
ROOF MEMBRANE
ROOF INSULATION
STEEL DECK
FOAM-IN-PLACE INSULATION TO 2'-0" ABOVE FINISH WALL SURFACE (OPTIONAL)
FOAM-IN-PLACE INSULATION FULL THICKNESS OF ROOF INSULATION
MODIFIED ADHESIVE
INSULATED WALL PANEL CURB CHANNEL
FILL FLUTES IN WALL PANEL PROFILE WITH BOARDING MANUFACTURER'S WATERSTOP/BLOCK PANEL FLUTES MUST BE FILLED TO BOTTOM OF FLASHING (SEE NOTE #4)
INSTALL ONE PART POLYURETHANE SEALANT AT ALL VERTICAL & ANY HORIZONTAL JOINTS IN SIDING WALL FROM TERMINATION BAR TO TOP OF WALL UNDER THE EDGE METAL OF UPPER ROOF.
NOTES:
1. ENSURE AIR INFILTRATION FROM OUTSIDE IS COMPLETELY RESTRICTED.
2. ENSURE THE VERTICAL JOINTS OF ALL INSULATED WALL PANELS ARE SEALED BY OTHERS.
3. TO ACHIEVE AN AIR TIGHT CONDITION, ENSURE NO VOIDS OR AIR BARRIER DEVELOP WHILE APPLYING SEALANT OR MASTIC.
4. ROOFING MANUFACTURER'S WATER BLOCK/STOP MAY BE USED IN THE PANEL FLUTES TO PREVENT THE CAULKING FROM DROPPING ONTO THE FACE OF THE PANEL. ALWAYS USE BUTYL/WATER BLOCK/STOP CAULK AT VAPOR BARRIER TERMINATION
5. THERMAL BREAK IN INSULATED WALL PANEL @ DOWER / DOORWAYS DISCRETIONAL

Figure 6.11

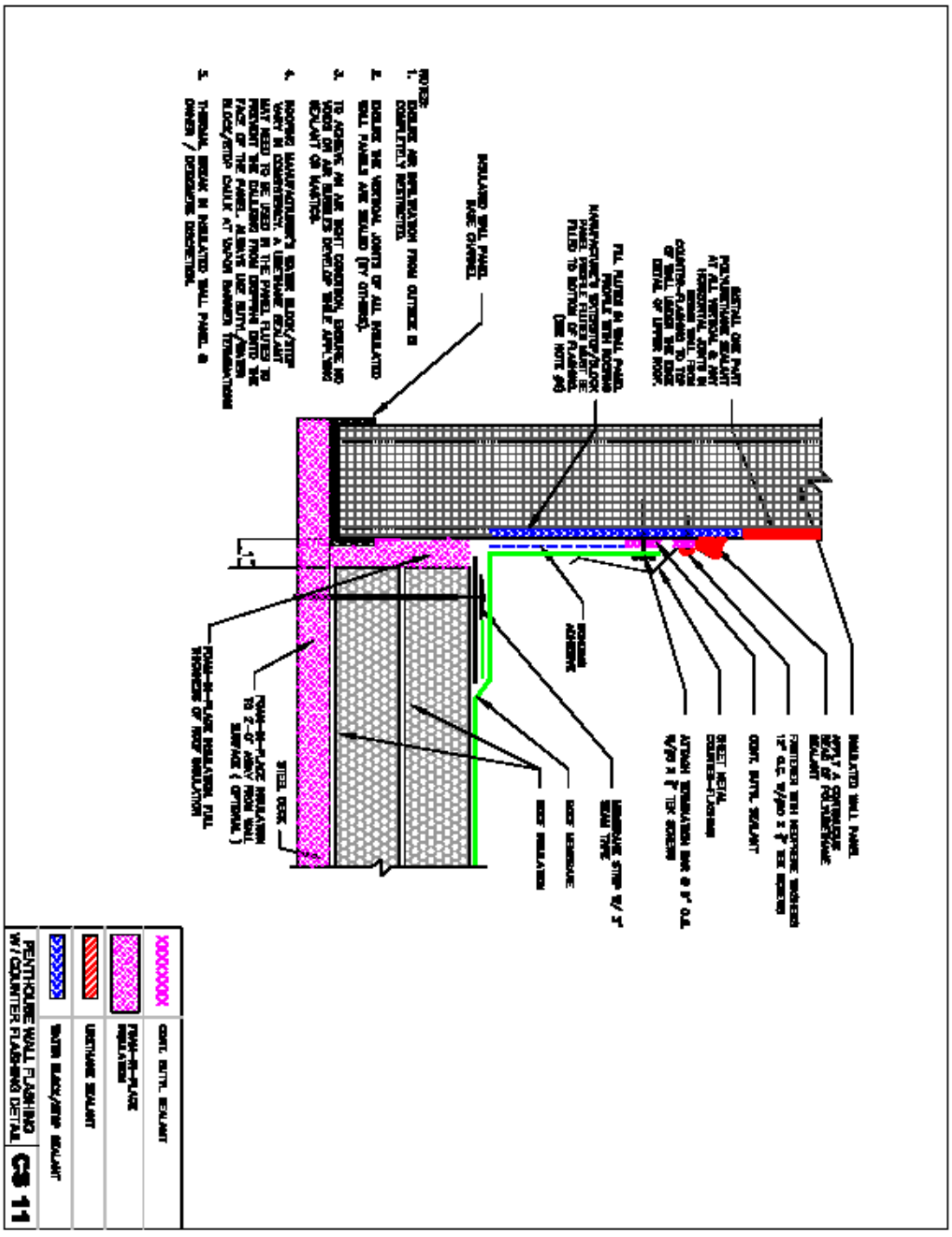

INSULATED WALL PANEL
APPLY A CONTINUOUS
BEAD OF POLYURETHANE
SEALANT
FASTENER WITH NEOPRENE WASHERS
12" O.C. MAX. & 2" FROM ENDS
CONT. BUTYL SEALANT
SHEET METAL
COUNTER-FLASHING
ATTACH SEPARATION BAR @ 2' O.C.
MAX. & 2" FROM ENDS
MEMBRANE STRIP W/ 3"
SEAM TAPE
ROOF MEMBRANE
ROOF INSULATION
STEEL DECK
FOAM-IN-PLACE INSULATION FULL
THICKNESS OF ROOF INSULATION
FOAM-IN-PLACE INSULATION
TO 2'-0" ABOVE ROOF
SURFACE (OPTIONAL)
ROOFING
ADHESIVE
INSTALL ONE PART
POLYURETHANE SEALANT
AT ALL VERTICAL & ANY
HORIZONTAL JOINTS IN
BRICK WALL FROM
COUNTER-FLASHING TO TOP
OF WALL UNDER THE EAVE
DETAIL OF UPPER ROOF.
FILL FLUTES IN WALL PANEL
PROFILE WITH NOMINAL
MANUFACTURER'S EXTERIOR/BLOCK
PANEL PROFILE FILLER MASTIC
FILLED TO BOTTOM OF FLASHING
(SEE NOTE #5)
INSULATED WALL PANEL
BASE CHANNEL
NOTES:
1. SEALANT AND INSULATION FROM OUTSIDE IS COMPLETELY RESTRICTED.
2. ENSURE THE VERTICAL JOINTS OF ALL INSULATED WALL PANELS ARE SEALED (BY OTHERS).
3. TO ASSURE AN AIR TIGHT CONDITION, ENSURE NO VOIDS OR AIR BUBBLES DEVELOP WHILE APPLYING SEALANT OR MASTIC.
4. ROOFING MANUFACTURER'S EDGE BLOCK/STRIP MAY BE USED IN CONJUNCTION WITH A LIGHTWEIGHT SEALANT MAY NEED TO BE USED IN THE PANEL FLUTES TO PREVENT THE BUILDING FROM DRAWING INTO THE FACE OF THE PANEL. ALWAYS USE BUTYL/WATER BLOCK/STOP CAULK AT VAPOR BARRIER TERMINATIONS
5. THERMAL BREAK IN INSULATED WALL PANEL @ OWNER / DESIGNERS DISCRETION
XXXXXXXX CONT. BUTYL SEALANT
FOAM-IN-PLACE INSULATION
URETHANE SEALANT
WATER BLOCK/STOP SEALANT
PENTHOUSE WALL FLASHING W/ COUNTER FLASHING DETAIL
CS 11

Figure 6.12

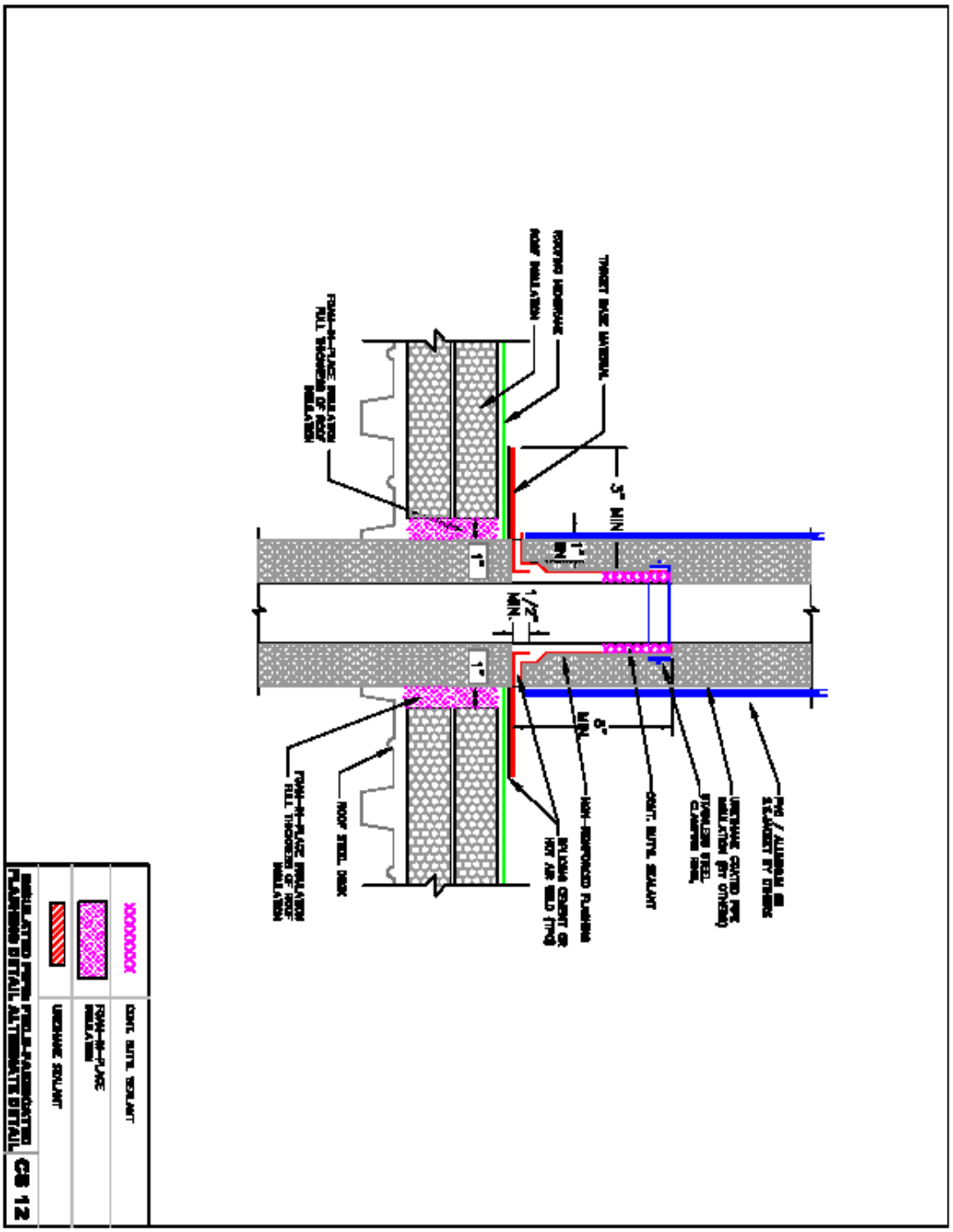

INSULATED FOAM-IN-PLACE PARAPET BITAIL ALTERNATE BITAIL
CB 12
XXXXXXXX
CONT. BUTYL SEALANT
FOAM-IN-PLACE INSULATION
URETHANE SEALANT
ROOF STEEL DECK
FOAM-IN-PLACE INSULATION FULL THICKNESS OF ROOF INSULATION
ROOFING MEMBRANE
ROOF INSULATION
TAPERED INSULATION FULL THICKNESS OF ROOF INSULATION
TARGET BASE MATERIAL
3" MIN
1" MIN
1"
1/2" MIN.
1"
6" MIN.
HIGH-REINFORCED FLASHING
BITUMA CEMENT OR HOT AIR WELD TYPE
CONT. BUTYL SEALANT
STAINLESS STEEL CLAMPING BAND
URETHANE COATED PIPE INSULATION (BY OTHERS)
PMR / ALUMINUM OR EQUIVALENT BY OTHERS

Figure 6.13

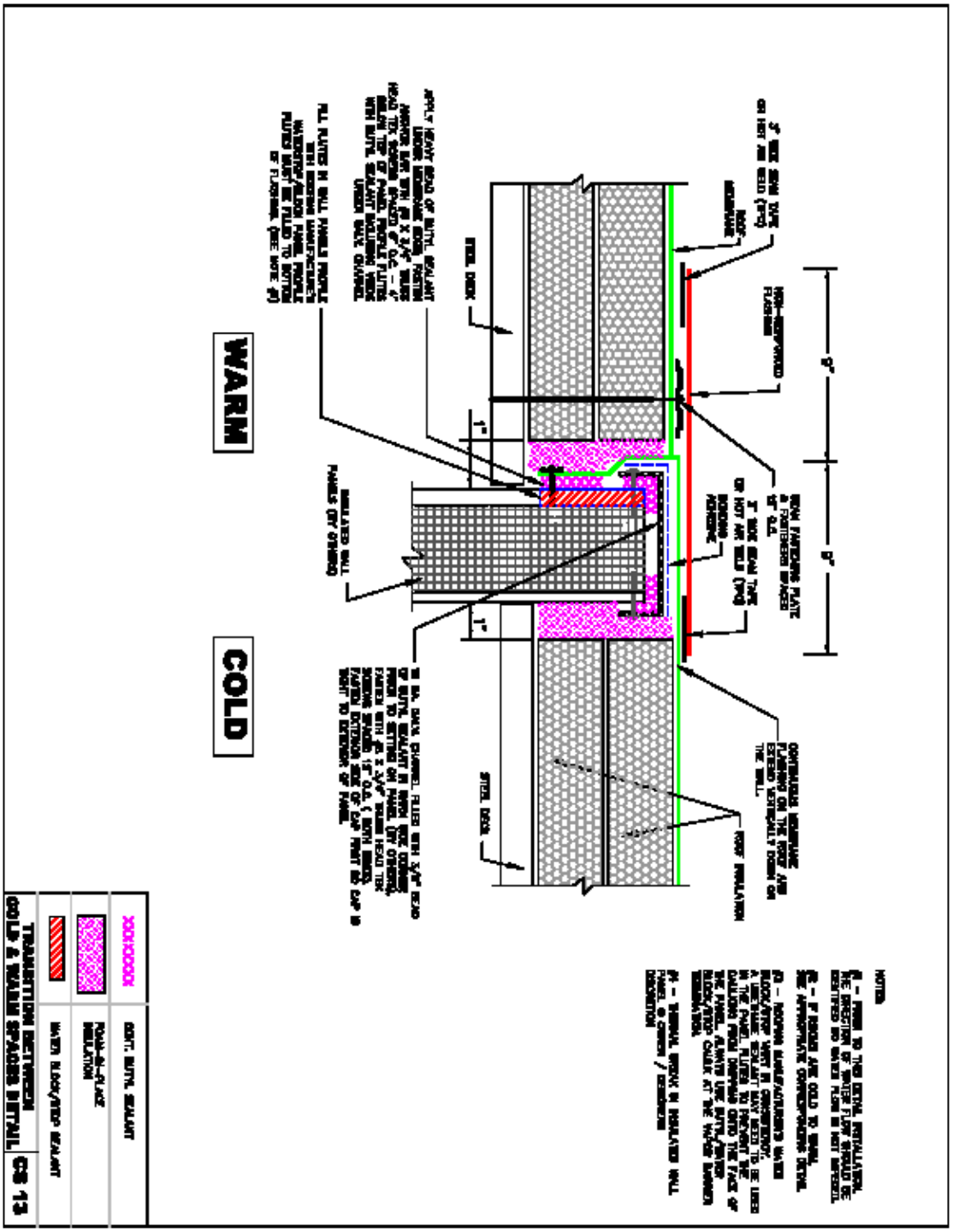

WARM
COLD
STEEL DECK
ROOF INSULATION
STEEL DECK
CONT. BUTYL SEALANT
ROOM-IN-PLACE INSULATION
WATER BLOCK/STOP SEALANT
TRANSITION SECTION COLD & WARM SPACERS DETAIL
CS 13

Figure 6.14

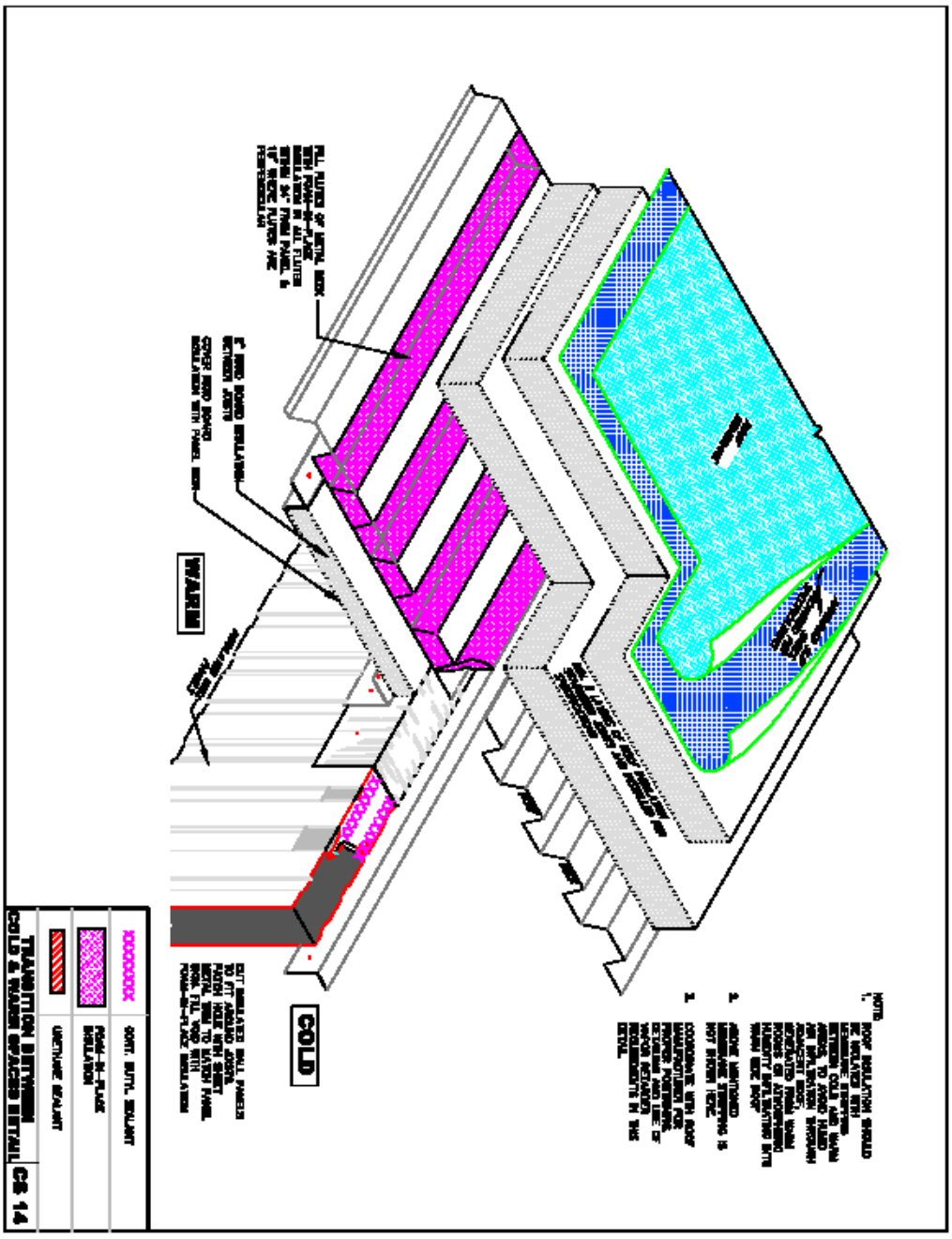


Figure 6.15

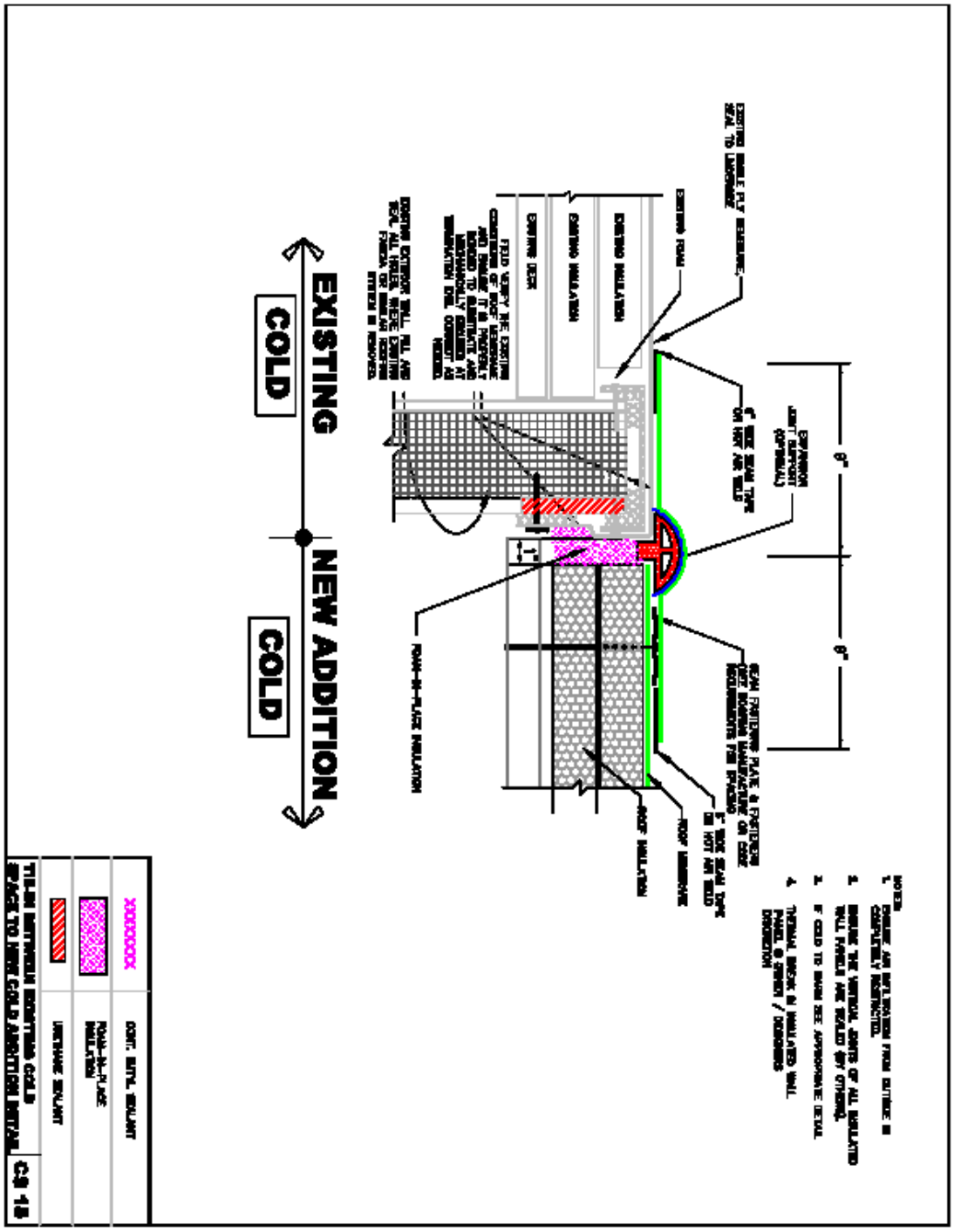

EXISTING
NEW ADDITION
COLD
COLD
CONT. BUTYL SEALANT
URETHANE SEALANT
CJI 18

Figure 6.16

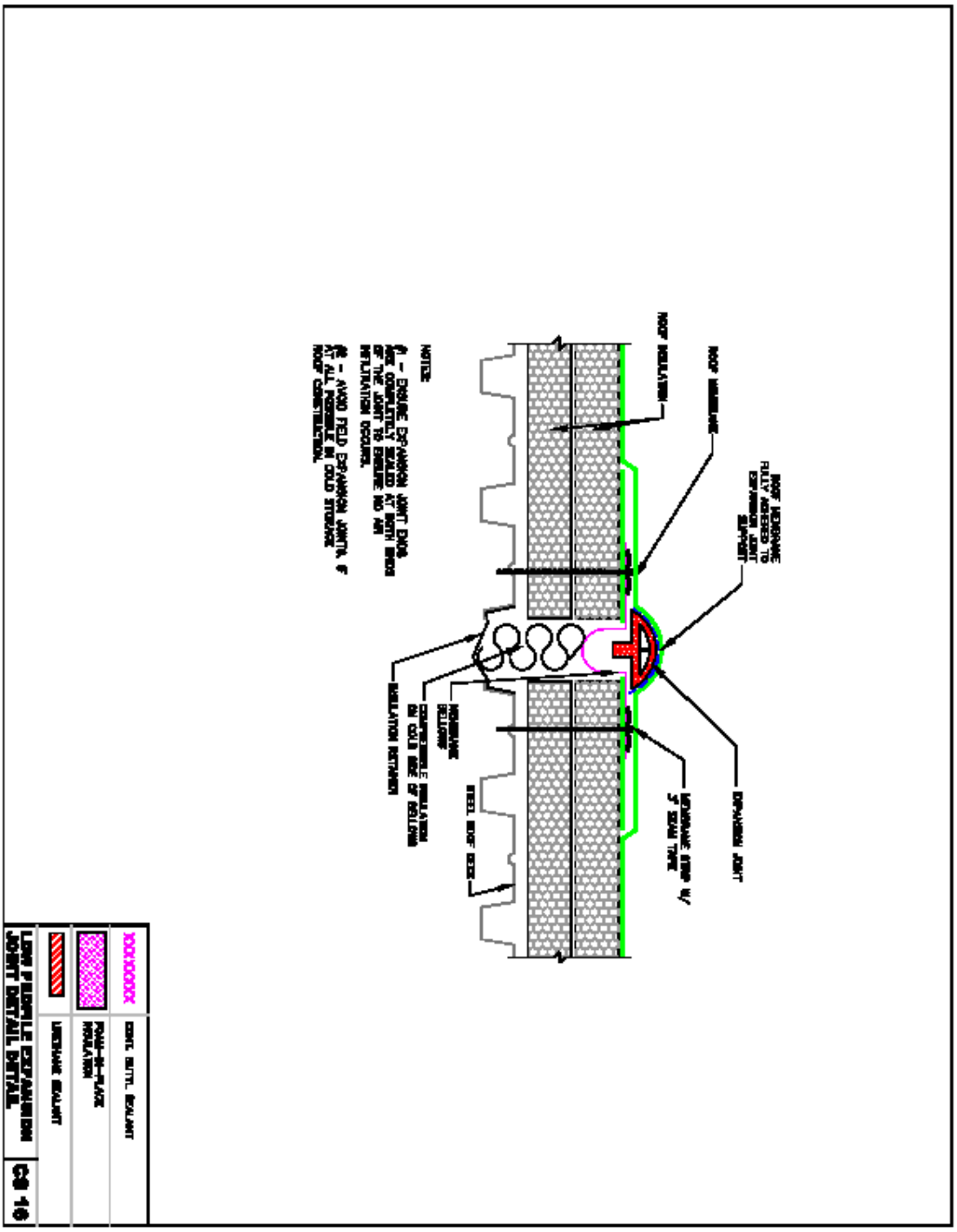
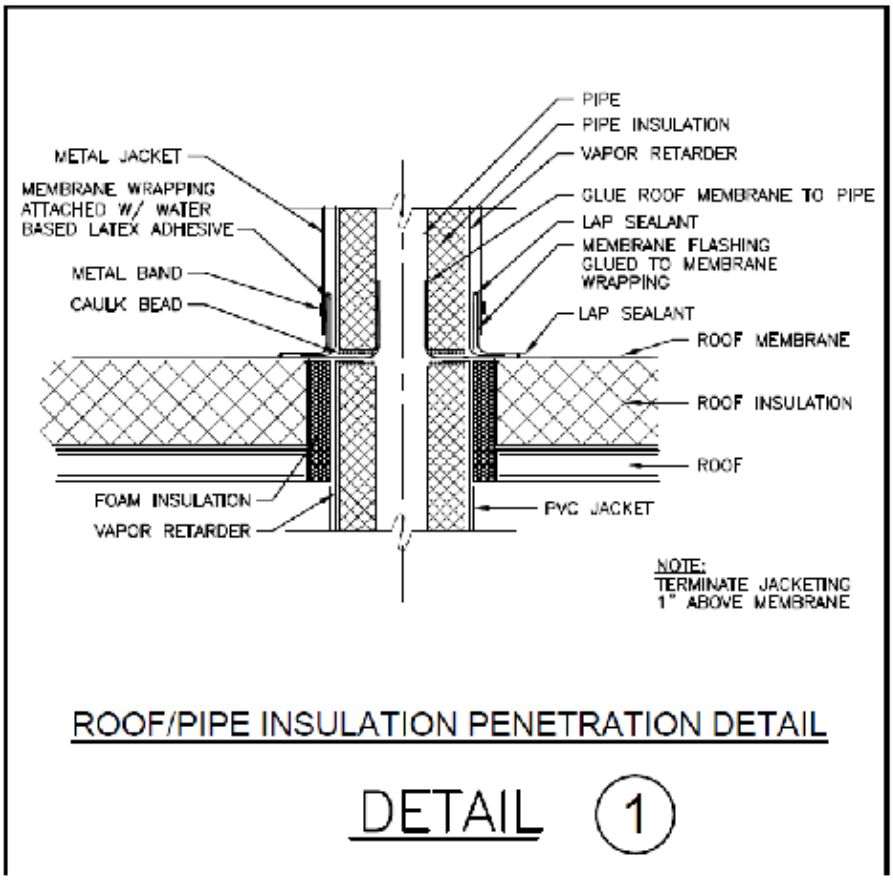

LOW PROFILE EXPANSION JOINT DETAIL
CS 16
CONT. SILTYL SEALANT
FOAM-IN-PLACE INSULATION
URETHANE SEALANT
ROOF INSULATION
ROOF MEMBRANE
ROOF MEMBRANE FULLY ADHERED TO EXPANSION JOINT SUPPORT
MEMBRANE STRIP W/ 3" SEAM TAPE
EXPANSION JOINT
STEEL ROOF DECK
MEMBRANE BELLOWS
COMPRESSIBLE INSULATION ON COLD SIDE OF BELLOWS
INSULATION RETAINER
NOTES:
1. - ENSURE EXPANSION JOINT ENDS ARE COMPLETELY SEALED AT BOTH ENDS OF THE JOINT TO ENSURE NO AIR INFILTRATION OCCURS.
2. - AVOID FIELD EXPANSION JOINTS, IF AT ALL POSSIBLE IN COLD STORAGE ROOF CONSTRUCTION.

Figure 6.17



Special thanks to Bob Hunt (The Haskell Company, Jacksonville, Florida, USA) and James Black (Gleeson Constructors & Engineers, L.L.C., Sioux City, Iowa, USA) for their assistance developing the cold storage roof vapor barrier details.

Chapter 7: Refrigeration

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Donald Fenton, Kansas State University, Manhattan, Kansas, USA

Ron Vallort, Ron Vallort and Associates, Ltd., Oak Brook, Illinois, USA

The purpose of this section is to provide the owner and his/her key personnel with a broad overview of the refrigeration aspect of the facility, including options for its design and maintenance, along with potential improvements in operating costs and safety for existing systems. It draws information from many sources and refers the user to other resources such as textbooks, handbooks, industry guides, standards, websites, and other resources. The bibliography at the end of this chapter also captures a good cross-section of the general information relating to industrial refrigeration.

7.1 Design

7.1.1 Introduction

There are numerous ways to accomplish the basic objectives of cooling and maintaining the temperature of the stored product. Depending on the type of business, its location, and other drivers such as energy cost and government regulations, the owner has many options. In addition, the technology associated with industrial refrigeration systems has advanced significantly over the past decade. It is the intent of this document to make the owner aware of the possibilities to meet his or her business objectives while, at the same time, controlling or reducing operating costs, maintaining the integrity of the product, and complying with governmental rules and regulations.

7.1.1.1 The Basics of Refrigeration

Refrigeration is the removal of thermal energy from a material. The field of refrigeration encompasses air-conditioning for buildings, commercial refrigeration typically applied to food supermarkets, and industrial refrigeration primarily for food processing and storage. By far, the largest segment of the refrigeration industry is the cooling of buildings for human comfort, in which the total sales volume and the number of units manufactured dominates both the commercial and industrial refrigeration segments.

Air-conditioning, when applied to human comfort, includes not only the cooling of air, but also the regulation of its humidity, cleanliness, and delivery to all the occupied

spaces in the building. As the evaporating temperature for air-conditioning systems is greater than the 32oF, the freezing temperature of water, evaporator temperatures vary from about 35oF to 60oF. For air-conditioning refrigeration systems, the difference between the ambient temperature outdoors and that of the evaporator is relatively narrow. Because of this small temperature difference and the large market for air-conditioning equipment, manufacturers have standardized their equipment line-ups for large volume production resulting in lower unit costs.

In industrial refrigeration systems, the lower evaporator temperature can reach -90oF. Obviously, this results in a larger temperature differences within which the industrial refrigeration system must operate. The field of cryogenics starts at the evaporating temperature of -90oF and continues down to temperatures approaching absolute zero or -459.67oF, where the use and production of liquid nitrogen, liquid oxygen, and liquefied hydrocarbons among other substances are of interest. As a result, refrigeration designers and technicians occasionally partake in the development and design of both industrial refrigeration and cryogenics fields.

7.1.1.2 Controls

Modern control strategies and equipment have greatly improved in recent years. The cost of the control equipment and variable speed motors has decreased to the point where they are now widely utilized in industrial refrigeration systems. The objectives for the controls of a refrigeration system are to:

- regulate the operation of the refrigeration equipment in order to maintain the desired temperature of the cold space or process,
- operate the refrigeration equipment efficiently
- protect the refrigeration equipment from damage.
- Report operational data to operators and warn of fault conditions.

To meet these objectives, the designer of the control system must have a thorough understanding of refrigeration systems and how they operate. Controls can be as simple as single function controllers to PLC controls, or as complex as facility wide central control systems.

As with all aspects of a refrigerated warehouse, the refrigeration system's design is governed by economics. With the increasing cost of electrical power, energy costs have risen to the point that they make up 40% or more of total operating costs and are likely to increase. Consequently, the energy cost of a facility over its planned lifetime will likely exceed the initial cost of the entire facility. Designers must, therefore, focus on developing efficient refrigeration systems to minimize energy consumption over the lifetime of the facility.

7.1.1.3 Refrigerants

The chloroflourocarbons (CFC) refrigerants, which include R-11 and R-12, have been identified as chemicals that deplete ozone (O_3) in the upper atmosphere.

Accordingly, these and other CFC refrigerants have not been produced in developed countries since the mid 1990's and in the rest of the world several years later. HCFC refrigerants (hydrogenated halocarbons), such as R-22, generally contain one hydrogen atom per molecule, resulting in a reduced level of ozone destruction. For example, R-22 has only 5% the destructive power regarding ozone depletion that R-11 has. Despite this, the production of HCFCs is now being curtailed as well. In Europe, regulations will make it illegal to add R22 to existing systems after January 1, 2015, while in the US a ban on production of virgin R22 will come into force by 2020. The HFC group of refrigerants (hydroflourocarbons), such as R-134a, do not contain chlorine and therefore do not deplete ozone in the upper atmosphere. However, these refrigerants do have significant global warming potential (GWP), and are under scrutiny at the present time. The search for refrigerants that do not cause environmental damage has put the refrigeration industry in turmoil for the past 20 years. However, the new refrigerants already developed have found application in the air-conditioning and commercial refrigeration segments.

There are natural refrigerants which are substances that exist in the environment that include: air (R-729), water (R-718), ammonia (R-717), carbon dioxide (R-744), and hydrocarbons (ethane (R-170), propane (R-290) among others). Theses natural refrigerants have two important features – they have no ozone depletion potential and they have either little or no negligible GWP. Consequently, their use is advantageous as future regulatory decisions concerning ozone depletion and global warming will not include the natural refrigerants. However, ammonia and carbon dioxide have drawbacks that must be recognized and accounted for in the design. Ammonia is toxic, where the OSHA Personal Exposure Limit is 50 ppm (volume/volume), and also mildly flammable, with a lower flammability limit of 15% in air (volume/volume). Carbon dioxide, on the other hand, can only exist as a vapor and solid at pressures below 75.1 psia and has a relatively low critical temperature (87.9°F) that may interfere with condensation processes that normally occur at constant temperature and constant pressure.

The new refrigerants already developed have found application in the air-conditioning and commercial refrigeration segments. Before the concerns with the earth's environment, the industrial refrigeration segment has used both R-717 (ammonia) and R-22, with ammonia comprising roughly three-quarters of all installations. Now, ammonia is nearly a unanimous choice in industrial refrigeration systems applied to the food industry. The reason is that ammonia has excellent heat transfer characteristics and remains an excellent refrigerant choice when developing energy efficient systems. The use of CO2 in cascade and liquid brine systems has become more common especially when facilities have low temperatures (-20°F) or desire the lower ammonia charge and/or ammonia isolated to engine room of the system. The application of hydrocarbons as refrigerants in the chemical industry remains about the same as it has been.

Safety regulations such as ANSI/ASHRAE Standard 15 Safety Code for Mechanical Refrigeration, constrain the design of an industrial refrigerating system and the building where it is used depending on the refrigerant. For example, ammonia systems have strict air ventilation requirements for the machinery room where the ammonia refrigeration

equipment is housed. The application of pressure relief valves is presented in detail in Standard 15.

7.1.2 Refrigeration Fundamentals

All materials contain thermal energy, which is measured by temperature. The term "heat" refers to the transfer of thermal energy, not the energy itself.

7.1.2.1 Action of Refrigeration

Taking this line of reasoning one step further illustrates two terms commonly used in refrigeration – hot and cold. In thermodynamics, an object that contains no thermal energy whatsoever is said to be at absolute zero. This temperature is 0°K (Kelvin absolute temperature scale), 0°R (Rankine absolute temperature scale), -273.15°C (Celsius temperature scale), or -459.67°F (Fahrenheit temperature scale). Obviously, an object that has a temperature greater than absolute zero contains thermal energy. Additionally, if this object has a temperature greater than another identical object, then it contains a greater quantity of thermal energy. Using the terms hot and cold, we say that the warmer object is "hotter" than the other object which we would call the "colder" object. Clearly, the term cold describes the relative absence of thermal energy in an object.

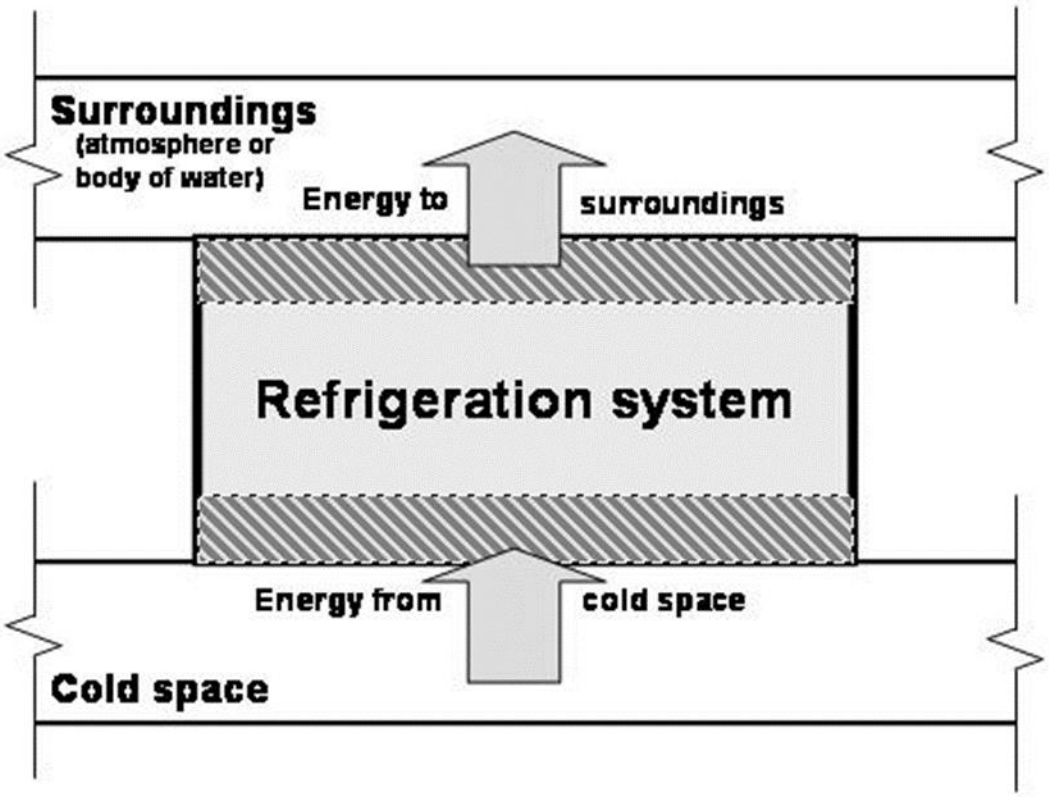
The transfer of thermal energy from one object to another is a process referred to as "heat transfer" and only occurs when two objects are at different temperatures. The heat transfer process continues until the temperatures of the two objects becomes equal or if the two objects are separated. Generally, the quantity of thermal energy that is transferred between the two objects is called the quantity of heat transferred or simply "heat." The first and second laws of thermodynamics apply here. The first law mandates that the quantity of heat lost by the warmer object is equal to the heat gained by the cooler object. The second law mandates that the direction of heat transfer is from the warmer object into the cooler object. Further, the second law states that it is, in general, impossible for heat transfer to proceed from a colder object to a warmer object unless energy is supplied to accomplish it. As an example, consider a cup of hot coffee sitting on a table. We expect that the coffee will cool by heat transfer to the surroundings until the temperature of the coffee cools to the temperature of the surrounding air. However, while it is conceivable that a quantity of thermal energy could burst from the air and enter the coffee, not a violation of the first law, we know that this is impossible by the second law of thermodynamics.

"Refrigeration" is the action of transferring thermal energy from an enclosed space or material so that its temperature is decreased. Observe that cold is not being added to the space or material. For refrigeration to occur, a surface colder than the space being cooled must be in contact with that space or material, so that heat is transferred from the space. Figure 7.1 is a diagram of a refrigeration system showing the two heat transfers that occur – from the cold space to the refrigeration system and from the refrigeration system to the surroundings. The refrigeration system is represented by the rectangle between the cold space which is being refrigerated and the surroundings, which is either the atmosphere or body of water. The energy transferred from the cold space ultimately

goes to the surroundings and is said to be rejected. For heat rejection to the surroundings to occur, the surface temperature of that part of the refrigeration system must be warmer than the surroundings.

For the refrigeration system to remove heat from the cold space and deliver it to the surroundings, energy (in the form of work) must be added. We cannot expect heat to naturally transfer from a cold object to a warm object, because to do so would be a violation of the second law of thermodynamics.

Figure 7. 1 Heat transfers in refrigeration systems



There are several types of refrigeration systems in use today. These include:

- vapor compression systems,
- air cycle systems,
- absorption systems,
- thermoelectric systems
- evaporative cooling.

With industrial refrigeration systems, the refrigeration requirements are relatively large as they are applied to the processing of foods, pharmaceutical products, and their storage for later distribution. Industrial refrigeration systems are generally custom-designed systems as most systems must meet varying temperature and refrigerating

capacities. The temperature range of concern for industrial refrigeration extends down to -900F. Below -900F refrigerating applications are generally handled by the field of cryogenics.

7.1.2.2 Vapor-Compression Cycles

Vapor-compression refrigeration cycles are the most prevalent in the industrial refrigeration industry. We shall consider three types of these systems: the single-stage cycle, the multi-stage cycle, and the cascade cycle.

The most common refrigerant used in these cycles is ammonia with R-22 used in about 20% of industrial refrigeration plants. R-22 will no longer be produced in the US after 2020 due to its ozone depletion characteristics. Carbon dioxide (CO_2), which was a refrigerant used until the early 1930's before being displaced by the chlorofluorocarbon refrigerants (R-11, R-12, and many others), is receiving new attention, because of its good refrigeration characteristics, does not adversely affect the ozone layer, and has negligible GWP. The vapor-compression refrigeration cycle is a type of refrigeration system that uses a fluid, called a refrigerant, which circulates through pipes connecting the components that make-up the system. Single-stage, multi-stage, and cascade cycles will be considered in this guide.

Single-stage VaporCompression Refrigeration Cycle

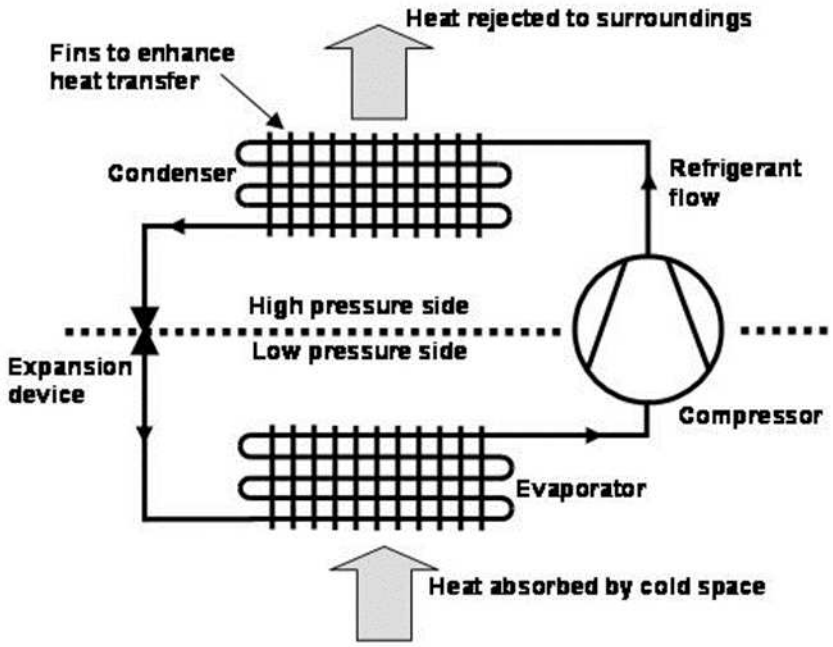
The simplest vapor-compression cycle consists of four basic components: compressor, condenser, expansion device, and evaporator. Because the cycle consists of only one stage of compression, it is called a single-stage vapor-compression cycle. The refrigerant moves through the components in the order shown in Figure 7.2 and thus operates as a cycle. The evaporator is the component in the cycle which draws heat from the fluid being cooled and thus refrigerates the cold space. Most of the time, this fluid is room air but it could also be another fluid such as water, glycol, brine, or CO_2. The most common design for an evaporator to be used in cooling room air consists of a bundle of tubes arranged in a manner which allows air in the cold space to pass through the bundle assisted by the action of a fan. The refrigerant enters the evaporator as a mixture of liquid and vapor at a pressure and, more importantly, a temperature lower than the desired temperature of the space being cooled. As heat from the space comes in contact with the liquid refrigerant, the liquid evaporates (thus, the term evaporator) and converts to a vapor. In doing so, liquid/vapor mixture absorbs heat from the cold space. The temperature of the boiling liquid in the evaporator is nearly constant which in turn maintains the temperature of the evaporator's surface nearly constant. Recall that water at standard atmospheric pressure boils at 212°F and that to boil the water, a large quantity of heat is required. The refrigerant is selected so that in combination with the pressure inside the evaporator, its temperature is less than the desired refrigerated space. Thus, in a similar fashion to boiling water, the boiling refrigerant inside the evaporator's tubes absorbs heat from the cold space. As an example, ammonia at a pressure of 35 psia boils at 5.9°F.

The preceding discussion focuses on an ideal vapor-compression cycle and, therefore, involves simplifications which aid in understanding how the cycle operates. These simplifications include:

- No pressure drop experienced by the refrigerant in the piping connecting the components.
- No heat transfer with the surroundings.
- The vapor leaving the evaporator is saturated vapor (stays at the same temperature as the liquid).
- The liquid leaving the condenser is saturated liquid.
- No pressure drop occurs across the evaporator and condenser.
- The compressor inlet or suction port receives the saturated refrigerant vapor and discharges the vapor as a superheated vapor. Superheat represents the temperature in degrees above the vapor's saturation temperature associated with the vapor's actual pressure.

Ideal compression occurs when the process is isentropic (constant entropy). Compressors typically used in industrial refrigeration systems are either reciprocating piston or rotary screw in configuration. Both operate by trapping the suction vapor in a closed chamber and subsequently decreasing the chamber's volume through the compression process to achieve an increase in pressure. The pressure at the discharge of the compressor must be sufficiently high enough in order to condense at the desired condensing temperature. The superheated refrigerant enters the condenser and must first be de-superheated before condensation can begin. Downstream from this point, the temperature of the vapor and liquid mixture remains constant in an ideal condenser (no pressure drop) and the quantity of condensed liquid increases until the last vapor condenses and only liquid exits the condenser. Any additional cooling results in subcooled liquid. Saturated liquid refrigerant at the condensing temperature drains from the condenser and is delivered to the expansion device. The expansion device provides a sudden drop in pressure so that the leaving refrigerant is at or near to the evaporator's operating pressure. The expansion device may be a pressure control valve, a capillary tube, a short tube restrictor, a thermostatic expansion valve, or some other device which causes a sharp drop in pressure. In the process of dropping to a lower pressure, the refrigerant changes to a mixture of liquid and vapor. This saturated mixture of liquid and vapor then enters the evaporator and the cycle repeats. These are the fundamental processes which make-up the refrigeration cycle.

Figure 7. 2 Basic vapor-compression refrigeration cycle



Calculations predicting the performance of an ideal single-stage vapor-compression cycle are straight-forward and utilize simple thermodynamic concepts. When the actual compressor efficiency is also incorporated into the calculations of the ideal cycle, remarkably accurate estimates result from ideal cycle calculations, generally within 5% of actual cycle performance.

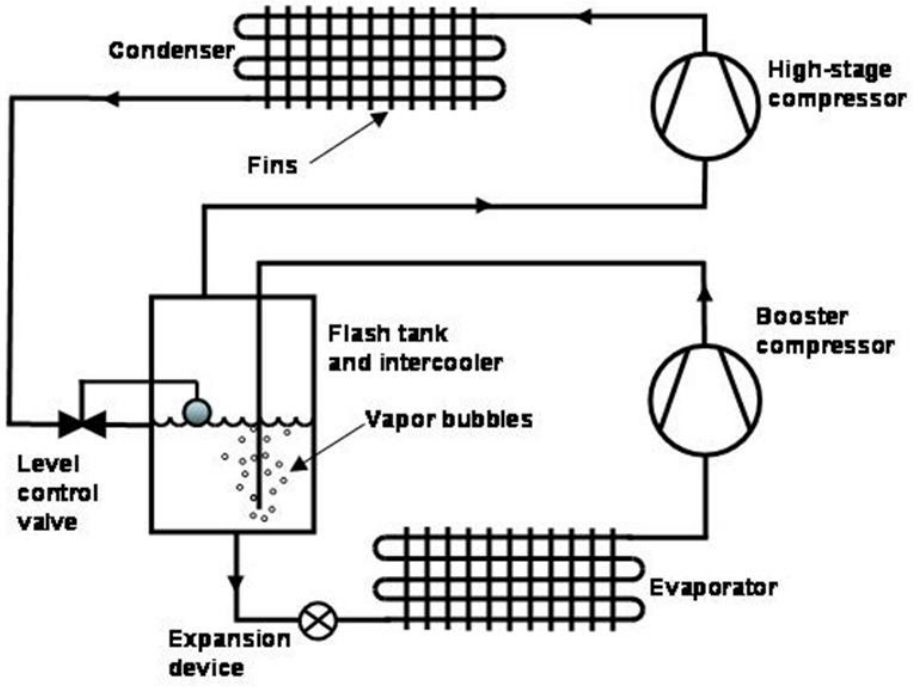
An energy balance on the cycle indicates that the energy (heat) rejected by the condenser to the surroundings is equal to the energy (heat) absorbed by the evaporator in the cold space, as well as the energy (work) added to the refrigerant by the compressor. In fact, the coefficient of performance for a refrigeration cycle, which is an important measure of a cycle's performance, is the quantity of energy absorbed by the evaporator divided by the energy needed to power the compressor. Ideally, this number would be equal to one, but the true vapor compression cycle has inherent inefficiencies represented by the actual coefficient of performance (COP).

In industrial refrigeration systems, which consist of coolers, docks, and process rooms, single-stage refrigeration systems are commonly applied. The evaporator temperatures economically achievable with single-stage vapor compression cycles cover a range from about 10°F to 40°F. A practical limitation occurs with reciprocating piston compressors due to a pressure ratio limitation of about 8. The rotary screw compressor has a much higher pressure ratio limitation, but its efficiency does decrease with increasing pressure ratios.

Multi-Stage Compression Vapor Compression Cycle

Two or more stages of compression are often needed to economically achieve temperatures lower than those obtainable from single-stage compression. As the evaporating temperature decreases, the corresponding saturation pressure also decreases. To achieve these conditions, a greater portion of the refrigerant must convert to vapor downstream from the expansion device and, therefore, less liquid enters the evaporator to perform refrigeration. To compensate for this effect, the initial expansion process may be interrupted, vapor is removed from the refrigerant mixture, and the expansion process is then continued in order to achieve the desired evaporator temperature and pressure. A schematic diagram of an ideal two-stage vapor compression cycle is shown in Figure 7.3, where the addition of a vessel, the flash tank intercooler, and the level control valve, are shown to be added to the process. Observe that the expansion of the refrigerant leaving the condenser is interrupted by the insertion of the flash tank intercooler and the level control valve. Once in the flash tank, the liquid becomes separated from the vapor. The liquid draining from the flash tank then continues its expansion. At this point, all of the liquid is at a lower temperature, after passing through the expansion device upstream from the evaporator and is at the desired temperature and pressure. The two phase mixture now contains a significantly larger portion of liquid, thereby providing more refrigeration.

Figure 7. 3 Ideal two-stage vapor compression cycle



More than two stages of refrigeration may be used to obtain even lower temperatures than would be practical with a two-stage system. Three stages are employed on occasion, but four stages are almost never used. An example of a three-stage system

would include the use of an additional compressor dedicated to serve a blast freezer operating at a very low temperature.

The traditional approach to controlling the liquid level in the flash tank is to use a float valve in which the expansion process starts at the liquid control valve and is controlled by a float inside the flash tank. When the liquid level rises in the flash tank, the upward movement of the float closes the valve and the refrigerant flow stops. When the liquid level drops, the downward movement of the float opens the valve and refrigerant flow starts. The discharge vapor from the booster (or first-stage) compressor is directed to the flash tank so that it bubbles through the liquid, causing it to cool, and reaching the liquid temperature. A small amount of liquid in the flash tank must evaporate to cause the cooling, or desuperheating, of the booster compressor's discharge vapor. This is the intercooling process that also occurs in the flash tank. This cooled vapor allows for a more efficient compression process in the high stage compressor depending on the refrigerant used. The vapor formed (usually called "flash gas") by the expansion at the float valve is captured in the flash tank and combines with the vapor from the booster compressor and the liquid that evaporates for intercooling. These three vapor flows combine and enter the suction line to the high-stage compressor. The high-stage compressor and condenser operate similarly to the compressor in the single-stage cycle. The cycle is now complete and the saturated liquid from the condenser proceeds again to the float valve near the flash tank. Intercooling may also be accomplished using electronic level control and electronic expansion valves.

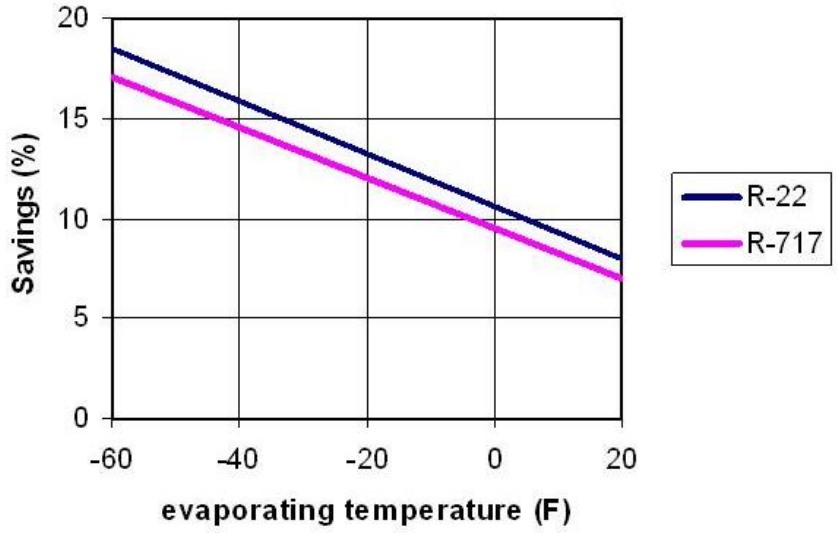
The intermediate pressure, or pressure in the flash tank, is optimal when it's nearly equal to the geometric mean of the condensing and evaporating absolute pressures. However, actual plants with multiple evaporators operating at different temperatures will dictate the operating pressure of the flash tank. Also, because ambient temperatures change over the seasons and throughout a given day, the condensing pressure (and consequent liquid temperature) will change as a result. Consequently, the high-stage compressor must adjust its capacity (flow rate) to match the ambient conditions.

In an actual industrial refrigeration facility, several compressors will likely serve as booster compressors and others as high-stage compressors, each with different rated flow capacities. This affords operating flexibility for off-design refrigerating loads where not all compressors need to operate at any given time. Multiple compressors also provide redundancy and thus better system reliability. Additionally, compressors operating near rated capacity operate at greater efficiency. It is often convenient to control one of the compressors with a variable frequency drive (VFD) allowing the compressors in total to operate at or near peak efficiency. The compressor with the VFD is often referred to as the trim compressor.

Besides providing higher refrigeration rates at lower temperatures, the two-stage vapor-compression cycle also reduces power consumption for the complete cycle. This results from several reasons, one of which is that the flash gas bypasses the booster compressor and thus is not compressed there. The flash gas is only recompressed in the high-stage compressor thus reducing the overall power. Figure 7.4 shows the relative savings in power between single-stage and two-stage vapor-compression cycles for both

ammonia and R22 refrigerants. With evaporator temperatures -20°F or less, two-stage systems should be carefully considered as they are likely to recover their greater initial cost in a reasonable time.

Figure 7. 4 Relative compressor power savings resulting from the two-stage vapor-compression cycle compared to a single-stage vapor-compression cycle.



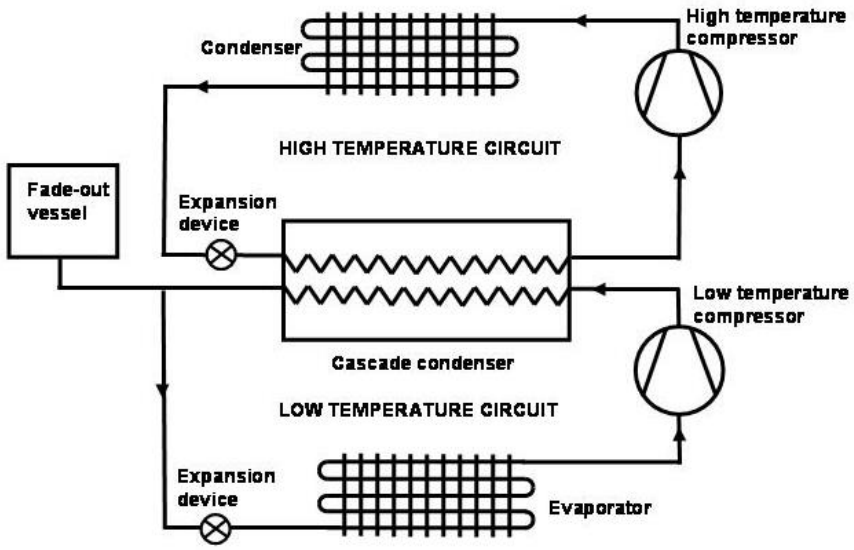
Cascade Vapor Compression Refrigeration Cycle

The cascade refrigeration cycle consists of a series of independent single-stage vapor compression refrigeration cycles, or "circuits," connected by heat exchangers. Because the refrigerant in each circuit is isolated from the refrigerant(s) in the other circuits, different refrigerants can be used in each circuit. Very low evaporating temperatures are possible with the cascade cycle, where two or more circuits may be employed. The advantage provided by the cascade system is that two or more refrigerants may be used that better match the high and low temperatures and pressures than any one refrigerant could in a multistage cycle. Thus, high pressure refrigerants such as carbon dioxide (R-744), R-23, or R-508 are selected for the low temperature circuit while a medium temperature refrigerant such as ammonia is selected for the high temperature circuit.

Figure 7.5 is a schematic diagram showing a cascade cycle where ammonia and carbon dioxide are the high and low temperature refrigerants, respectively. Observe that the two refrigeration circuits are coupled together by means of a heat exchanger, or "cascade condenser," that serves simultaneously as the condenser for the low temperature circuit and as the evaporator for the high temperature circuit. With operation of the cascade cycle, the heat absorbed by the evaporator in addition to the compression heat of the low temperature circuit is absorbed by the evaporator of the high temperature circuit. An important advantage of the cascade system is that ammonia is not distributed

throughout the plant, only the low-temperature refrigerant travels to the evaporators outside of the machinery room. This prevents ammonia leaks in locations outside the machinery room.

Figure 7. 5 Schematic diagram of a cascade refrigeration cycle utilizing a fade-out vessel.



A disadvantage of the cascade cycle relative to the multistage cycle is that a temperature difference must be established in the cascade condenser allowing heat to pass from the low temperature circuit to the high temperature circuit. To accomplish this, the condensing temperature of the low temperature circuit must exceed the evaporating temperature of the high temperature circuit. A penalty in compression power accompanies this needed temperature difference.

CO_2 has the advantage of being a natural refrigerant, but has the peculiarity of only existing as a vapor or solid at pressures less than 75.1 psia. This presents challenges that must be handled in the design and operation of the system. The CO_2 may alternatively be employed as a brine in that the liquid is mechanically pumped rather than compressing a vapor. From an energy perspective, liquid pumping uses far less energy per pound of refrigerant than vapor compression. The pumped liquid is then sent to the evaporator coils where the heat absorbed causes a phase change of the CO_2 to a vapor, which returns to the machinery room where it is condensed and pumped out to the evaporators again. Here, a multi-stage vapor compression ammonia system may serve both the high- and low-sides, while still confined to the machinery room.

When a cascade system is started, the high temperature compressor is started first. The low temperature compressor is started when the evaporator temperature reaches a sufficiently low temperature. Figure 7.5 shows a special vessel called a “fade-out” vessel serving as an expansion tank added to the low temperature circuit. This vessel is needed

to prevent the pressure in the low temperature circuit from becoming dangerously high when the system is shut down and the refrigerant warms to room temperature. The pressures can become particularly high when liquid refrigerant still remains in the system at room temperature. For example, the saturation pressure of R-23 (Trifluoromethane) and R-744 (carbon dioxide) at 75°F is 663 psia and 936 psia, respectively. The volume of the fade-out vessel is carefully determined, such that a reasonable maximum pressure occurs when the liquid has fully evaporated. For higher temperatures, the pressure only increases in proportion to the absolute temperature.

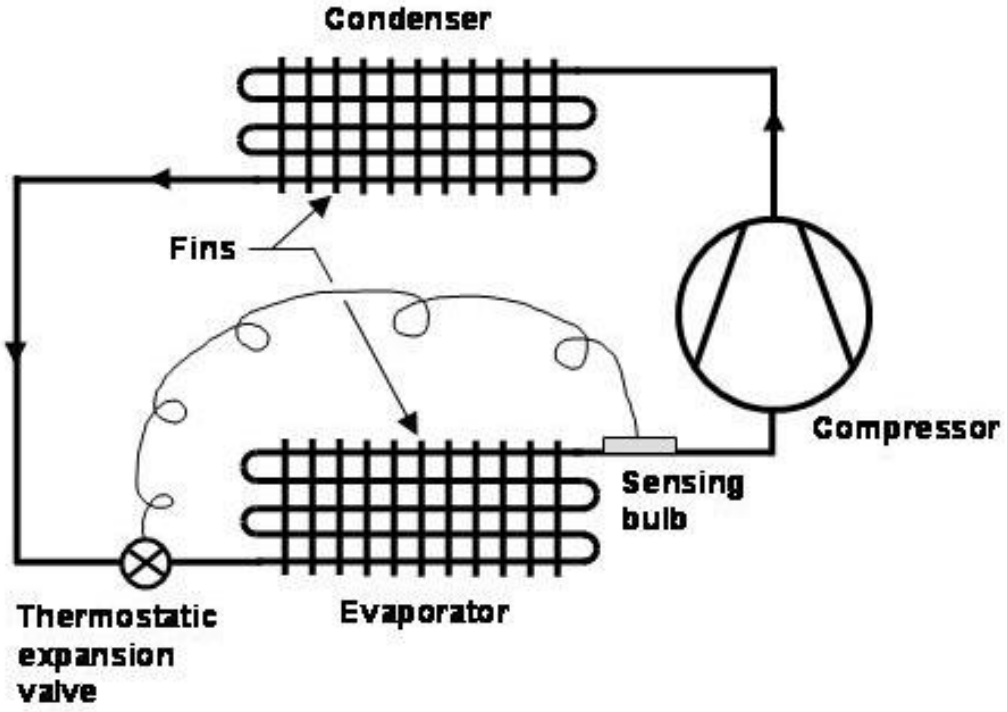
7.1.2.3 Refrigerant Supply Method

One further classification of industrial refrigeration systems involves the method by which the refrigerant is delivered to the evaporator. Three refrigerant feed methods are used in industrial refrigeration: direct expansion, flooded (also called gravity fed), and pumped recirculated liquid (also called overfeed). There are many different criteria used in determining the best type of refrigerant feed. Among the criteria are first costs, operating costs, ammonia charge, size of the facility, location of the evaporators within the facility, system complexity, and available space.

Direct Expansion Systems

Direct expansion involves the throttling of high pressure liquid refrigerant near the entrance of the evaporator coil, where a sudden drop in pressure (expansion) results in the formation of a mixture of vapor and liquid at a lower temperature. Figure 7.6 shows a thermostatic expansion valve using input from a sensing bulb that is in contact with the outlet tube (known as the suction line) of the evaporator coil. This saturated mixture of liquid and vapor refrigerant enters the inside of the coil's tube and progresses through the circuit where the liquid boils (or evaporates) absorbing thermal energy (heat) from the cold space or fluid being refrigerated. As we have shown previously, a drop in pressure leads to a drop in temperature. Therefore, the pressure drop through the evaporator coil must be low enough to ensure that the resulting temperature remains sufficiently below that of the cold space so that heat transfer occurs from the cold space into the boiling refrigerant liquid. The special valve that regulates the flow rate of refrigerant to the evaporator accommodating refrigerating loads, while at the same time maintaining the desired evaporator temperature, is called an expansion valve. There are a number of different types of expansion valves in use today, including the thermostatic expansion valve as shown in Figure 7. 6, pulse width modulating valve (PWM), and motorized valve.

Figure 7. 6 Direct expansion refrigerant feed for an evaporator air coil in a single-stage vapor compression system.



The expansion valve accomplishes the above two tasks by maintaining the required level of superheat at the evaporator outlet. Superheat is important in order to ensure that no liquid enters the compressor but it is also detrimental to both the performance of the evaporator as well as the overall performance of the refrigeration cycle. Therefore, it is always a desirable effect to keep the superheat as low as possible while still ensuring that there is no liquid carryover to the compressor.

The most prevalent device and most traditional is called a thermostatic expansion valve. It is an electro-mechanical device which can accommodate varying refrigerating loads, while at the same time maintaining the desired evaporator temperature. Thermostatic expansion valves are normally set to provide for 10°F to 20°F of superheat for the vapor leaving the evaporator. That portion of the evaporator tube that contains superheated vapor does negligible refrigeration because the heat transfer performance of vapor alone is very low. For a number of reasons, thermostatic expansion valves have been very difficult to use on ammonia systems and, in particular, low temperature ammonia systems. In addition, because the thermostatic expansion valve is a mechanical device which relies on springs and pressures to regulate the flow properly, facilities have often been forced to maintain higher than optimum discharge temperatures in order to ensure the proper function of the valve. Fortunately, new technology has arrived in the marketplace which replaces the thermostatic expansion valve. Two different types of

electronic expansion valves are motorized valves and pulse width modulation valves. Both valve types have the advantage of being controlled electronically (much faster and more responsive) instead of mechanically while not requiring high discharge pressures along with the ability to achieve superheat values of 6°F to 10°F.

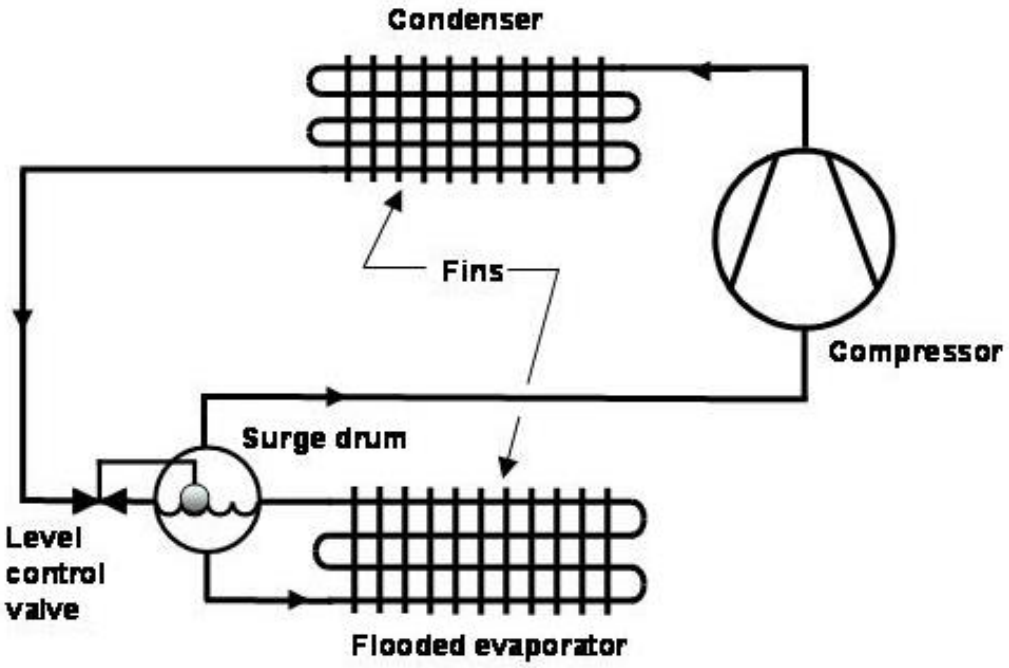
Flooded and Pumped Recirculated Liquid Systems

Flooded and liquid recirculation systems feed refrigerant to the evaporator in a different manner from that of direct expansion. In a pumped recirculated liquid system, refrigerant liquid is stored in vessels in a machinery room some distance away from where the liquid is supplied to the evaporator at the required rate. The liquid is either mechanically pumped or "pushed" by high pressure vapor. For flooded evaporators, a vessel is usually located near the evaporator. An expansion valve controlled by either a float or by an electronic level sensor regulates the flow of refrigerant to this vessel (known as a surge drum).

In general, flooded evaporators are supplied with liquid refrigerant at a rate approximately equal to the evaporation rate of the liquid refrigerant in the evaporator. Because the return liquid is being transferred back to the surge drum, there is little danger of liquid returning to the compressor. Through the separation provided by the surge drum at the flooded evaporator, vapor returns to the machinery room in the suction line. The refrigerant side of a flooded evaporator is nearly entirely wet. This helps to maximize the heat transfer performance of the evaporator.

A diagram of a single-stage flooded evaporator vapor compression system is shown in Figure 7.7. Note that Figure 7.7 shows the evaporator and condenser as tube-and-plate fin coils. For flooded coils, gravity provides the driving force for the refrigerant flow inside the tubes. As boiling occurs, vapor bubbles form inside the evaporator's tubes resulting in a decrease of the average density of the two phase fluid. The consequent density difference between the liquid in the supply drop leg and the evaporator's refrigerant mixture results in a natural buoyancy which moves the flow through the evaporator, returning to the surge drum above. The surge drum provides a volume big enough in size to separate the liquid from the vapor, thereby allowing only vapor to enter the suction line back to the compressor(s). Additionally, the liquid in the surge drum is adequate to serve as a supply of liquid for the flooded evaporator. Sudden changes in refrigerating load with flooded evaporators may cause the liquid level in the surge drum to abruptly change which could potentially cause liquid to enter the suction line. It is important to realize that the surge drum is designated a pressure vessel and falls under the jurisdiction of ASHRAE Standard 15 *Safety Code for Mechanical Refrigeration*, and under the ASME (American Society of Mechanical Engineers) *Boiler and Pressure Vessel Code*. It is also important to understand that, in the absence of pumps, gravity and the consequent buoyancy provides the driving force for refrigerant flow. Therefore, it is critical that all pressure losses be minimized.

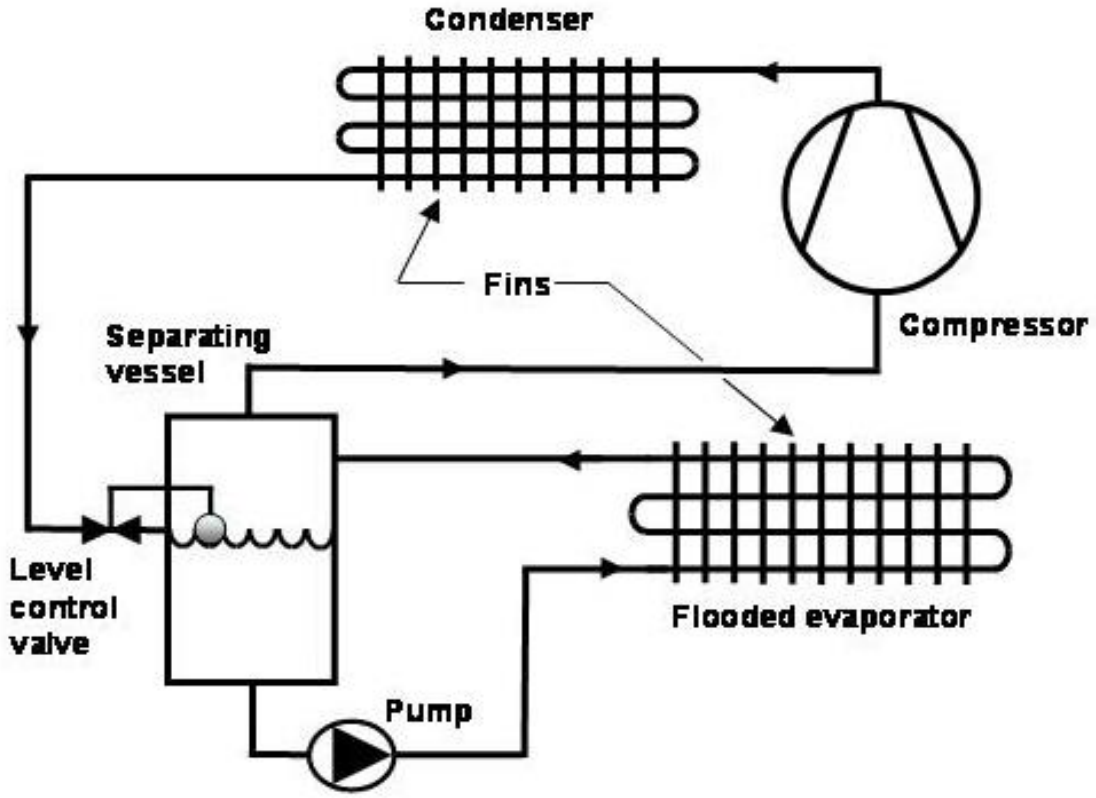
Figure 7. 7 Flooded evaporator air coil in a single-stage vapor compression system.



Pumped recirculated liquid to evaporators is a common method of refrigerant feed, especially in a facility with a large number of evaporators. This method is also called "overfeed". Figure 7.8 shows a diagram of how this system would be configured for a single-stage vapor compression system. Because liquid is supplied to the evaporator at a rate which exceeds the evaporation rate occurring inside the evaporator, liquid will be returned with the vapor in the wet suction line back to the machinery room. Observe from Figure 7.8 that separation of the liquid and vapor occurs in a separating vessel located in the machinery room. As liquid is returned to the separating vessel from the recirculated evaporator, additional liquid is metered into the separating vessel replacing the liquid refrigerant boiled-off in the evaporator. Liquid is pumped back to the recirculated evaporator, maintaining the supply of refrigerant.

For a pumped recirculated liquid evaporator, an adjustable control, balance valve immediately upstream from the evaporator regulates the flow of refrigerant liquid with some degree of overfeed. Note that this valve is not a thermostatic expansion valve. It is commonly called a hand expansion valve but, while some expansion does occur across the valve, a more appropriate name would be a flow balancing valve. A typical overfeed rate is 3:1. The significance of this ratio is that, in this particular instance, there is 3 times the amount of refrigerant being supplied to the evaporator than is required for the heat transfer load. However, overfeed rates have been decreasing to as low 1.25:1 due to better control systems and a desire to reduce the ammonia charge of facilities. This results in a large amount of liquid and vapor returning to the supply vessel, typically referred to as the recirculator.

Figure 7. 8 Recirculation refrigerant feed for an evaporator air coil in a single-stage vapor compression system.



A mechanical pump, shown in Figure 8, is necessary to raise the pressure in order to move the refrigerant liquid to the recirculated evaporator. The required pressure may also be provided by high pressure vapor applied to liquid in a separate vessel (often called pumper drums) and controlled by sequencing valves. With both approaches, the pressure generated must be sufficient to overcome the pressure drop in the liquid supply line, the pressure drop through the valves (in particular, the flow balancing valve), and the pressure drop through the evaporator. The balancing valve, often referred to as a hand expansion valve, regulates the flow in order to provide the desired overfeed ratio. This ratio *n,* the circulation or overfeed ratio, characterizes the operation of recirculated coils.

$$n = \frac{refrigerant\ mass\ flow\ rate\ supplied\ to\ evaporator}{refrigerant\ mass\ rate\ vaporized\ in\ evaporator}$$

When n is greater than 1.0, liquid will return with the vapor in the suction line to the separating vessel. Higher values of n are desirable due to better heat transfer performance, but higher values also result in higher pressure drops, higher pumping costs, and larger ammonia charges. Typical values for n range from about 3 to 4 for

ammonia and for R-22 usually about 3 because of its higher density than ammonia and its larger flow rates needed to obtain the same refrigeration.

7.1.3 Moisture in Air and the Psychrometric

The fact that frost forms from air proves that water vapor is present in air. While water is only a small fraction of the air's mass, it has a large influence on the behavior of the air.

7.1.3.1 Moisture in Air

Water freezes at a temperature at or below 32°F. In refrigerated warehouses, and in some processing plants, operating temperatures in these facilities are less than 32°F. An obvious example is a typical freezer room in a refrigerated warehouse controlled to maintain -10°F or lower. In this space, all surfaces are subject to frost, especially the evaporator coils operating at refrigerant temperatures approximately 10°F lower than the desired room temperature. To maintain operation, the coils are equipped with a means of defrost which in-turn removes moisture from the freezer room. Three approaches are used to defrost coils: water sprayed onto the frosted coil, hot refrigerant gas directed through the evaporator tubes, and room air blown through the coil. All defrost methods add moisture and heat to the refrigerated space thereby increasing the refrigeration load. The formation of frost on coils must be understood to accurately determine refrigeration loads and to achieve a good defrost.

Another section of the refrigerated facility where frost hinders operation is the doors that isolate the warmer spaces from the freezer. These doors, or other devices, generate a barrier keeping the warm air out of the freezer and are, therefore, indispensable in managing the facility's refrigeration load. Infiltration air passing through an open door into a refrigerated space operating at less than 32°F may generate frost inside the space if the temperature is sufficiently low. Surfaces near freezer doors may collect frost when the same conditions are present – the surface temperatures are less than 32°F and the dew point temperature of the air is above 32°F. Undesirable consequences result from frost in a refrigerated warehouse, especially in the transition zone between freezers and docks. Frost generates unsafe working conditions for plant personnel if allowed to form on the floor where product is moved in and out. Because warm air infiltrating into a cold space less than 32°F contains moisture, it may form frost inside the cold space producing unsafe conditions if allowed to accumulate. Frost formation on door guides and door frames inhibit operation of doors and preventative measures may be needed.

Psychrometrics is the study of the behavior of moisture in air and thus important to the operation and design of industrial refrigeration systems. A brief summary of psychrometrics is given below.

Air is primarily a mixture of two gases: nitrogen and oxygen. While many other gases exist in the atmosphere in trace quantities, the next most prevalent gas is water vapor which may reach 3.5% by weight. In the field of air conditioning and refrigeration,

there are two temperature measures which are used extensively: dry bulb temperature and wet bulb temperature. Dry bulb temperature is the temperature of the air measured with a common thermometer and basically represents the temperature that one senses. Wet bulb temperature is a bit more complicated in that it represents a temperature which characterizes the amount of water vapor in the air. Saturated air is air that is holding as much water as it can possibly hold at a given temperature. For saturated air, the dry bulb temperature and wet bulb temperature are essentially the same. As the water content decreases, the wet bulb temperature decreases, but not necessarily the dry bulb temperature. Wet bulb temperature plays a significant role in the performance of an evaporative condenser. Air is considered as containing two parts: dry air, which represents the mixture of all the gases; and water vapor, which is the moisture in the air. Psychrometrics is the study of the thermodynamics of moist air and the processes that it may undergo. Psychrometrics is important with the operation of evaporator air coils because condensation or frost may occur on the air side. Evaporative condensers operate using the evaporation of water governed by psychrometrics.

7.1.3.2 Psychrometric Chart

Moist air is composed of two gases, assumed to behave as ideal gases, which do not interact with each other. Therefore, each of these parts behaves according to the ideal gas law:

dry air: $p_a V = n_a RT$ (1)

water vapor: $p_w V = n_w RT$ (2)

where,

p_a = partial pressure of dry air (psia)

p_w = partial pressure of water vapor (psia)

V = total mixture volume (ft^3)

n_a = number of moles of dry air

n_w = number of moles of water vapor

R = universal gas constant, (1545.32 ft·lbf /lbmol·°R)

T = absolute temperature (°R)

The pressure that is measured by a barometer is the sum of the dry air and water vapor pressures,

$p = p_a + p_w$ (3)

where p (psia) is the total pressure of the air which is a mixture of dry air and water vapor.

7.1.3.3 Psychrometric Important Terms

Several terms important to psychrometrics are defined as follows:

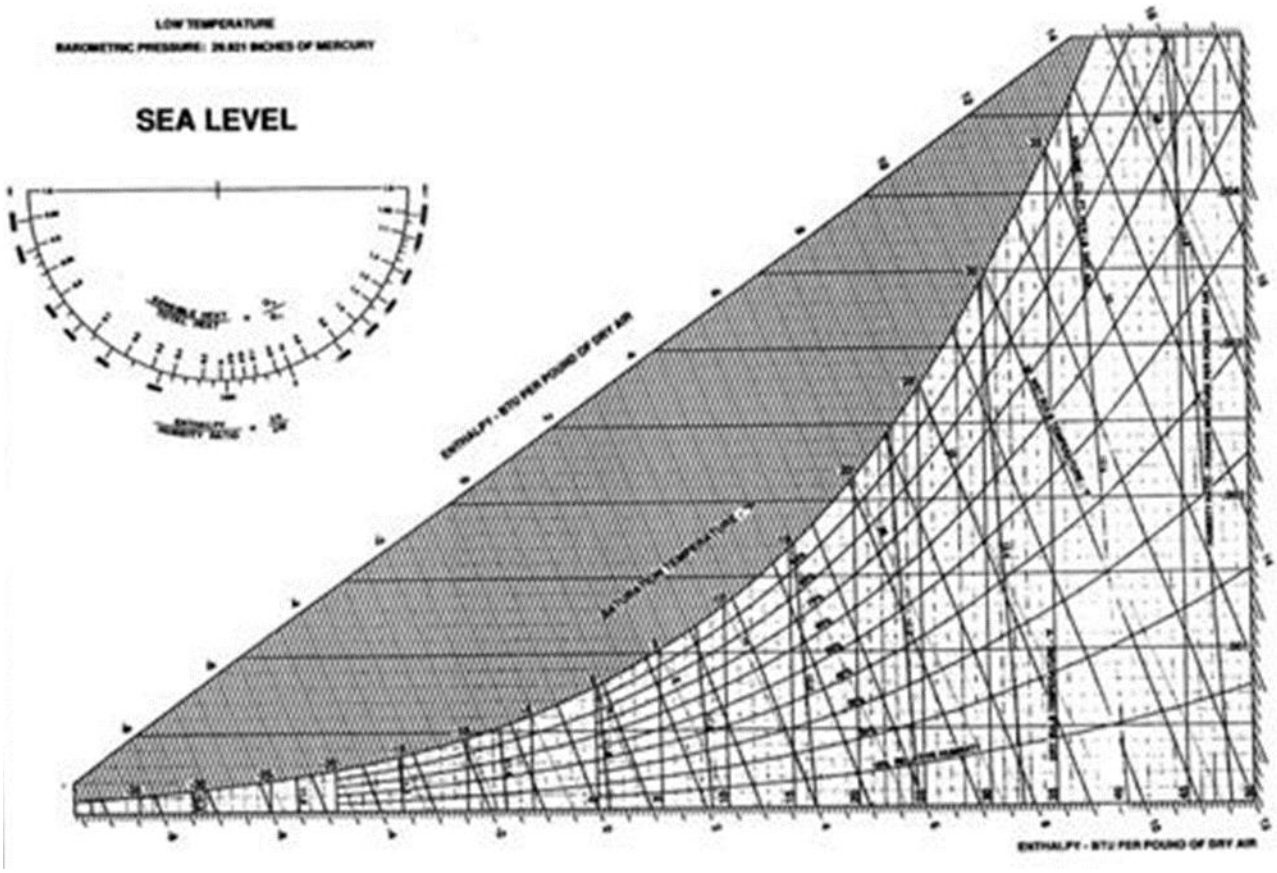
- **Saturated Air** - The water vapor in the moist air is at its saturated pressure and temperature. The saturated steam tables show the thermodynamic properties of saturated liquid and saturated vapor for water where for each saturated temperature there is a unique saturated pressure.
- **Dry-bulb Temperature** - The air temperature, T, as measured by an ordinary thermometer.
- **Wet-bulb Temperature** - The temperature measured by a thermometer moving rapidly in moist air that has its sensing element covered with a wetted cotton wick. A psychrometer measures simultaneously the dry-bulb and wet-bulb temperatures. To obtain an accurate indication of the wet-bulb temperature, the psychrometer must be rotated rapidly in the moist air. Evaporation from the wick cools the sensing bulb to the wet-bulb temperature. If the temperature is below 32°F, then an ice bulb forms and the temperature is sometimes called the "ice-bulb" temperature.
- **Thermodynamic Wet-bulb Temperature** - The temperature, T*, that moist air obtains when undergoing an adiabatic heat transfer with water (or ice) and becoming saturated at a constant dry-bulb temperature and humidity ratio, W. Measuring the wet-bulb temperature is a different process than that for thermodynamic wet-bulb temperature. But, the numerical differences between the wet-bulb and thermodynamic wet-bulb temperature are very small and so may be neglected.
- **Humidity Ratio** - Defined as W, the ratio of water vapor mass to the dry air mass in a given quantity of moist air. Thus, W = humidity ratio = mw / ma , where mw is the water vapor mass and ma is the dry air mass.
- **Relative Humidity** - Defined as φ, the ratio of the actual water vapor pressure, pw, in the moist air to the saturated water vapor pressure, pws, for the same temperature. Thus, relative humidity = φ = pw / pws.
- **Dew PointTemperature** - The temperature, Td, of moist air that is saturated at the same pressure and humidity ratio as that for the given sample of moist air.
- **Specific Volume** - The specific volume of moist air is defined as the moist air mixture volume per unit mass of dry air. So, the ideal gas equation of state gives,

$$v = \frac{R_a T}{(p - p_w)} \qquad (4)$$

  where v is the specific volume (ft3/lbm dry air), Ra = R/Ma the gas constant for air, and Ma the molecular weight of air (28.97 lb/lbmol).
- **Enthalpy** - The sum of the enthalpy for dry air and water vapor that comprises the moist air. Thus, h = ha + Whg, where hg is the enthalpy for the saturated water vapor at the temperature of the moist air.

The thermodynamic properties above can be combined into a single plot called the psychrometric chart. An example of these charts is given in Figure 7.9 (ASHRAE 2009) for below-freezing water temperatures.

Figure 7. 9 Low-temperature psychrometric chart (ASHRAE 2009)



7.1.4 Equipment Selections

There are numerous options available to the facility owner in terms of equipment selections. Selection of equipment is driven by:

- the type of facility: storage or distribution, blast freezing requirements, temperature flexibility requirements
- capital considerations
- size limitations
- future expansion plans
- operating criteria
    - local work force availability and capability
    - energy costs
    - maintenance demands
    - local code issues
- type of refrigeration system

As noted in the beginning of this chapter, the purpose of this guide is not to teach the facility owner how to design a refrigeration system, but rather to expose him/her to the numerous options available. In this section, we will look at the fundamental types of equipment options available to the owner for new facilities, as well as for expansions and major remodels and overhauls.

7.1.4.1 Compressors

There are a variety of different compressor types available in the air conditioning and refrigeration market segments. Industrial refrigeration systems are primarily populated with two types of compressors: open drive reciprocating compressors and rotary screw compressors.

Open Drive Reciprocating Compressors (ODRC)

Open drive reciprocating compressors (ODRC) are characterized by a piston driven compressor provided with shaft power external to the system. This shaft power is most often provided by an electric motor and can be direct coupled or belt driven. ODRC's have a long history in industrial refrigeration, but do have limitations on compression ratios (typically 8:1). In the age of the large refrigeration facilities, the reciprocating compressor is somewhat limited in terms of capacity (usually about 300 tons for high stage) and generally requires more maintenance than the rotary screw compressor. Most ODRC's have some type of capability to "unload" in order to match compressor capacity with actual refrigeration load. There are 3 basic ways for the compressor to unload:

1. Eliminate refrigerant flow to various cylinders. The pistons continue to move up and down in the empty cylinders but do not compress any refrigerant vapor. While energy is still expended, the actual power requirements can be dramatically reduced.
2. Use a variable speed drive to control the speed of the compressor.
3. Use a combination of variable speed drive and cylinder unloading. This allows for savings when capacity requirements are between the incremental steps of cylinder unloading.

Rotary Screw Compressors

Rotary screw compressors are characterized by two types: single screw (also referred to as mono-screw) and twin screw compressors. In either case, the basic vapor compression process is accomplished by drawing refrigerant vapor into a section of a rotating helical screw which then compresses the gas by reducing the internal volume as the screw rotates. Twin screw compressors make use of two screw drives which rotate together to compress the vapor. A single screw compressor also draws the vapor into the screw mechanism but, in this case, the vapor is compressed by the action of the driven screw and two "floating" gate rotors. As with ODRC's, the rotary screw compressor also has the capability to unload as the refrigeration load decreases, but at a reduction in energy efficiency. Unloading can also be accomplished in one of 3 ways:

1. Both compressor types make use of a slide valve to regulate the flow of refrigerant vapor into the screw. The slide valve essentially opens and closes depending on the load requirements.
2. Use a variable speed drive to control the speed of the compressor.
3. Use a combination of variable speed drive and slide valve.

7.1.4.2 Evaporators

In the context of this chapter on refrigeration, evaporators are referred to as coils. The coil consists of a fin and tube heat exchanger in which refrigerant flows into the tube as mostly liquid and, as it passes through the evaporator, picks up heat from the air and turns into vapor. Air passes through the fin side of the coil. Air can be drawn into the coil by fans located on the leaving side of the evaporator, or it can be blown through the coil by fans located on the entering side of the evaporator.

As noted in the section on psychrometrics, coils which operate with refrigerant below 32°F, will likely need to be defrosted periodically. There are essentially 3 methods of defrost:

1. **Hot Gas Defrost -** This is, by far, the most common method of defrosting an air coil. While somewhat more complicated than the description which follows, the liquid supply to the coil is shut off, the coil is "pumped down" to remove as much liquid remaining in the coil tubes, and hot refrigerant vapor (usually from the compressor discharge line) is introduced into the coil tubes and the drain pan to melt the ice which has formed on the outside of the tubes and in the pan. While this method is the typical methodology for defrosting a coil, there are some items of concern associated with its application. Fortunately, significant advances in valves and control technology have been introduced over the past five years to eliminate many of the historical issues.
2. **Water Defrost -** This type of defrost is seldom used in refrigerated warehouse design. This approach to defrost involves a simple hot water deluge over the outside of the tubes. From a piping perspective, it provides a simpler methodology but adds a new element into the design (water) and also can add a significant amount of humidity to the refrigerated space.
3. **Electric Defrost -** This method involves the addition of electric resistance heaters to specially adapted spaces on the coil fins. While simple in concept, energy consumption is significantly higher and there has been concern regarding the reliability of the heating elements.

Coil defrosting is an important aspect of the evaporator design, as well as system performance. As the coil becomes "loaded" with ice, less heat transfer surface becomes available to provide cooling. On the other hand, it should be noted that the very process of defrosting not only eliminates cooling during the process, but actually adds heat to the space being cooled. Therefore, while a critical element to the process, it can also be a significant energy drain. Various control schemes have been developed over the years in

an attempt to optimize both the time required to defrost, as well as the frequency of defrosts. Some significant advances in control technology have been introduced over the past five years which contribute to minimizing both risk and energy consumption during the defrost process. It should be noted that defrost frequency can be minimized by good door management and/or dehumidification of the air entering the space.

7.1.4.3 Chillers

While not used significantly in the cold storage segment of the industry, it would be remiss not to mention this particular type of cooling system. A chiller represents an extra step in the cooling process. In most cases, a chiller is a liquid to liquid heat exchanger. Refrigerant liquid or a mixture of liquid and vapor is introduced as one stream into the heat exchanger. The other stream (the one being chilled) is some type of intermediate fluid such as glycol, brine, water, or CO_2. The refrigerant is typically evaporated as a result of the heat transferred from the intermediate fluid. This chilled fluid is then distributed to air coils throughout the facility. In the case of glycol or water, no evaporation is taking place in the air coils. In the case of pumped CO_2, evaporation is taking place and, thus, overall efficiency may be higher than it is for a glycol or water system.

One of the prime motivations behind the growing use of chillers in the cold storage industry is the desire to minimize refrigerant charge in general, and more specifically ammonia charge. Depending on the type of chiller used, overall system efficiency is impacted; however, if there is a strong need to reduce refrigerant charge, the use of a chiller provides a viable means to accomplish this objective.

7.1.4.4 Condensers

There are 3 basic type of condensers used in industrial refrigeration: 1) evaporative condensers; 2) water cooled condensers; and 3) air cooled condensers. The cooling process for a condenser starts with desuperheating the hot compressor discharge gas. Once the temperature of the refrigerant has dropped to its saturated state, condensing begins with little, if any, temperature change. Finally, a small amount of subcooling may take place. Subcooling drops the temperature of the liquid to some level below the saturation temperature. The condensed liquid is then, typically, sent to the high pressure receiver.

Evaporative Condensers

Evaporative condensers are the most common type used in refrigerated warehouse design and actually evaporate and condense at the same time. The evaporation process occurs as spray water on the outside of the tubes is evaporated by the hot refrigerant in the condenser tubes. At the same, once desuperheating has concluded, the refrigerant, by virtue of rejecting its heat to the wetted outside surface of the tube, is condensed to a liquid. Evaporative condensers can operate with lower discharge pressures (and, thereby, temperatures) because the temperature differential between refrigerant and the cooling medium (in this case air and water) is driven by the air's wet bulb temperature rather than

its dry bulb temperature. In typical installations, wet bulb temperatures range from 14°F to 25°F lower than the dry bulb temperatures. This translates to significant power savings. There are two basic configurations for evaporative condensers: Induced Draft and Forced Draft. Induced draft configurations require the use of axial fans. Forced Draft configurations can use axial or centrifugal style fans.

Variable Frequency Drives will be discussed in Section 4.6; however, the evaporative condenser just might be the best application for variable frequency drives in the entire refrigeration system. Because power consumption in fans varies to the cube power of the speed, a small drop in speed translates to a much larger drop in power consumption. The advantages of evaporative condensers include:

- Excellent heat transfer.
- Reduced surface area than air cooled condensers.
- Smaller footprint than water cooled or air cooled.
- Higher capacity potential than air cooled.

The disadvantages of evaporative condensers include:

- Water requirements.
- Potential for tube scaling.
- Need for expanded maintenance (cleaning, descaling, water treatment).

Water Cooled Condensers

Water cooled condensers are included in this discussion because there are rare circumstances when there is plenty of water available to serve as the means for heat rejection. However, this is typically not the case in most parts of the country. There are many different versions of water cooled condensers in use today, but the most common is likely the shell and tube condenser. The condenser can also be coupled with a cooling tower to provide a means of recycling the majority of the water used for cooling; however the capital and space requirements can be quite significant.

Air Cooled Condensers

Air cooled condensers are generally constructed of tubes and fins. These type of condensers do not rely on the wet bulb temperature of the air to cool and therefore, the saturated refrigerant temperature must be higher than the air temperature (dry bulb) in order to condense. A fan provides for the movement of air across the fin and tube surface. The advantages of air cooled condensers include:

- First cost effective for small facilities.
- No water treatment required.
- No safety issues associated with water treatment.
- While the capital cost can be high for larger systems, they can benefit from lower overall operating costs compared to evaporatively cooled systems in most

climates once water costs, water treatment, and maintenance are taken into account.

- The disadvantages of air cooled condensers include:
- Significant increase in use of energy.
- High capital cost in comparison to evaporative condensers.
- In most climates, as the facility becomes larger, the cost of the equipment and the footprint rise significantly.

7.1.4.5 Valves and Controls

In the past, there would be limited, if any discussion, of this particular aspect of the refrigeration system. Historically, the functions of valves in the refrigeration system were to:

- Isolate sections of the system when required (stop valves).
- Remove particulate (strainers).
- Keep flow from moving in the wrong direction (check valves).
- Balance flow to evaporators (hand expansion valves or flow balancing valves).
- Provide a means for maintaining pressures at various points in the system (pressure regulators).
- Provide controlled expansion of refrigerant to lower pressures and temperatures.
- Prevent dangerous pressure increases in system vessels (safety relief valves).

All industrial refrigeration systems are populated with valves of all sizes and functions throughout the facility. From a cost perspective, valves are one of the least expensive of all the major system components, although they can add pressure drop to the refrigeration system resulting in an increase in energy cost. They can also prove to be a major asset or liability when it comes to safety, reliability, efficiency, and maintenance. Over the past decade, major advances in valve designs and controls have been made, which have led to:

- Higher strength materials.
- More corrosion resistant materials.
- Reduction or elimination of flanged joints.
- More precise and controlled flow control of refrigerant liquid and vapor.
- Significantly improved expansion devices.
- Simpler maintenance procedures.

It should be emphasized that the level of true control capability from a control valve has improved dramatically over the past decade. In the past, abrupt changes in operating conditions often meant abrupt changes in refrigeration flow, and occasionally with serious consequences. The new technology in the market today brings great promise to the industry for more precise control, smoother transitions, and marked improvements in energy efficiency.

Control technology has also advanced significantly over the past decade. Controls can be as simple as single function controllers to programmable logic controllers (PLCs), to plant wide systems which can be web based and remotely controlled. The integration of plant wide controls with electronic valves offers the potential to dramatically improve productivity, energy efficiency, safety, and reliability of the facility.

7.1.4.6 Variable Frequency Drives

Variable frequency drives, VFD's, (also known as variable speed drives) have been commercially available for over 50 years. In the past decade, significant emphasis has been given to integrating these devices into industrial refrigeration systems. In essence, anything with an electric motor has the potential for a VFD application. The key to deciding where the most appropriate applications are lies in the variation of conditions that a particular component is subject to:

- **Evaporative Condensers** – Perhaps the best application for all of the motor-driven devices in an industrial refrigeration facility, these devices see changes in load as a result of changes in cooling loads and they see changes in climatic conditions such as temperature and humidity. Because fans or blowers are used to move air through the evaporative condenser, small changes in speed can mean large changes in power consumption. As an example, a reduction of fan speed to 50% of full capacity translates to roughly an 82% reduction in power consumption. It should be noted, however, that this can also cause the compressor to operate at a higher load level. A properly designed control system will have a compressor/condenser speed algorithm within it to be able to continuously decide where the optimum operating point is as conditions change.
- **Evaporators** – As air coils are the most prevalent form of evaporators in the cold storage industry, it is obvious that they also make use of fans or blowers to move air through the coil. The use of VFD's can, once again, dramatically reduce the energy consumption of the coil but the designer must be able to ensure that, as fan speed is reduced, air throw is still sufficient enough to reach and cool all areas of the room.
- **Compressors** – Because most compressors already have some form of unloading built into the equipment, the use of a VFD is not quite as obvious as it is with evaporators and evaporative condensers. As noted earlier, the most common use of a VFD on a compressor is on, what is frequently referred to as a trim compressor. When configured properly, the other compressors operate at or near their peak efficiency. As loads change, the trim compressor's speed is raised and lowered to meet the demand.
- **Pumps** – This is a relatively simple application and one which can work quite well with electronic liquid make-up control. As noted earlier, liquid pumping is not nearly the energy consumer as is vapor compression; however, it should be obvious that as liquid level demand decreases, there is certainly no point in running the pumps at 100% of their capacity.

7.2 Maintenance

7.2.1 Introduction

A well thought out design is an excellent first step in the development of an efficient, reliable, and safe refrigeration plant. It is just as important, however, to have a strong maintenance program to maintain efficiency, reliability, and safety. As with the comments in the design section, it is not the intention of the authors to lay out a comprehensive maintenance program in this document. Each facility has its own unique characteristics in terms of design, equipment, load, operating and maintenance personnel, and geography. The intention in this section is to note the key elements to consider when developing and implementing a comprehensive and functional maintenance program.

This section addresses the key components in an industrial refrigeration system:

- Compressors
- Pumps
- Motors
- Evaporators
- Condensers
- Vessels
- Valves
- Piping and Insulation

The information contained in these sections comes directly from the manufacturers who chose to participate in this effort. Not all major manufacturers participated in the development of this section so it is possible that some of the major manufacturers have additional guidelines which are not found in this document. It has also been kept as generic as possible with the understanding that the owner/operator will consult the technical bulletins from the specific manufacturers of his/her equipment.

Maintaining Compressors

- While servicing and opening the system for inspection, take special precautions to keep dirt, moisture, and other contaminants from entering the system. Refrigerant and oil should be keep clean and dry.
- The suction strainer should be inspected on a regular basis and cleaned or replaced as needed. New systems generally require more frequent inspections. Consult the manufacturers recommendations with respect to frequency of inspections.
- Clean and/or replace oil filters on regular intervals. Increases in pressure drop across the filters is a good indication that the filter needs to be inspected.
- During long periods of shut down, it is advised to evacuate to low pressure and charge with dry nitrogen or oil. Pressures should be periodically monitored to ensure that system integrity is being maintained.

- Vibration analysis should be performed on a regular basis to ensure that no changes in the system dynamics have occurred.

Maintaining Pumps

- Inspect bearings.
  - Sliding surface
  - Wear inside bore
  - Wear on thrust surface
- Inspect shaft sleeve and thrust collar for:
  - Corrosion
  - Sliding surface wear
- Check Filter and circulation pipe for blockage.
- Check for any other visible abnormalities.

Maintaining Motors

- Inspect bearings.
- Depending on motor type, inspect windings.
- Inspect for damage due to high overheat.
- Check motor mounts.

Maintaining Evaporators

- Check for proper defrost and defrost timing – adjust as required.
- Inspect and clean, if necessary:
  - Coil surface if necessary and note any corrosion
  - Defrost drain pan
  - For water defrost coils, inspect water distribution pans
- Inspect and repair, if necessary:
  - Insulated supply and drain lines for proper support and operation
  - Wiring – check for frayed wires, loose and/or corroded electrical connectors
  - Motors and fans – pay particular attention to mounts

Maintaining Condensers

- Check and clean strainers, if required.
- For evaporative condensers, check water distribution system.
  - Ensure that coil surface is getting fully wetted
  - Replace spray nozzles, if necessary
  - Check coil surface for scaling
- Check cold water basin on evaporative condensers.

- Bleed lines purges accumulated solids from the water side of an evaporative condenser. These systems should be examined for effectiveness and modifications to operating criteria made as required.
- If the system is equipped with a water treatment system, ensure that it is working in a fashion to ensure its effectiveness.
- Whether direct drive or belt drive, make sure that the basic components of the system are operating properly: belts, bearings, and mounts.

Maintaining Vessels

- Check external surface of vessels for corrosion.
- Check for damage to insulation or vapor barrier.
- Mechanical integrity should be evaluated if external corrosion is noted.
- The system should be checked for non-condensible gases; if necessary, purge from receiver(s) and/or condenser(s), preferably into a non-condensible gas remover or purger but alternatively into water.
- Where automatic purgers are installed, its correct operation should be confirmed. If there is a large accumulation of non-condensible gases the reason should be investigated and the fault, which could include a leak on the LP side or incorrect maintenance practice, should be corrected.
- Liquid level gauges should be inspected for oil build-up and gauges drained if necessary.

Maintaining Valves

Items which typically fall under the general category of valves include:

- Isolation valves
- Strainers
- Hand expansion or regulating valves
- Check valves
- Pressure regulators and Solenoids
- Motorized expansion and metering valves
- Gauge/purge/needle valves
- Safety relief valves
- Other peripheral components such as gauges, pressure transmitters, temperature sensors, level sensors, and some controls.

Over the past decade, there have been significant advances in valve technology. The guidelines contained in this document reflect very generic guidelines as well as the maintenance guidelines provided by the manufacturers who chose to participate in the development of this section.

7.2.2 General Maintenance Guidelines

In general, most components which fall under the "valve" category give direct access to the refrigeration system. Maintenance personnel should always:

- Be fully aware of all safety guidelines and procedures including but not limited to:
  - Appropriate protective equipment
  - Pump-down/isolation procedures
  - The appropriate materials available for repair including gaskets and o-rings.
- Understand the function of the valve/component.
- Follow the manufacturer's instructions for proper servicing of the valve.
- Test the serviced/repaired component for leak-tightness.

All valves and line components should be checked for mechanical integrity. Items to look for include corrosion on the body and bonnet of the valve. If the valve is flanged, check to ensure that there are no leaks at the flanges and that any corrosion is only superficial. Flange bolts should also be checked for corrosion.

Isolation Valves – These are also known as stop valves and shut-off valves. As the name implies, their purpose is to stop flow to a part of the refrigeration system. Good maintenance practice suggests that isolation valves are "exercised" at least once a year and, preferably, every six months. Clearly, the facility owner wants to be assured that, if and when, the need to isolate a portion of the system is required, the valve performs as indicated. During the process of exercising the valve, the packing gland should be checked for leakage. If any leaks are detected, the packing gland should be replaced. Well designed isolation valves allow the user to "backseat" the valve and replace the packing gland without the need to pump down the system.

Strainers – The strainer protects not only the other valves in the refrigeration system but also the other key mechanical elements such as pumps and compressors. Strainers should be checked and cleaned periodically. The frequency of servicing the strainer is highly dependent on the cleanliness of the system. During initial start-up of a system, strainers should be cleaned more frequently. A good indication of the cleanliness of the strainer is pressure differential across the strainer. In very clean systems, most strainers can be maintained under a regular maintenance schedule. Dirtier systems should be more closely monitored and serviced as required. Dirty strainers can, not only, lead to poor performance of the valves but also may lead to poor performance of other key components of the system.

Hand Expansion/Regulating Valves – The hand expansion valve is similar to an isolation valve except that it is almost always in a partially opened position. Its primary purpose is to regulate flow. As with the isolation valve, packing glands should be checked for leaks. It is also a good idea to verify that the hand expansion valve is set for the proper flow condition. An improper setting can lead to underperformance of the evaporator (in pumped liquid lines) or excessive flow which can negatively impact system efficiency.

Check Valves/Stop Check Valves – The purpose of the check valve is to prevent reverse flow through that part of the system where the check valve has been installed. Check valves should be monitored for that purpose. Poorly performing checks can lead to poor performance in the best case and catastrophic failure in the worst case. As with isolation valves and hand expansion valves, the stop/check valve has an isolation component with a packing gland. It should be checked periodically for leaks.

Pressure Regulators and Solenoids – As the name implies, the pressure regulator is used to control pressure at various points in the refrigeration system. Also included in the function of the pressure regulator is flow control and temperature control. Proper set up and maintenance of pressure regulators ensures precise system control and the anticipated system efficiency. If the pressure regulator is flanged, be sure to check the integrity of the flanges and bolts as well as the leak tightness of the flanged joint.

Solenoids are often simple versions of the pressure regulator in that the pilot is a simple solenoid pilot rather than a pressure regulating pilot. Smaller solenoids are often direct acting and are opened or closed simply by the magnetic force of the electric coil attached to the solenoid armature.

Once visual inspection of the valve has occurred, verify that the guide jacking stem is in the automatic mode. Before servicing the valve, the valve must be isolated and the guide jacking stem should be put in guide mode to ensure that all refrigerant has been purged from the valve. Most pressure regulators have pressure gauges installed for initial set-up of the pilot and for monitoring the pressure which is to be controlled. The first step in ensuring proper function of the valve is to calibrate the gauge itself. Once the accuracy of the gauge has been verified, check to ensure that the pressure is being maintained as expected. Dual function pressure regulators typically have a solenoid module as well as a pressure regulating module. Check to ensure that the solenoid module is functioning as designed.

Motorized Expansion and Regulating Valves – This type of valve is used in a variety of applications such as direct expansion, liquid injection, liquid make-up, and hot gas and suction regulation. In most cases, the valve can be controlled with either a relay or an analog signal. It is important to periodically verify that the valve is responding correctly to the control signal. Period calibration of the valve is also recommended. In addition, motorized valves should open and close smoothly. Rough operation can be evidence of dirt trapped in the valves operating mechanism. It is always recommended to have a strainer upstream of the valve and that this strainer is periodically inspected and cleaned as necessary.

Gauge, Purge, and Needle Valves – As the name implies, these small valves have a variety of functions. They should be periodically inspected for valve stem integrity and also for any accumulation of foreign material in the valve.

Safety Relief Valves – This particular valve is generally maintained per the requirements of IIAR. Periodic replacement of the safety relief valve is dictated by the requirements of IIAR 2-1999 or local jurisdiction. If the system is constructed with rupture discs, periodic inspection of the rupture discs is also recommended. In general,

relief valves only vent when there is some other underlying issue at work. It is always recommended to take a pro-active approach in determining the root cause of the venting activity.

Other Peripheral Devices – In general, this category includes sensors and transmitters. It is always recommended to either calibrate the device or to validate the accuracy of the device.

Piping and Insulation - Piping and insulation effectiveness are often two of the most important and most difficult aspects of the refrigeration system to inspect and maintain properly. At the same time, they are extremely critical not only to the performance of the refrigeration system but, more importantly, to the safety of the system as well.

Visual Inspection – Uninsulated pipe is generally fairly easy to inspect since corrosion rarely occurs on the inside of the pipe. On the other hand, most refrigeration facilities have miles of pipe and a rigorous and comprehensive program should be developed to periodically inspect all of this pipe for signs of corrosion or wear. The good news is that there are many logical places where corrosion is more likely to occur. Obviously, these are the areas where inspection should begin and should undergo inspection more frequently. Insulated pipe, on the other hand, is extremely difficult to thoroughly inspect although there are many indications of potential pipe corrosion issues even to the casually trained eye:

- Breeches in the insulation can allow water and/or water vapor to accumulate between the insulation and the pipe. When coupled with oxygen, this creates the perfect environment for corrosion to initiate.
- Ice formation on an insulated pipe – An insulated pipe when properly designed and installed will not allow ice to form on the outside of the insulation. Ice formation is a certain indication that the insulation system has failed and is a good warning sign that there are more problems lying below the surface.
- Other External Indications – Other tell-tale signs of problems lying below the surface of the insulation include dents, deformations, and condensation on the external insulation jacket. In addition, biological growth on pipes is an excellent indicator of system degradation.
- Also check for corrosion on flanges, welds, and pipe supports.
- IIAR Bulletin 110 indicates that all insulated piping shall be inspected at least annually.

Other Inspection Techniques – Beyond visual inspection, there are new techniques available which can provide a more in-depth and detailed picture of the integrity of the piping system. Most of these other techniques are referred to as NDT (non-destructive testing) or NDI (non-destructive inspection). Among the techniques used effectively today are:

- Dye Penetrant Testing
- Magnetic Particle Testing
- Ultrasonic
    - Pulse echo

- Transmission technique
- Reflection technique
- Guided wave

Each of these NDT approaches has its own strengths and limitations. The facility owner will need to determine which is the most appropriate for his/her own needs.

A well constructed, documented, and managed preventive maintenance program is essential to the long term success of any refrigerated facility. Maintaining the refrigeration system properly is the best way to ensure that the system will run as it was designed and will also provide assurance of a high level of compliance with all national, regional, and local code criteria.

7.3 How Well Do You Know Your Refrigeration System?

Use this quick questionnaire to assess your facility's refrigeration system.

All temperatures should be in degrees Fahrenheit

1. What is the actual operating room temperature of each type of refrigerated storage room in the facility? *[Example: frozen storage room, chilled storage room, etc.]* Also, what is the saturated suction temperature of the compressor(s) in the compressor room serving each type?

Room Type	Operating Temperature in F	Saturated Suction Temperature in F

2. What is the compressor discharge or condensing temperature?

   Discharge/Temp (F) = _____

3. What is wet bulb outside? **Wet Bulb (F) = _____**
   [To find wet bulb: Visit www.4wx.com - it is a weather information center. Record your dry bulb (temperature) and humidity. Click on "WX calculators" on the left side menu. Then click on "Dew Point and Wet Bulb from Relative Humidity" in the green section of the page. Enter the dry bulb temperature in the blank indicated for temperature and the relative humidity in the percentage box. Enter "30" in the box for "Enter your actual station pressure (not the altimeter setting):" and select "in of mercury". Click "Convert" to see your wet bulb.] Record the Fahrenheit results.

4. How many inches of insulation are in your walls and ceiling?

   Inches of Insulation = _____
   Is it urethane (R value of 6) or expanded polystyrene (R value of 4)? **R=6/R=4**

Multiply the inches of insulation in your wall by the value of your insulation and record it here.
(_____ In.) X (R= _____) = _____

5. What is your dock's actual operating air temperature? **Temp (F) = _____**
6. How many pallets a day go in and out of your storage rooms? **Pallets = _____**
7. What kinds of doors are between your dock and freezer and cooler *(select all that apply)*:
   a. bi-parting b. horizontal doors c. vertical doors d. other _____
8. Are the doors opened and closed automatically? **Yes/No**
9. When the doors are open, is there any curtain? **Yes/No**

   [Example: strip curtains, roll-up curtains, bi-folding doors, etc.]
10. What is your kilowatt hour (KWH) usage per cubic foot (cu. Ft.)? ***(For storage space only, excluding blast freezing)***
    [To Calculate: Ask your accountant to add up the number of kilowatt hours your building consumed for the last 12 months. ***Subtract the kilowatt hours for blast freezing, if any****. Calculate the number of cubic feet of your building [square footage of refrigerated storage multiplied by the total ceiling height]. Divide the cu. ft. into the kilowatt hours [KWH/cu. ft.]. The number should be in the range of .7 or 1.5 or some reasonably similar number.]*

    KWH/cu. Ft = _____
11. What is your average cost per kilowatt?
    [To Calculate: Add up the total 12 months of electric bills and divide by the total number of operating hours. The result should be in the range of $.07, $.10, $.12 per kilowatt or some reasonably similar number.]

    Average cost per KW = _____
12. Do you have enough refrigeration capacity to turn the system off for 8 hours a day in the summer?
    Yes/No
13. Do you operate your system steadily or do you shut it down during peak power hours, running it harder on off-peak. Do you have a control system to do that?
    Yes/No

7.4 RMP Program Level 3 Process Checklist

RMP Program Level 3 Process Checklist	Facility Name: _____		
Section A – Management [68.15]			
Has the owner or operator:			
1. Developed a management system to oversee the implementation of the risk management program elements? [68.15(a)]	☐Y	☐N	☐N/A
2. Assigned a qualified person or position that has the overall responsibility for the development, implementation, and integration of the risk management program elements? [68.15(b)]	☐Y	☐N	☐N/A
3. Documented other persons responsible for implementing individual requirements of the risk management program and defined the lines of authority through an organization chart or similar document? [68.15(c)]	☐Y	☐N	☐N/A
Section B: Hazard Assessment [68.20-68.42]			
Hazard Assessment: Offsite consequence analysis parameters [68.22]			
1. Used the following endpoints for offsite consequence analysis for a worst-case scenario: [68.22(a)] ☐ For toxics: the endpoints provided in Appendix A of 40 CFR Part 68? [68.22(a)(1)] ☐ For flammables: an explosion resulting in an overpressure of 1 psi? [68.22(a)(2)(i)]; or ☐ For flammables: a fire resulting in a radiant heat/exposure of 5 kw/m^2 for 40 seconds? [68.22(a)(2)(ii)] ☐ For flammables: a concentration resulting in a lower flammability limit, as provided in NFPA documents or other generally recognized sources? [68.22(a)(2)(iii)]	☐Y	☐N	☐N/A
2. Used the following endpoints for offsite consequence analysis for an alternative release scenario: [68.22(a)] ☐ For toxics: the endpoints provided in Appendix A of 40 CFR Part 68? [68.22(a)(1)] ☐ For flammables: an explosion resulting in an overpressure of 1 psi? [68.22(a)(2)(i)] ☐ For flammables: a fire resulting in a radiant heat/exposure of 5 kw/m^2 for 40 seconds? [68.22(a)(2)(ii)] ☐ For flammables: a concentration resulting in a lower flammability limit, as provided in NFPA documents or other generally recognized sources? [68.22(a)(2)(iii)]	☐Y	☐N	☐N/A
3. Used appropriate wind speeds and stability classes for the release analysis? [68.22(b)]	☐Y	☐N	☐N/A
4. Used appropriate ambient temperature and humidity values for the release analysis? [68.22(c)]	☐Y	☐N	☐N/A
5. Used appropriate values for the height of the release for the release analysis? [68.22(d)]	☐Y	☐N	☐N/A
6. Used appropriate surface roughness values for the release analysis? [68.22(e)]	☐Y	☐N	☐N/A
7. Do tables and models, used for dispersion analysis of toxic substances, appropriately account for dense or neutrally buoyant gases? [68.22(f)]	☐Y	☐N	☐N/A
8. Were liquids, other than gases liquefied by refrigeration only, considered to be released at the highest daily maximum temperature, based on data for the previous three years appropriate for a stationary source, or at process temperature, whichever is higher? [68.22(g)]	☐Y	☐N	☐N/A
Hazard Assessment: Worst-case release scenario analysis [68.25]			
9. Analyzed and reported in the RMP one worst-case release scenario estimated to create the greatest distance to an endpoint resulting from an accidental release of a regulated toxic substance from covered processes under worst-case conditions? [68.25(a)(2)(i)]	☐Y	☐N	☐N/A
10. Analyzed and reported in the RMP one worst-case release scenario estimated to create the greatest distance to an endpoint resulting from an accidental release of a regulated flammable substance from covered processes under worst-case conditions? [68.25(a)(2)(ii)]	☐Y	☐N	☐N/A
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RMP Program Level 3 Process Checklist	Facility Name: _____		
11. Analyzed and reported in the RMP additional worst-case release scenarios for a hazard class if the worst-case release from another covered process at the stationary source potentially affects public receptors different from those potentially affected by the worst-case release scenario developed under 68.25(a)(2)(i) or 68.25(a)(2)(ii)? [68.25(a)(2)(iii)]	☐Y	☐N	☐N/A
12. Has the owner or operator determined the worst-case release quantity to be the greater of the following: [68.25(b)] ☐ If released from a vessel, the greatest amount held in a single vessel, taking into account administrative controls that limit the maximum quantity? [68.25(b)(1)] ☐ If released from a pipe, the greatest amount held in the pipe, taking into account administrative controls that limit the maximum quantity? [68.25(b)(2)]	☐Y	☐N	☐N/A
13.a. Has the owner or operator for toxic substances that are normally gases at ambient temperature and handled as a gas or liquid under pressure:			
13.a.(1) Assumed the whole quantity in the vessel or pipe would be released as a gas over 10 minutes? [68.25(c)(1)]	☐Y	☐N	☐N/A
13.a.(2) Assumed the release rate to be the total quantity divided by 10, if there are no passive mitigation systems in place? [68.25(c)(1)]	☐Y	☐N	☐N/A
13.b. Has the owner or operator for toxic gases handled as refrigerated liquids at ambient pressure:			
13.b.(1) Assumed the substance would be released as a gas in 10 minutes, if not contained by passive mitigation systems or if the contained pool would have a depth of 1 cm or less? [68.25(c)(2)(i)]	☐Y	☐N	☐N/A
13.b.(2) [Optional for owner / operator] Assumed the quantity in the vessel or pipe would be spilled instantaneously to form a liquid pool, if the released substance would be contained by passive mitigation systems in a pool with a depth greater than 1 cm? [68.25(c)(2)(ii)]	☐Y	☐N	☐N/A
13.b.(3) Calculated the volatilization rate at the boiling point of the substance and at the conditions specified in 68.25(d)? [68.25(c)(2)(ii)]	☐Y	☐N	☐N/A
13.c. Has the owner or operator for toxic substances that are normally liquids at ambient temperature:			
13.c.(1) Assumed the quantity in the vessel or pipe would be spilled instantaneously to form a liquid pool? [68.25(d)(1)]	☐Y	☐N	☐N/A
13.c.(2) Determined the surface area of the pool by assuming that the liquid spreads to 1 cm deep, if there is no passive mitigation system in place that would serve to contain the spill and limit the surface area, or if passive mitigation is in place, was the surface area of the contained liquid used to calculate the volatilization rate? [68.25(d)(1)(i)]	☐Y	☐N	☐N/A
13.c.(3) Taken into account the actual surface characteristics, if the release would occur onto a surface that is not paved or smooth? [68.25(d)(1)(ii)]	☐Y	☐N	☐N/A
13.c.(4) Determined the volatilization rate by accounting for the highest daily maximum temperature in the past three years, the temperature of the substance in the vessel, and the concentration of the substance if the liquid spilled is a mixture or solution? [68.25(d)(2)]	☐Y	☐N	☐N/A
13.c.(5) Determined the rate of release to air from the volatilization rate of the liquid pool? [68.25(d)(3)]	☐Y	☐N	☐N/A
13.c.(6) Determined the rate of release to air by using the methodology in the RMP Offsite Consequence Analysis Guidance, any other publicly available techniques that account for the modeling conditions and are recognized by industry as applicable as part of current practices, or proprietary models that account for the modeling conditions may be used provided the owner or operator allows the implementing agency access to the model and describes model features and differences from publicly available models to local emergency planners upon request? [68.25(d)(3)] What modeling technique did the owner or operator use? [68.25(g)] _____	☐Y	☐N	☐N/A
13.d. Has the owner or operator for flammables:			
13.d.(1) Assumed the quantity in a vessel(s) of flammable gas held as a gas or liquid under pressure or refrigerated gas released to an undiked area vaporizes resulting in a vapor cloud explosion? [68.25(e)]	☐Y	☐N	☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____		
13.d.(2) For refrigerated gas released to a contained area or liquids released below their atmospheric boiling point, assumed the quantity volatilized in 10 minutes results in a vapor cloud? [68.25(f)]	☐Y	☐N	☐N/A
13.d.(3) Assumed a yield factor of 10% of the available energy is released in the explosion for determining the distance to the explosion endpoint, if the model used is based on TNT-equivalent methods? [68.25(e)]	☐Y	☐N	☐N/A
14. Used the parameters defined in 68.22 to determine distance to the endpoints? [68.25(g)]	☐Y	☐N	☐N/A
15. Determined the rate of release to air by using the methodology in the RMP Offsite Consequence Analysis Guidance, any other publicly available techniques that account for the modeling conditions and are recognized by industry as applicable as part of current practices, or proprietary models that account for the modeling conditions may be used provided the owner or operator allows the implementing agency access to the model and describes model features and differences from publicly available models to local emergency planners upon request? [68.25(g)] What modeling technique did the owner or operator use? [68.25(g)] _____	☐Y	☐N	☐N/A
16. Ensured that the passive mitigation system, if considered, is capable of withstanding the release event triggering the scenario and will still function as intended? [68.25(h)]	☐Y	☐N	☐N/A
17. Considered also the following factors in selecting the worst-case release scenarios: [68.25(i)] ☐ Smaller quantities handled at higher process temperature or pressure? [68.25(i)(1)] ☐ Proximity to the boundary of the stationary source? [68.25(i)(2)]	☐Y	☐N	☐N/A
Hazard Assessment: Alternative release scenario analysis [68.28]			
18. Identified and analyzed at least one alternative release scenario for each regulated toxic substance held in a covered process(es) and at least one alternative release scenario to represent all flammable substances held in covered processes? [68.28(a)]	☐Y	☐N	☐N/A
19. Selected a scenario: [68.28(b)] ☐ That is more likely to occur than the worst-case release scenario under 68.25? [68.28(b)(1)(i)] ☐ That will reach an endpoint off-site, unless no such scenario exists? [68.28(b)(1)(ii)]	☐Y	☐N	☐N/A
20. Considered release scenarios which included, but are not limited to, the following: [68.28(b)(2)] ☐ Transfer hose releases due to splits or sudden hose uncoupling? [68.28(b)(2)(i)] ☐ Process piping releases from failures at flanges, joints, welds, valves and valve seals, and drains or bleeds? [68.28(b)(2)(ii)] ☐ Process vessel or pump releases due to cracks, seal failure, or drain, bleed, or plug failure? [68.28(b)(2)(iii)] ☐ Vessel overfilling and spill, or overpressurization and venting through relief valves or rupture disks? [68.28(b)(2)(iv)] ☐ Shipping container mishandling and breakage or puncturing leading to a spill? [68.28(b)(2)(v)]	☐Y	☐N	☐N/A
21. Used the parameters defined in 68.22 to determine distance to the endpoints? [68.28(c)]	☐Y	☐N	☐N/A
22. Determined the rate of release to air by using the methodology in the RMP Offsite Consequence Analysis Guidance, any other publicly available techniques that account for the modeling conditions and are recognized by industry as applicable as part of current practices, or proprietary models that account for the modeling conditions may be used provided the owner or operator allows the implementing agency access to the model and describes model features and differences from publicly available models to local emergency planners upon request? [68.28(c)] What modeling technique did the owner or operator use? [68.25(g)] _____	☐Y	☐N	☐N/A
23. Ensured that the passive and active mitigation systems, if considered, are capable of withstanding the release event triggering the scenario and will be functional? [68.28(d)]	☐Y	☐N	☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____
24. Considered the following factors in selecting the alternative release scenarios: [68.28(e)] ☐ The five-year accident history provided in 68.42? [68.28(e)(1)] ☐ Failure scenarios identified under 68.50? [68.28(e)(2)]	☐Y ☐N ☐N/A
Hazard Assessment: Defining off-site impacts–Population [68.30]	
25. Estimated population that would be included in the distance to the endpoint in the RMP based on a circle with the point of release at the center? [68.30(a)]	☐Y ☐N ☐N/A
26. Identified the presence of institutions, parks and recreational areas, major commercial, office, and industrial buildings in the RMP? [68.30(b)]	☐Y ☐N ☐N/A
27. Used most recent Census data, or other updated information to estimate the population? [68.30(c)]	☐Y ☐N ☐N/A
28. Estimated the population to two significant digits? [68.30(d)]	☐Y ☐N ☐N/A
Hazard Assessment: Defining off-site impacts–Environment [68.33]	
29. Identified environmental receptors that would be included in the distance to the endpoint based on a circle with the point of release at the center? [68.33(a)]	☐Y ☐N ☐N/A
30. Relied on information provided on local U.S.G.S. maps, or on any data source containing U.S.G.S. data to identify environmental receptors? [Source may have used LandView to obtain information] [68.33(b)]	☐Y ☐N ☐N/A
Hazard Assessment: Review and update [68.36]	
31. Reviewed and updated the off-site consequence analyses at least once every five years? [68.36(a)]	☐Y ☐N ☐N/A
32. Completed a revised analysis and submit a revised RMP within six months of a change in processes, quantities stored or handled, or any other aspect that might reasonably be expected to increase or decrease the distance to the endpoint by a factor of two or more? [68.36(b)]	☐Y ☐N ☐N/A
Hazard Assessment: Documentation [68.39]	
33. For worst-case scenarios: a description of the vessel or pipeline and substance selected, assumptions and parameters used, the rationale for selection, and anticipated effect of the administrative controls and passive mitigation on the release quantity and rate? [68.39(a)]	☐Y ☐N ☐N/A
34. For alternative release scenarios: a description of the scenarios identified, assumptions and parameters used, the rationale for the selection of specific scenarios, and anticipated effect of the administrative controls and mitigation on the release quantity and rate? [68.39(b)]	☐Y ☐N ☐N/A
35. Documentation of estimated quantity released, release rate, and duration of release? [68.39(c)]	☐Y ☐N ☐N/A
36. Methodology used to determine distance to endpoints? [68.39(d)]	☐Y ☐N ☐N/A
37. Data used to estimate population and environmental receptors potentially affected? [68.39(e)]	☐Y ☐N ☐N/A
Hazard Assessment: Five-year accident history [68.42]	
38. Has the owner or operator included all accidental releases from covered processes that resulted in deaths, injuries, or significant property damage on site, or known offsite deaths, injuries, evacuations, sheltering in place, property damage, or environmental damage? [68.42(a)]	☐Y ☐N ☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____	
39. Has the owner or operator reported the following information for each accidental release: [68.42(b)] ☐ Date, time, and approximate duration of the release? [68.42(b)(1)] ☐ Chemical(s) released? [68.42(b)(2)] ☐ Estimated quantity released in pounds and percentage weight in a mixture (toxics)? [68.42(b)(3)] ☐ NAICS code for the process? [68.42(b)(4)] ☐ The type of release event and its source? [68.42(b)(5)] ☐ Weather conditions (if known)? [68.42(b)(6)] ☐ On-site impacts? [68.42(b)(7)] ☐ Known offsite impacts? [68.42(b)(8)] ☐ Initiating event and contributing factors (if known)? [68.42(b)(9)] ☐ Whether offsite responders were notified (if known)? [68.42(b)(10)] ☐ Operational or process changes that resulted from investigation of the release? [68.42(b)(11)]		☐Y ☐N ☐N/A
Section C: Prevention Program		
Prevention Program- Safety information [68.65]		
1. Has the owner or operator compiled written process safety information, which includes information pertaining to the hazards of the regulated substances used or produced by the process, information pertaining to the technology of the process, and information pertaining to the equipment in the process, before conducting any process hazard analysis required by the rule? [68.65(a)] Does the process safety information contain the following for hazards of the substances: [68.65(b)] ☐ Material Safety Data Sheets (MSDS) that meet the requirements of the OSHA Hazard Communication Standard [29 CFR 1910.1200(g)]? [68.48(a)(1)] ☐ Toxicity information? [68.65(b)(1)] ☐ Permissible exposure limits? [68.65(b)(2)] ☐ Physical data? [68.65(b)(3)] ☐ Reactivity data? [68.65(b)(4)] ☐ Corrosivity data? [68.65(b)(5)] ☐ Thermal and chemical stability data? [68.65(b)(6)] ☐ Hazardous effects of inadvertent mixing of materials that could foreseeably occur? [68.65(b)(7)]		☐Y ☐N ☐N/A
2. Has the owner documented information pertaining to technology of the process? ☐ A block flow diagram or simplified process flow diagram? [68.65(c)(1)(i)] ☐ Process chemistry? [68.65(c)(1)(ii)] ☐ Maximum intended inventory? [68.65(c)(1)(iii)] ☐ Safe upper and lower limits for such items as temperatures, pressures, flows, or compositions? [68.65(c)(1)(iv)] ☐ An evaluation of the consequences of deviation? [68.65(c)(1)(iv)]		☐Y ☐N ☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____		
3. Does the process safety information contain the following for the equipment in the process: [68.65(d)(1)] ☐ Materials of construction? 68.65(d)(1)(i)] ☐ Piping and instrumentation diagrams [68.65(d)(1)(ii)] ☐ Electrical classification? [68.65(d)(1)(iii)] ☐ Relief system design and design basis? [68.65(d)(1)(iv)] ☐ Ventilation system design? [68.65(d)(1)(v)] ☐ Design codes and standards employed? [68.65(d)(1)(vi)] ☐ Material and energy balances for processes built after June 21, 1999? [68.65(d)(1)(vii)] ☐ Safety systems? [68.65(d)(1)(viii)]	☐Y	☐N	☐N/A
4. Has the owner or operator documented that equipment complies with recognized and generally accepted good engineering practices? [68.65(d)(2)]	☐Y	☐N	☐N/A
5. Has the owner or operator determined and documented that existing equipment, designed and constructed in accordance with codes, standards, or practices that are no longer in general use, is designed, maintained, inspected, tested, and operating in a safe manner? [68.65(d)(3)]	☐Y	☐N	☐N/A
Prevention Program- Process Hazard Analysis [68.67]			
6. Has the owner or operator performed an initial process hazard analysis (PHA), and has this analysis identified, evaluated, and controlled the hazards involved in the process? [68.67(a)]	☐Y	☐N	☐N/A
7. Has the owner or operator determined and documented the priority order for conducting PHAs, and was it based on an appropriate rationale? [68.67(a)]	☐Y	☐N	☐N/A
8. Has the owner used one or more of the following technologies to conduct process PHA: [68.67(b)] ☐ What-if? [68.67(b)(1)] ☐ Checklist? [68.67(b)(2)] ☐ What-if/Checklist? [68.67(b)(3)] ☐ Hazard and Operability Study (HAZOP) [68.67(b)(4)] ☐ Failure Mode and Effects Analysis (FMEA) [68.67(b)(5)] ☐ Fault Tree Analysis? [68.67(b)(6)] ☐ An appropriate equivalent methodology? [68.67(b)(7)]	☐Y	☐N	☐N/A
9. Did the PHA address: ☐ The hazards of the process? [68.67(c)(1)] ☐ Identification of any incident that had a likely potential for catastrophic consequences? [68.67(c)(2)] ☐ Engineering and administrative controls applicable to hazards and interrelationships?[68.67(c)(3)] ☐ Consequences of failure of engineering and administrative controls? [68.67(c)(4)] ☐ Stationary source siting? [68.67(c)(5)] ☐ Human factors? [68.67(c)(6)] ☐ An evaluation of a range of the possible safety and health effects of failure of controls? [68.67(c)(7)]	☐Y	☐N	☐N/A
10. Was the PHA performed by a team with expertise in engineering and process operations and did the team include appropriate personnel? [68.67(d)]	☐Y	☐N	☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____		
11. Has the owner or operator established a system to promptly address the team's findings and recommendations; assured that the recommendations are resolved in a timely manner and documented; documented what actions are to be taken; completed actions as soon as possible; developed a written schedule of when these actions are to be completed; and communicated the actions to operating, maintenance, and other employees whose work assignments are in the process and who may be affected by the recommendations? [68.67(e)]	☐Y	☐N	☐N/A
12. Has the PHA been updated and revalidated by a team every five years after the completion of the initial PHA to assure that the PHA is consistent with the current process? [68.67(f)]	☐Y	☐N	☐N/A
13. Has the owner or operator retained PHAs and updates or revalidations for each process covered, as well as the resolution of recommendations for the life of the process? [68.67(g)]	☐Y	☐N	☐N/A
Prevention Program- Operating procedures [68.69]			
14. Has the owner or operator developed and implemented written operating procedures that provide instructions or steps for conducting activities associated with each covered process consistent with the safety information? [68.69(a)]	☐Y	☐N	☐N/A
15 Do the procedures address the following: [68.69(a)] Steps for each operating phase: [68.69(a)(1)] ☐ Initial Startup? [68.69(a)(1)(i)] ☐ Normal operations? [68.69(a)(1)(ii)] ☐ Temporary operations? [68.69((a)(1)(iii)] ☐ Emergency shutdown including the conditions under which emergency shutdown is required, and the assignment of shutdown responsibility to qualified operators to ensure that emergency shutdown is executed in a safe and timely manner? [68.69(a)(1)(iv)] ☐ Emergency operations? [68.69(a)(1)(v)] ☐ Normal shutdown? [68.68(a)(1)(vi)] ☐ Startup following a turnaround, or after emergency shutdown? [68.69(a)(1)(vii)] Operating limits: [68.69(a)(2)] ☐ Consequences of deviations [68.69(a)(2)(i)] ☐ Steps required to correct or avoid deviation? [68.69(a)(2)(ii)] Safety and health considerations: [68.69(a)(3)] ☐ Properties of, and physical hazards presented by, the chemicals used in the process [68.69(a)(3)(i)] ☐ Precautions necessary to prevent exposure, including engineering controls, administrative controls, and personal protective equipment? [68.69(a)(3)(ii)] ☐ Control measures to be taken if physical contact or airborne exposure occurs? [68.69(a)(3)(iii)] ☐ Quality control for raw materials and control of hazardous chemical inventory levels? [68.69(a)(3)(iv)] ☐ Any special or unique hazards? [68.69(a)(3)(v)] ☐ Safety systems and their functions? [68.69(a)(4)]	☐Y	☐N	☐N/A
16. Are operating procedures readily accessible to employees who are involved in a process? [68.69(b)]	☐Y	☐N	☐N/A
17. Has the owner or operator certified annually that the operating procedures are current and accurate and that procedures have been reviewed as often as necessary? [68.69(c)]	☐Y	☐N	☐N/A
18. Has the owner or operator developed and implemented safe work practices to provide for the control of hazards during specific operations, such as lockout/tagout? [68.69(d)]	☐Y	☐N	☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____		
Prevention Program - Training [68.71]			
19 Has each employee involved in operating a process, and each employee before being involved in operating a newly assigned process, been initially trained in an overview of the process and in the operating procedures? [68.71(a)(1)]	☐Y	☐N	☐N/A
20. Did initial training include emphasis on safety and health hazards, emergency operations including shutdown, and safe work practices applicable to the employee's job tasks? [68.71(a)(1)]	☐Y	☐N	☐N/A
21. In lieu of initial training for those employees already involved in operating a process on June 21, 1999, an owner or operator may certify in writing that the employee has the required knowledge, skills, and abilities to safely carry out the duties and responsibilities as specified in the operating procedures [68.71(a)(2)]	☐Y	☐N	☐N/A
22. Has refresher training been provided at least every three years, or more often if necessary, to each employee involved in operating a process to assure that the employee understands and adheres to the current operating procedures of the process? [68.71(b)]	☐Y	☐N	☐N/A
23, Has owner or operator ascertained and documented in record that each employee involved in operating a process has received and understood the training required? [68.71(c)]	☐Y	☐N	☐N/A
24. Does the prepared record contain the identity of the employee, the date of the training, and the means used to verify that the employee understood the training? [68.71(c)]	☐Y	☐N	☐N/A
Prevention Program - Mechanical Integrity [68.73]			
25. Has the owner or operator established and implemented written procedures to maintain the on-going integrity of the process equipment listed in 68.73(a)? [68.73(b)]	☐Y	☐N	☐N/A
26. Has the owner or operator trained each employee involved in maintaining the on-going integrity of process equipment? [68.73(c)]	☐Y	☐N	☐N/A
27. Performed inspections and tests on process equipment? [68.73(d)(1)]	☐Y	☐N	☐N/A
28. Followed recognized and generally accepted good engineering practices for inspections and testing procedures? [68.73(d)(2)]	☐Y	☐N	☐N/A
29. Ensured the frequency of inspections and tests of process equipment is consistent with applicable manufacturers' recommendations, good engineering practices, and prior operating experience? [68.73(d)(3)]	☐Y	☐N	☐N/A
30. Documented each inspection and test that had been performed on process equipment, which identifies the date of the inspection or test, the name of the person who performed the inspection or test, the serial number or other identifier of the equipment on which the inspection or test was performed, a description of the inspection or test performed, and the results of the inspection or test? [68.73(d)(4)]	☐Y	☐N	☐N/A
31. Corrected deficiencies in equipment that were outside acceptable limits defined by the process safety information before further use or in a safe and timely manner when necessary means were taken to assure safe operation? [68.73(e)]	☐Y	☐N	☐N/A
32. Assured that equipment as it was fabricated is suitable for the process application for which it will be used in the construction of new plants and equipment? [68.73(f)(1)]	☐Y	☐N	☐N/A
33. Performed appropriate checks and inspections to assure that equipment was installed properly and consistent with design specifications and the manufacturer's instructions? [68.73(f)(2)]	☐Y	☐N	☐N/A
34. Assured that maintenance materials, spare parts and equipment were suitable for the process application for which they would be used? [68.73(f)(3)]	☐Y	☐N	☐N/A
Prevention Program - Management Of Change [68.75]			
35. Has the owner or operator established and implemented written procedures to manage changes to process chemicals, technology, equipment, and procedures, and changes to stationary sources that affect a covered process? [68.75(a)]	☐Y	☐N	☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____		
36. Do procedures assure that the following considerations are addressed prior to any change: [68.75(b)] ☐ The technical basis for the proposed change? [68.75(b)(1)] ☐ Impact of change on safety and health? [68.75(b)(2)] ☐ Modifications to operating procedures? [68.75(b)(3)] ☐ Necessary time period for the change? [68.75(b)(4)] ☐ Authorization requirements for the proposed change? [68.75(b)(5)]	☐Y	☐N	☐N/A
37. Were employees, involved in operating a process and maintenance, and contract employees, whose job tasks would be affected by a change in the process, informed of, and trained in, the change prior to start-up of the process or affected parts of the process? [68.75(c)]	☐Y	☐N	☐N/A
38. If a change resulted in a change in the process safety information, was such information updated accordingly? [68.75(d)]	☐Y	☐N	☐N/A
39. If a change resulted in a change in the operating procedures or practices, had such procedures or practices been updated accordingly? [68.75(e)]	☐Y	☐N	☐N/A
Prevention Program - Pre-startup Safety Review [68.77]			
40. If the facility installed a new stationary source, or significantly modified an existing source, (as discussed at 68.77(a)) did it perform a pre-startup safety review prior to the introduction of a regulated substance to a process to confirm: [68.77(b)] ☐ Construction and equipment was in accordance with design specifications? [68.77(b)(1)] ☐ Safety, operating, maintenance, and emergency procedures were in place and were adequate? [68.77(b)(2)] ☐ For new stationary sources, a process hazard analysis had been performed and recommendations had been resolved or implemented before startup? [68.77(b)(3)] ☐ Modified stationary sources meet the requirements contained in management of change? [68.77(b)(3)] ☐ Training of each employee involved in operating a process had been completed? [68.77(b)(4)]	☐Y	☐N	☐N/A
Prevention Program - Compliance audits [68.79]			
41. Has the owner or operator certified that the stationary source has evaluated compliance with the provisions of the prevention program at least every three years to verify that the developed procedures and practices are adequate and being followed? [68.79(a)]	☐Y	☐N	☐N/A
42. Has the audit been conducted by at least one person knowledgeable in the process? [68.79(b)]	☐Y	☐N	☐N/A
43. Are the audit findings documented in a report? [68.79(c)]	☐Y	☐N	☐N/A
44. Has the owner or operator promptly determined and documented an appropriate response to each of the findings of the audit and documented that deficiencies had been corrected? [68.79(d)]	☐Y	☐N	☐N/A
45. Has the owner or operator retained the two most recent compliance reports? [68.79(e)]	☐Y	☐N	☐N/A
Prevention Program - Incident investigation [68.81]			
46. Has the owner or operator investigated each incident that resulted in, or could reasonably have resulted in a catastrophic release of a regulated substance? [68.81(a)]	☐Y	☐N	☐N/A
47. Were all incident investigations initiated not later than 48 hours following the incident? [68.81(b)]	☐Y	☐N	☐N/A
48. Was an accident investigation team established and did it consist of at least one person knowledgeable in the process involved, including a contract employee if the incident involved work of a contractor, and other persons with appropriate knowledge and experience to thoroughly investigate and analyze the incident? [68.81(c)]	☐Y	☐N	☐N/A

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RMP Program Level 3 Process Checklist	Facility Name: _____		
49. Was a report prepared at the conclusion of every investigation? [68.81(d)]	☐Y	☐N	☐N/A
50. Does every report include: [68.81(d)] ☐ Date of incident? [68.81(d)(1)] ☐ Date investigation began? [68.81(d)(2)] ☐ A description of the incident? [68.81(d)(3)] ☐ The factors that contributed to the incident? [68.81(d)(4)] ☐ Any recommendations resulting from the investigation? [68.81(d)(5)]	☐Y	☐N	☐N/A
51. Has the owner or operator established a system to address and resolve the report findings and recommendations, and are the resolutions and corrective actions documented? [68.81(e)]	☐Y	☐N	☐N/A
52. Was the report reviewed with all affected personnel whose job tasks are relevant to the incident findings including contract employees where applicable? [68.81(f)]	☐Y	☐N	☐N/A
53. Has the owner or operator retained incident investigation reports for at least five years? [68.81(g)]	☐Y	☐N	☐N/A
Section D - Employee Participation [68.83]			
1. Has the owner or operator developed a written plan of action regarding the implementation of the employee participation required by this section? [68.83(a)]	☐Y	☐N	☐N/A
2. Has the owner or operator consulted with employees and their representatives on the conduct and development of process hazards analyses and on the development of the other elements of process safety management in chemical accident prevention provisions? [68.83(b)]	☐Y	☐N	☐N/A
3. Has the owner or operator provided to employees and their representatives access to process hazards analyses and to all other information required to be developed under the chemical accident prevention rule? [68.83(c)]	☐Y	☐N	☐N/A
Section E - Hot Work Permit [68.85]			
1. Has the owner or operator issued a hot work permit for each hot work operation conducted on or near a covered process? [68.85(a)]	☐Y	☐N	☐N/A
2. Does the permit document that the fire prevention and protection requirements in 29CFR 1910.252(a) have been implemented prior to beginning the hot work operations? [68.85(b)]	☐Y	☐N	☐N/A
3. Does the permit indicate the date(s) authorized for hot work and the object(s) upon which hot work is to be performed? [68.85(b]	☐Y	☐N	☐N/A
4. Are the permits being kept on file until completion of the hot work operations? [68.85(b)]	☐Y	☐N	☐N/A
Section F - Contractors [68.87]			
1. Has the owner or operator obtained and evaluated information regarding the contract owner or operator's safety performance and programs when selecting a contractor? [68.87(b)(1)]	☐Y	☐N	☐N/A
2. Informed contract owner or operator of the known potential fire, explosion, or toxic release hazards related to the contractor's work and the process? [68.87(b)(2)]	☐Y	☐N	☐N/A
3. Explained to the contract owner or operator the applicable provisions of the emergency response or the emergency action program? [68.87(b)(3)]	☐Y	☐N	☐N/A
4. Developed and implemented safe work practices consistent with §68.69(d), to control the entrance, presence, and exit of the contract owner or operator and contract employees in the covered process areas? [68.87(b)(4)]	☐Y	☐N	☐N/A

RMP Program Level 3 Process Checklist	Facility Name: _____		
5. Periodically evaluted the performance of the contract owner or operator in fulfilling their obligations (as described at 68.87(c)(1) - (c)(5))? [68.87(b)(5)]	☐Y	☐N	☐N/A
Section G - Emergency Response [68.90 - 68.95]			
1. Is the facility designated as a "first responder" in case of an accidental release of regulated substances"	☐Y	☐N	☐N/A
1.a. If the facility is not a first responder:			
1.a.(1) For stationary sources with any regulated substances held in a process above threshold quantities, is the source included in the community emergency response plan developed under 42 U.S.C. 11003? [68.90(b)(1)]	☐Y	☐N	☐N/A
1.a.(2) For stationary sources with only regulated flammable substances held in a process above threshold quantities, has the owner or operator coordinated response actions with the local fire department? [68.90(b)(2)]	☐Y	☐N	☐N/A
1.a.(3) Are appropriate mechanisms in place to notify emergency responders when there is need for a response? [68.90(b)(3)]	☐Y	☐N	☐N/A
2. An emergency response plan is maintained at the stationary source and contains the following? [68.95(a)(1)] ☐ Procedures for informing the public and local emergency response agencies about accidental releases? [68.95(a)(1)(i)] ☐ Documentation of proper first-aid and emergency medical treatment necessary to treat accidental human exposures? [68.95(a)(1)(ii)] ☐ Procedures and measures for emergency response after an accidental release of a regulated substance? [68.95(a)(1)(iii)]	☐Y	☐N	☐N/A
3. The emergency response plan contains procedures for the use of emergency response equipment and for its inspection, testing, and maintenance? [68.95(a)(2)]	☐Y	☐N	☐N/A
4. The emergency response plan requires, and there is documentation of, training for all employees in relevant procedures? [68.95(a)(3)]	☐Y	☐N	☐N/A
5. The owner or operator has developed and implemented procedures to review and update, as appropriate, the emergency response plan to reflect changes at the stationary source and ensure that employees are informed of changes? [68.95(a)(4)]	☐Y	☐N	☐N/A
6. Did the owner or operator use a written plan that complies with other Federal contingency plan regulations or is consistent with the approach in the National Response Team's Integrated Contingency Plan Guidance (''One Plan'')? If so, does the plan include the elements provided in paragraph (a) of 68.95, and also complies with paragraph (c) of 68.95? [68.95(b)]	☐Y	☐N	☐N/A
7. Has the emergency response plan been coordinated with the community emergency response plan developed under EPCRA? [68.95(c)]	☐Y	☐N	☐N/A
Section H – Risk Management Plan [40 CFR 68.190 – 68.195]			
1. Does the single registration form include, for each covered process, the name and CAS number of each regulated substance held above the threshold quantity in the process, the maximum quantity of each regulated substance or mixture in the process (in pounds) to two significant digits, the five- or six-digit NAICS code that most closely corresponds to the process and the Program level of the process? [68.160(b)(7)]	☐Y	☐N	☐N/A
2. Did the facility assign the correct program level(s) to its covered process(es)? [68.160(b)(7)]	☐Y	☐N	☐N/A

RMP Program Level 3 Process Checklist	**Facility Name:** _____		
3. Has the owner or operator reviewed and updated the RMP and submitted it to EPA [68.190(a)]? Reason for update: ☐ Five-year update. [68.190(b)(1)] ☐ Within three years of a newly regulated substance listing. [68.190(b)(2)] ☐ At the time a new regulated substance is first present in an already regulated process above threshold quantities. [68.190(b)(3)] ☐ At the time a regulated substance is first present in a new process above threshold quantities. [68.190(b)(4)] ☐ Within six months of a change requiring revised PHA or hazard review. [68.190(b)(5)] ☐ Within six months of a change requiring a revised OCA as provided in 68.36. [68.190(b)(6)] ☐ Within six months of a change that alters the Program level that applies to any covered process. [68.190(b)(7)]	☐Y	☐N	☐N/A
4. If the owner or operator experienced an accidental release that met the five-year accident history reporting criteria (as described at 68.42) subsequent to April 9, 2004, did the owner or operator submit the information required at 68.168, 68.170(j) and 68.175(l) within six months of the release or by the time the RMP was updated as required at 68.190, whichever was earlier. [68.195(a)]	☐Y	☐N	☐N/A
5. If the emergency contact information required at 68.160(b)(6) has changed since June 21, 2004, did the owner or operator submit corrected information within thirty days of the change? [68.195(b)]	☐Y	☐N	☐N/A

Rev 04/14/2005

7.5 Bibliography and Recommended Reading

Ammonia Data Book: the Profile of a Sustainable Refrigerant.

2nd edition. Arlington, VA: IIAR, 2008. Print.

ANSI/ASHRAE Standard 15. *Safety Standard for Refrigeration Systems*. 2010. ASHRAE. 1791 Tullie Circle, N.E., Atlanta, GA.

> **The stated purpose of Standard 15 is to specify the** safe design, construction, installation, and operation of refrigeration systems. Standard 15 articulates the required "safeguards for life, limb, health, and property and prescribes safety requirements" by means of the (a.) "design, construction, test, installation, operation, and inspection of mechanical and absorption refrigeration systems including heat pump systems used in stationary applications," (b) "modifications including replacement of parts or components if they are not identical in function and capacity," and, (c.) "substitutions of refrigerant having a different number designation."

ANSI/ASHRAE Standard 34-2010 -- Designation and Classification of Refrigerants 2010

ASHRAE. 2009. *ASHRAE Handbook of Fundaments. I-P Edition*. ASHRAE. 1791 Tullie Circle, N.E., Atlanta, GA.

> The theory associated with refrigeration cycles, fluid flow, heat transfer, mass transfer, and psychrometrics are presented along with useful tables of data. Refrigerants are reviewed and their thermophysical properties are given. Secondary coolants and their thermophysical properties are provided.

ASHRAE. 2010. *ASHRAE Handbook of Refrigeration. I-P Edition*. ASHRAE. 1791 Tullie Circle, N.E., Atlanta, GA.

> Reference material for the design and operation of refrigeration systems consisting of: refrigeration system practices, food storage and equipment, food refrigeration, and distribution of chilled and frozen food. The heat gains that contribute to the refrigeration load for a facility are presented. Industrial refrigeration applications in addition to food and low-temperature applications are also presented.

ASHRAE. 2011. *ASHRAE Handbook of HVAC Applications. I-P Edition*. ASHRAE. 1791 Tullie Circle, N.E., Atlanta, GA.

> This ASHRAE guide, while focusing on human comfort applications, also presents useful information on building operations and management along with selected building applications such as fire and smoke management.

ASHRAE. 2012. *ASHRAE Handbook of Systems and Equipment. I-P Edition*. ASHRAE. 1791 Tullie Circle, N.E., Atlanta, GA.

The general components section of this ASHRAE guide includes: compressors, condensers, cooling towers, liquid coolers, liquid-chilling systems, centrifugal pumps, motors, motor controls, variable speed drives, pipes, tubes, fittings, valves, heat exchangers, and air-to-air energy recovery, and air-handling equipment.

ASME. 2010. *ASME International Boiler and Pressure Vessel Code – 2010 Edition*. American Society of Mechanical Engineers (ASME). Three Park Avenue, New York, NY.

This important code rules for designing, constructing, and inspecting boilers and pressure vessels ensuring safe operation and mechanical integrity.

Bonar II, Henry B. "1.4.3 Ammonia Refrigeration." *Successful Refrigerated Warehousing*. 12th ed. Alexandria, VA: World Food Logistics Organization, 2011. 60-71. Print.

Cascade Energy Engineering, Inc. 2007. Industrial Refrigeration Best Practices Guide. Cascade Energy Engineering, Inc. 6 ½ N. Second Ave. Suite 310, Walla Walla, WA.

Suggested approaches, methods, and procedures to improve the energy efficiency of industrial refrigeration systems. Specific topics addressed are: electrical energy efficiency, system considerations, life-cycle costing, no energy benefits such as labor costs, and energy management.

Cleland, A. E. 1990. Food Refrigeration Processes Analysis, Design and Simulation. Elsevier Applied Science, London. UNITED KINGDOM.

This text begins with simulations of food product cooling and freezing, thawing, dynamic behavior of industrial refrigeration systems, and simulation of refrigeration components and complete systems.

Fenton, D. L. 2011. Fundamentals of Refrigeration, 2nd Edition. ASHRAE. 1791 Tullie Circle, N.E., Atlanta, GA.

This is a self-study text available from ASHRAE presenting the subject of refrigeration, including industrial refrigeration, to newcomers. The reader of this text is assumed to have some technical background, but not necessarily in refrigeration. Homework problems are available at the end of each chapter the solutions of which may be requested from ASHRAE after students submit their own solutions.

Fenton, D. L. and W. V. Richards. 2003. "User's Manual for *ANSI ASHRAE Standard 15-2001 Safety Standard for Refrigeration Systems*." ASHRAE. 1791 Tullie Circle, N.E., Atlanta, GA.

A guide written to assist designers of refrigeration systems for compliance to ANSI/ASHRAE Standard 15. While some updates to Standard 15 have been incorporated since the 2001 edition, much of the information is current with the present Standard 15.

Gooseff, A, Horton, J. 2008, Ammonia as The Suitable Refrigerant: An Ammonia-Halocarbon Comparison, Technical Papers, 2008 IIAR Conference and Exposition, Colorado Springs, Colorado, USA

Hardenburg, R. E., A. E. Watada, and C. Y. Wang. 1990. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. Agriculture Handbook 60. United States of Agriculture, Agriculture Research Service, Government Printing Office, Washington, DC.

A general practice reference giving storage requirements for fresh fruits, vegetables, cut flowers, and other horticultural crops. Product quality, relative humidity, respiration rates, and some refrigeration information are discussed.

IARW-WFLO. 2010. WFLO Commodity Storage Manual. World Food Logistics Organization (WFLO). International Headquarters. Alexandria, VA.

An important resource for the handling and storage requirements for perishable food products and other items.

IIAR. (Fenton, D. L.). 2006. Ammonia Data Book, 2nd Edition. International Institute of Ammonia Refrigeration (IIAR). Alexandria, VA.

A review of the applications, production, thermophysical properties, toxicity, and regulations that is pertinent to ammonia as a refrigerant.

IIAR. 2012. "Ammonia Refrigeration Library." International Institute of Ammonia Refrigeration (IIAR), Alexandria, VA.

A collection of the IIAR technical bulletins, ANSI/IIAR Standard 1 *Definitions and Terminology* and ANSI/IIAR Standard 2 *Equipment, Design and Installation of Closed-Circuit Ammonia Mechanical Refrigerating Systems*.

IIAR. 2012. Ammonia Refrigeration Piping Handbook. International Institute of Ammonia Refrigeration (IIAR), Alexandria, VA.

This manual focuses on ammonia industrial refrigeration systems beginning with information for sizing of pipes and then proceeds to pipe installation, evaporator piping, condenser piping, machinery room piping, pressure and relief valve sizing, welding procedures, and insulation of refrigeration systems. Also covered are applicable codes and standards.

IIAR. 2010. The Carbon Dioxide Industrial Refrigeration Handbook. International Institute of Ammonia Refrigeration (IIAR). Alexandria, VA.

A design manual only considering the use of CO2 for industrial refrigeration applications where the thermophysical properties of CO2, system design configurations and details, system safety, pipe sizing, heat exchangers, compressors, lubricants, evaporators, and defrost methods are presented.

Industrial Refrigeration. Rev. ed. Glenview, IL: Refrigerating Engineers and Technicians Association, 2003. Print.

International Institute of Refrigeration (IIR) Cold Store Guide 1993. International Institute of Refrigeration, 177 Boulevard Malesherbes – 75017, Paris. FRANCE.

The planning, design, insulation, operation, and safety of refrigerated warehouses are presented in this text originating from Western Europe.

Kader, A. A. (Technical Editor). 1992. Post Harvest Technology of Horticultural Crops. Publication 3311. University of California - Davis, Division of Agriculture and Natural Resources, Oakland, CA.

A review of the postharvest technologies appropriate for fresh fruits, vegetables, and ornamentals. Postharvest handling systems are also covered.

King, Guy R. *Basic Refrigeration: Principles, Practice, Operation: a Simplified Presentation of the Fundamentals of Refrigeration*. 3rd ed. Troy, Mich., USA: Business News Pub. Co. 1986. Print.

Koelet, P. C. 1992. Industrial Refrigeration Principles, Design and Applications. Marcel Dekker, Inc., New York, NY.

Introduction to industrial refrigeration as it is applied in Western Europe including: thermodynamics, refrigeration system components, load calculations, and plant maintenance among several other items.

Reindl, D.T., Jekel, T.B. August 2009 Defrosting Industrial Refrigeration Evaporators, ASHRAE Journal

RSES Basic Refrigeration. Des Plaines, IL: Refrigeration Service Engineers Society, 1990. Print.

Stoecker, W. F. 1998. Industrial Refrigeration Handbook. McGraw-Hill Companies, Inc., New York, NY.

This book covers all aspects of industrial refrigeration beginning with the basic vapor- compression cycle. It discusses all the major components of a refrigeration system, refrigerants, safety, codes, energy conservation, refrigeration loads,

lubrication, and controls among other topics. This book is the best comprehensive treatment on industrial refrigeration.

Stoecker, W. F. *Industrial Refrigeration Volume II*. Troy, Mich.: Business News Pub. Co, 1995. Print.

Vallort, Ronald P. "1.8.1 Facility Design and Construction." *Successful Refrigerated Warehousing*. 12th ed. Alexandria, VA: World Food Logistics Organization, 2011. 111-122. Print.

Vallort, Ronald P. "1.8.2 The Contractor's Perspective." *Successful Refrigerated Warehousing*. 12th ed. Alexandria, VA: World Food Logistics Organization, 2011. 123-127. Print.

Chapter 8: Doors

Acknowledgements

Chuck Zimmermann, Vice President, Enviro Doors, An ASI Technologies Company, and John T. Williams, President/CEO Jamison Door Company

Figure 8.5 courtesy of Jamison; all other Figures courtesy of ASI Technologies

8.1 Design

In today's world of high paced refrigerated warehousing and rising energy costs, it has never been more important to insure proper door selection. Critical factors are often overlooked when designing a cold storage facility. Yet, studies have shown that improper door selection can result in higher energy costs, higher maintenance costs, lower productivity, wasted man-hours and lower usable door life. Efficient facility operation depends on controlling all of these factors. This report will primarily focus on properly selecting doors to achieve energy conservation and material handling efficiency in a cold storage facility.

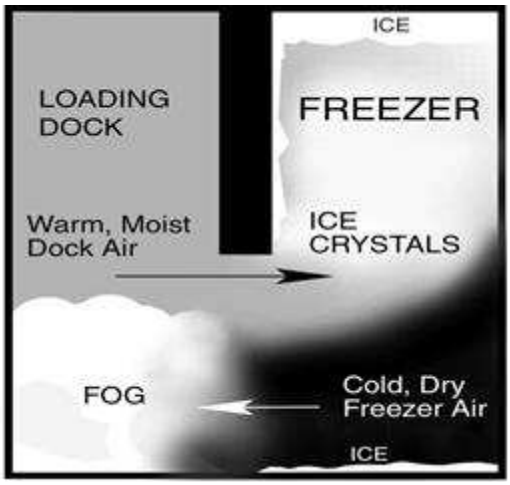
Energy conservation in a cold storage facility starts with heat ...the intrusion of unwanted heat into the cold storage area. This heat can be transferred three different ways: convection, conduction and infiltration. If these forces are not adequately controlled, they can cost facilities tens of thousands of dollars in annual energy costs and lost man-hours. This article will examine how these factors can result in excess but avoidable costs, and how the right door selections can enhance the overall efficiency of a cold storage warehouse.

8.1.1 The Cost of Operations

Convection

In a refrigerated warehouse, product is moved in and out of cold storage space...hundreds...even thousands of times a day. And with each opening of a door, two air streams are set in motion at the doorway...cold, dry air escapes from the cold storage area along the floor into the dock area...and warm, moist air from the dock area enters the cold storage area through the upper part of the door opening (Figure 8.1). This effect is referred to as convection (mass air flooding), where heat transfer is accompanied by a transfer of air molecules from one area to another. Convection costs can amount to 85% of the energy loss associated with door openings.

Figure 8. 1 Laminar Flow



The warm air stream enters and mixes with the cold air just inside and above the doorway to create ice crystals on the walls, ceiling and the door itself (Figure 8.2). Conversely, cold air streams out of the door along the floor, mixing with the warm, moist dock air, to form fog and even ice and snow on the floor in front of the door.

Figure 8. 2 Ice Build-up



How fast this frost builds up depends largely upon the frequency and duration of door openings. With each opening of the door, more moisture enters the cold storage room and the frost/ice layer grows, acting as an insulator on the walls and evaporator coils.

As a result, system efficiency degrades, ultimately causing the refrigeration unit to become ineffective or inoperative. With decreased system efficiency through frost build

up, the warm air entering the cold storage room requires the refrigeration system to run longer and use more energy to compensate.

As the frost buildup becomes significant, the refrigeration process must be suspended and the system must be defrosted by applying heat or manually chopping off the ice. This process consumes energy for melting ice, refrigerating the additional air, and any required man-hours.

Fortunately, the full effect of this air exchange does not occur immediately when the door is opened. The rush of the door opening, traffic going through the door, and differential pressures - along with other conditions - will initially disrupt the course of the air flow, causing the warm and cold air streams to mix only a little at the doorway. The air streams typically will begin and sustain a steady intermixing flow pattern referred to as ***laminar flow*** between 10 to 15 seconds of the door being opened.

Preventing or minimizing the ability of the air streams to reach ***laminar flow*** requires reducing the open-door time. Basic powered doors give you a better chance of minimizing infiltration by reducing open door time but high speed doors offer the greatest reduction of open time.

Conduction

In addition to the costs associated with open doorways, the transfer of heat or cold through a door can also be a substantial operational cost to a facility. **Conduction** losses occur when heat is transmitted through one medium to another of different density, such as heat transmission through a closed door. Solid panel insulated doors have been the traditional choice to handle conduction problems…typically coolers and freezers where there is a large temperature differential. These applications tend to be door openings which are cycled less and tend to spend substantial periods of time in the closed position. In these applications insulation value becomes a paramount issue to stop the transfer of heat and cold. Inadequate insulation value can contribute significantly to not only the cost of operations but to the amount of frost, ice and moisture build up on the door and floor surfaces. Low insulation values can create slippery floor conditions due to condensation formation and safety hazards. Conduction related problems can also necessity the use of peripheral heated blowers or infrared heat lamps which can add up to substantial energy costs.

Infiltration

Air passage created by an inability to provide tight seals around door surfaces can be the cause of substantial refrigeration loss and heat gain. The air creeping in through damaged or missing gaskets, through cracks in strip curtains, or under door panels is a constant daily operational cost. This is a common problem on doors in which the seals are not in good working condition or the sealing surface for the door is not level.

Aside from energy loss, the infiltrated moisture will also turn the doorway into a hazard area. The frost becomes ice on the floor and fog around the threshold, making unsafe, slippery conditions and poor visibility for personnel. Material handling suffers as the driver slows down in response to the hazardous conditions. Scraping away frost from

floors, walls, product, racks and other areas of the cold storage room also means higher maintenance costs.

Defrosting

Let's examine another hidden cost of heat intrusion...removing the ice buildup. In addition to the energy cost connected with the ice buildup on the walls and evaporator coils, there is the cost of defrosting. Theoretically, defrosting using heat would require about 50 to 100% of the energy used to make the frost in the first place. If manual ice chipping is used, then the cost of labor should also be considered.

8.1.2 The Impact of Closing the Door in Dollars & Cents

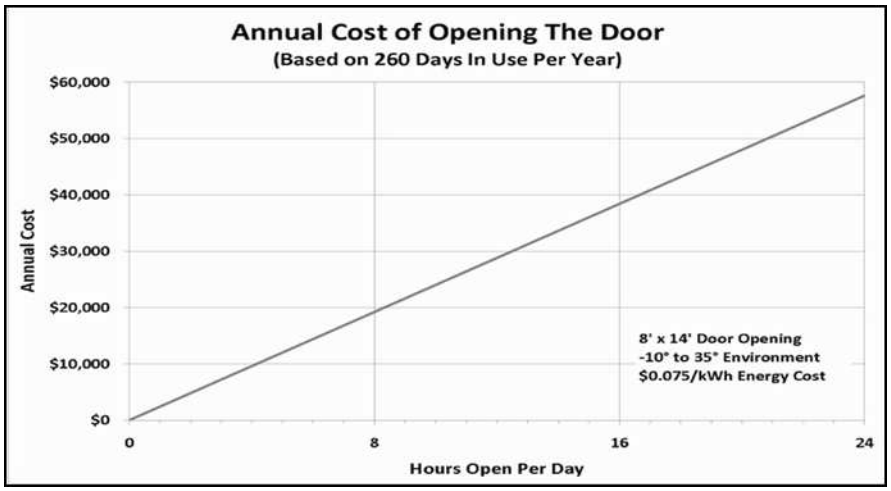
Take a look at the impact of closing a doorway on the energy costs for a typical 8' by 14' freezer opening. For this example, we will use a freezer where the inside temperature is kept at -10°F, and the dock temperature is 35°F. Figuring an average of 40 trips are made through the doorway each hour during an eight-hour shift for this two shift operation. Let's compare the costs of the following three scenarios with electricity at an average total cost of $.075/kwh (which includes power and facility charges).

The Wide-Open Door

In our first situation, the door is left open at all times by personnel who do not want to stop the flow of traffic. Using calculations presented by ASHRAE in the *Handbook of Fundamentals*, we find that refrigeration requirements for this cold storage room have increased at a rate of 35 tons of refrigeration/hr.

The open door in this example will cost the warehouse $9.23 per hour, $73.86 per shift and $38,408 a year (260 days) in electricity. As ***Figure 8.3*** shows, if the operation has three shifts, this cost can skyrocket to over $57,000/year. Of course, the amount of open door time will vary in an actual cold storage facility.

Figure 8. 3 Wide Open Doorway



A Slow Powered Door

Opening and closing the door with each trip will reduce this cost, with differences in door speed yielding different results. Many powered single-slide insulated panel doors operate at a speed of 12"/sec. With an open-door time of 34 seconds, energy costs are reduced to $3.49 per hour, $27.90 a shift and $14,510 per year (two shifts).

This type of door is often too slow for a ***busy*** warehouse. Simply waiting for the door to open will consume five minutes out of every hour of forklift driver time. Impatient with the slow door speed, warehouse personnel will often tend to leave the door open.

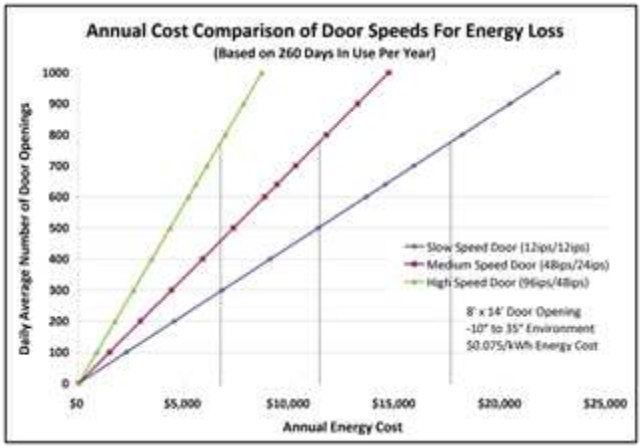
When the slow powered door is opened, and closed, it will tend to get hit by forklifts more often, causing door downtime (and more open door time). The combination of open door time and downtime may result in greatly reduced expected savings.

The High Speed Powered Door

A high speed powered door, operating at 96"/sec., will reduce the open-door time by almost 21 seconds over the slow powered door. Annual cost for operating the faster door of $5,548 is $8,962 less than the slower door - and $32,860 below the cost of the wide-open door.

Users have found that with high speed doors, forklift crews are less likely to leave the door open and will be more likely to close the door every time they go through it. For a comparison of the annual door costs based upon daily usage for doors operating at various operating speeds, refer to ***Figure 8.4***.

Figure 8. 4 Comparison of Annual Costs



8.1.3 Why Doors Stay Open

Surprisingly, most of the problems resulting from convection losses are known in one form or another to warehouse forklift drivers...yet doors still remain open for long periods of time. Although the open doors are often chalked up to inattentive driving or an intentional dislike of the door, the reasons why doors are not closed may be more complex, including:

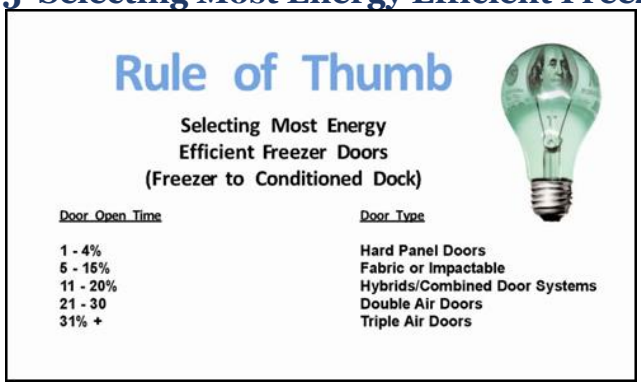
- **Rush Hour** - the pace at the dock is hectic, as soon as one truck is unloaded and gone, another pulls up to the dock. The choice comes down between falling behind schedule or the perceived loss of a little refrigeration through an open door.
- **False Activations** - drivers moving perpendicular to the door openings set off numerous false activations adding substantially to the amount of open door time.
- Lack of Automation - doors within the facility are manually controlled by pull cords or push buttons allowing doors to stay open frequently.
- **Door Downtime** - the door does not operate or seal correctly, because of forklift collision damage or poor maintenance. For the operation to go on, the door has to be left open.
- **After Hours** - with management personnel off site, drivers are less mindful about closing the door. Many times, door collisions occur during these times of lower supervision.

Rules and regulations can temporarily make drivers aware of the need to close doors. Intense supervision works for a while, but in time the drivers rationalize, "I'll leave the door open just this one time." Quickly, these exceptions become the rule.

The best long-term solution is to select the right type of door and activation based on the number of cycles an application is going to experience. Generally speaking, peak traffic of 30 trips or more through a doorway per hour calls for a high-speed door - operating at a minimum of 50"/sec. - with automatic actuators such as uni-directional motion detectors or a combination of a loop detector and time delay close. The goal is to automate the door so that the drivers can concentrate on their work.

Overall…faster door speed means less time spent waiting for the door to open. Although the time reduction amounts to just seconds per door passage…the accumulated amount of time over a year can add up to man-weeks - time that could be better spent on other tasks (***Figure 8.5***)

Figure 8. 5 Selecting Most Energy Efficient Freezer Doors

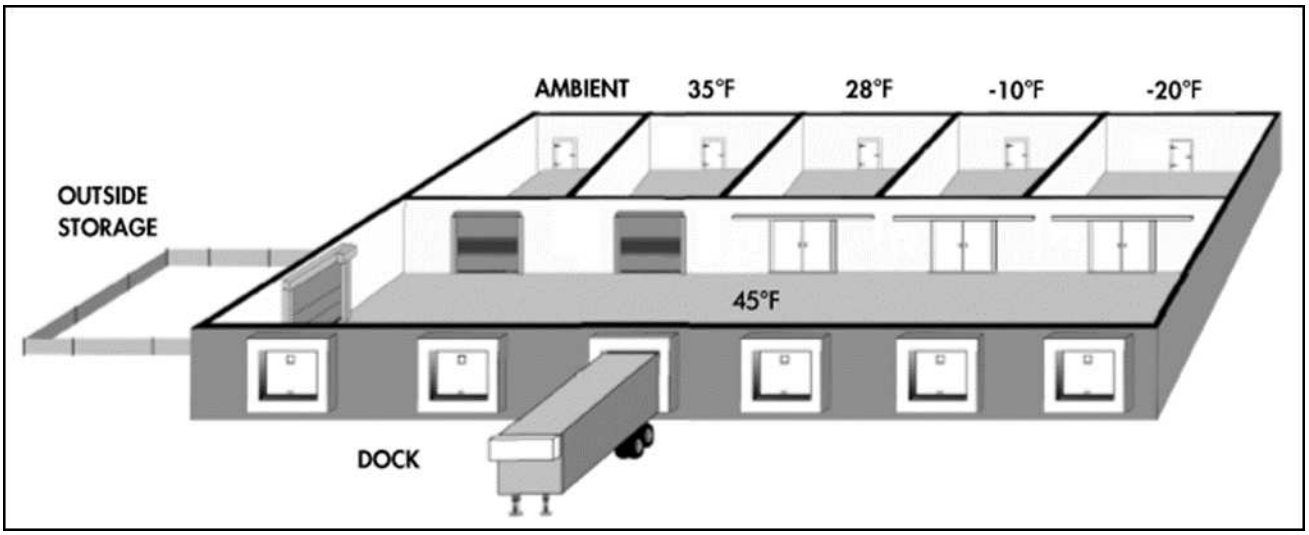


Furthermore, in most of these situations, we see drivers in a hurry. These are the times when doors get hit. Faster door speed will get the panel out of the path of oncoming vehicles, reducing the chance of collisions and damage.

8.1.4 Selecting the Proper Doors

The typical cold storage facility uses a wide variety of door types, depending on the temperature of storage spaces, function and usage. (***Figure* 8.6**).

Figure 8. 6 Typical Cold Storage Facility



8.1.4.1 Dock Doors

The typical types of doors applied on the dock are shown below. Vertical sliding doors are often used in the dock area because they require minimal side room and can be closely positioned along a dock wall. There are three main types to choose from:

Vertical Rise Sectional - ***(Figure 8.7)*** This type of door is the most commonly applied and is ideal for areas with limited side and headroom. The costs for these types of doors can vary substantially based on the quality of hardware, types and thicknesses of insulation, track designs, gasket systems, spring life and skin material. Upgradeable options are available for impactable or breakaway versions which release panel sections if hit by forklifts.

Since these doors are either manual or run at slow speeds, their application is primarily for low volume operations. Care should be taken to utilize models with appropriate insulation values for temperature spreads. Track designs which release the door panels from the gaskets during door movement are preferred. Door models utilizing weighted counterbalance vs. springs can also add up to substantial future maintenance cost savings.

Figure 8. 7



<u>Single Piece Vertical Rise</u> - ***(See Figure 8.8)*** In applications requiring higher levels of insulation value and seal efficiency a single piece vertical rise door moving straight up the wall is a great option. These types of doors are constructed in a single panel to avoid the seal breaks and lack of insulation associated with sectional types of doors. They also utilize down and in track designs which greatly extend gasket life. Most models utilize heavy duty commercial drives and counterbalancing weights rather than torsion springs, requiring little adjustment or replacement, eliminating maintenance down the road. Higher speed versions are available for interior applications as well. These models do require more headroom than the sectional door, but very little side clearance. A multitude of skin types and colors are available. If possible, oversize the height of the door to get the bottom 6" to 8" out of the opening and utilize vertical storing levelers. These choices will help prevent door damage.

Figure 8. 8



<u>Vertical Rise Bypass</u> - ***(See Figure 8.9)*** In applications requiring high levels of insulation value with more limited head clearance, bypass doors are available. These types of doors are a compromise between sectional and single piece doors. Models utilize two

vertical rise panels on two independent track systems. Typical overhead space saving is about 25% of a single panel door. The bypass door has high insulation values to combat conduction, and aggressive gasket seals to prevent infiltration. It is also weight counterbalanced. This door's design, however, makes it more costly.

Figure 8. 9



8.1.4.2 Entry-Dry, Storage-Outside, & Storage-Ambient Doors

Exterior applications in cold storage warehouses are often utilized by fork truck traffic to get to outside storage areas or for unloading trucks which cannot utilize the standard dock doors. Most facilities also have ambient areas which are utilized for vehicle maintenance and or battery charging. There are once again a number of models which can be applied in these types of applications. Care should be taken to evaluate the temperatures and cyclage requirements for these openings. In addition to the previously mentioned doors, high speed fabric roll up doors are often applied if the openings experience a higher level of traffic.

The fabric roll-up door consists of a flexible panel that rides up and down inside of wall-mounted guides and rolls-up into a cylinder above the doorway. These doors require very little side clearance and a minimal amount of header space. They open quickly, with typical speeds in the range of 36" to 100" per second and are designed for high cycle usage. Multiple styles are available:

High Speed Fabric Roll-Up - ***(Figures 8.10 & 8.11)***. Fabric roll-up doors have become very popular because they operate at a high rate of speed, are able to breakaway and be easily reset and operational if accidentally hit…with little or no damage. They are available in interior and exterior versions, with the exterior version using a heavier panel material and weatherproofing. Curtain panels are typically non-insulated but newer versions are now available with a thin layer of insulation. Typically, models are constructed of PVC with varying pressure holding capability, so care should be taken to apply the right model depending on interior or exterior applications. Because of their high speed, these doors typically use a photo eye and bottom edge to prevent injuries or

damage while they are closing. Since these models have little to no insulation value they should be applied in high traffic areas where convection reduction is the main goal.

Figure 8.10



Figure 8.11



<u>High Speed Rigid Insulated Roll-up Door</u> - ***(Figure 8.12)***. The high speed rigid panel roll-up door is an exterior door constructed of individual interlocking slats. The door slats have an aluminum exterior and plastic interior…filled with urethane foam insulation. This unique door provides higher insulation value to stop conduction and high speed to stop mass air flow and convection of outside air. In addition, these doors, because of their aluminum exterior, provide a high level of security…compared to fabric roll-up doors.

Figure 8.12



8.1.4.3 Cooler, Freezer, & Deep Freezer Doors

Refrigerated docks in today's modern cold storage warehouse are a busy metropolis of high speed material handling. Proper door application is dependent upon a number of influencing factors. These include but are not limited to, the type of traffic,

temperature differential, anticipated cycles, number of shifts and environmental conditions. This section will present a number of different available door types and some basic guidelines on their proper application.

Hard Panel Sliding Doors

Horizontal Single Panel Sliding - ***(See Figure 8.13)*** Single panel sliding doors are the standard for low to moderate cycle cold storage applications at a reasonable low price point. Their sliding design enables powered, high-speed operation and permits traffic to go through the doorway without stopping. This type of door stays close to the wall as it moves and presents minimum traffic hazards. Single sliding panel doors are highly insulated and gasketed to stop convection, conduction and infiltration. High speed operators can be utilized to allow for up to 48"/second opening speeds. Single slides are cost efficient because of a combination of speed, insulation, simplicity of design and relatively low maintenance.

Figure 8.13



Horizontal Bi-Part Sliding - ***(See Figure 8.14)*** Bi-part sliding doors have a 10-25% greater cost over the single panel door. The additional investment gives you 100% faster operation for greater material handling efficiency, reduced energy loss and a reduced possibility of door collisions. High speed operators allow for up to 96"/second operation, giving this model one of the fastest opening speeds. Bi-part doors are also an excellent application with more limited clearance on either side of the opening.

Figure 8.14



Strip Curtains - The cheapest solution to provide some degree of mass air flow and convection protection is the installation of a strip curtain, in conjunction with the hard panel door. While this strategy cuts some of the convection loss, the presence of a strip curtain ***(Figure 8.15)*** in the doorway encourages personnel to leave the solid cold storage doors open and is a detriment to material handling efficiency. A typical application for the addition of strip curtains is in areas of significant temperature spread or in areas where doors are left open for significant periods of time.

If you are using strip curtains, make sure they are kept in good condition and use 100% overlapping strips whenever possible. Even a small separation of less than 1/2" between the floor and a strip curtain can form an almost 1/2 square foot gap, for an annual energy loss of $700. And of course, the large gaps from the inevitable rips result in even larger losses.

Figure 8.15



Infitting/Personnel - Standard hinged walk-through style ***(See Figure 8.16).*** Constructed of fiberglass or metal. Majority are manually operated. Automatic closing devices are available. These doors are commonly used for personal traffic and emergency

exit from the cold storage room. They are highly insulated and gasketed to stop convection, conduction and infiltration

Infitting doors can also be used as access and egress doors at the exterior walls. Fireman access doors can be required at rack building as noted in the International Fire Code. Egress doors as required by the local building code. Egress infitting doors may require an upgrade to the exit hardware beyond more the standard plunger and include a panic bar or added "bump bar" that depresses the standard plunger to meet the local building code.

Doors sill details should be designed based on the use of the door and to prevent energy loss through gaps between the door bottom and the sill of the floor slab. Typical infitting doors to the exterior should have a 1 ¼" overlap at the bottom edge of door to top of finish floor to minimize thermal loss. However accessible egress from freezers spaces, particularly in California, will not permit this 1 ¼" overlap. You must then provide a flush sill condition and include a heated sill to prevent freezing the door shut. Typical infitting doors at interior applications would also have a flush sill condition due to similar floor elevations on both sides of a door location.

Figure 8.16



High Speed Doors

Bi-Folding Doors - ***(Figures 8.17a & 8.17b)*** Once the standard in high speed, high cycle door technology, the bi-folding door provides an opening speed of up to 8'/sec. These types of doors were popular in the past because they provided high speed operation, implactability and clear vision through the door opening. Bi-folding doors provide a mini vestibule at the cold storage door opening. They are typically made up of a six panel ½" clear PVC. Clear panels are connected by means of ropes, straps or Velcro to prevent separation from pressure differentials or air currents. Freezer versions of the bi-folding doors typically use heated blowers or infrared heat lamps to prevent the build-up of frost

or ice on panels. Bi-folding technology has become less desirable as the energy costs associated with its operation can be high.

Figure 8.17a



Figure 8.17b



<u>Fabric Roll-Up Doors</u> - ***(See Figure 8.18)*** Fabric roll up doors have continued to become more popular in refrigerated warehousing and are available in a variety of styles. They combine the benefits of high speed operation, and impactability with a very low profile which allows for increased dock space. Operating at speeds of up to 100" per second, these models can have a dramatic impact on reducing refrigeration loss and heat gain. Fabric roll up doors are available in non-insulated and insulated styles. Typical applications for fabric doors are moderate to high cycle applications with little to no down time. Since this category of door provides low levels of insulation value, they are not typically applied on low cycle applications. Depending on temperature differentials some models may require peripheral heat to prevent frost and ice formation. These energy usage considerations should be taken into account when applying these types of doors.

Figure 8.18



Impactable Panel Sliding Doors - Recognizing the disadvantages of losing insulation value and high seal compression associated with fabric doors a newer category of cold storage doors was developed. These types of doors were designed to provide higher levels of insulation and seal efficiency with the same or greater opening speeds of fabric roll-up doors. The problem with hard panel doors of the past was they moved slow and if you impacted them substantial damage occurred. Impactable panel doors utilize a number of different styles to allow the panels to flex or breakaway in the event of a fork truck collision. This combined with their high-speed operation, insulation values and seal capabilities have made them a popular selection **(Figure 8.19).**

Figure 8.19



Air Doors - Applications in the mid to high cycle range with little to no down time, can be well serviced by the use of air doors **(Figure 8.20)**. This type of product provides a high velocity laminar flow of air horizontally across a cooler or freezer door opening providing high levels of seal efficiency with no physical door in the opening. These products are available in non-heated and heated versions. Heat is typically applied to suspend any moisture which attempts to form at the door openings. These types of doors can be very effective in terms of reducing and eliminating the formation of fog, frost and ice around freezer openings. This combined with unlimited material handling efficiency provides for substantial payback in today's busiest openings.

Figure 8. 10



Combined Door Systems (Air Systems With Secondary Doors) - Although most refrigerated warehouses experience high door cycles, in most applications there is still considerable downtime. Whether this is due to meal breaks, shift changes, non-peak demand times, one or two shifts or weekend shut down, most applications see a substantial period of downtime. When applying combined door systems, the goal is to achieve the highest rates of material handling without sacrificing seal efficiencies during peak demand while also providing high levels of insulation and energy cost savings during low usage times. This desire can be accomplished through the use of combined door systems. Recirculatory air doors are used to maintain high levels of seal efficiency during peak traffic periods. When door openings go into slow traffic time spans, secondary doors are allowed to close creating a 100% seal during non-usage. These doors are usually a high-speed fabric roll up door or an insulated sliding door depending on the expected length of time associated with downtime. A further energy cost savings option is to use a timing sequence to automatically turn off the air systems after a preset period of time when the secondary door system closes.

Figure 8. 11

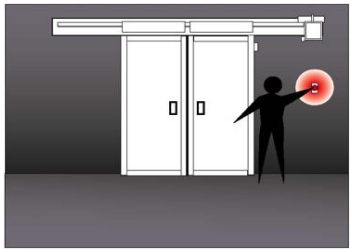


8.1.4.3 Door Actuation

Door actuation is as important to proper door selection as the door itself. To achieve the goal of energy conservation, it is the door that provides the speed, and it is the actuator devices that enable you to limit the time the door is open. However, specifying the right actuator for your door means knowing the limitations of your facility.

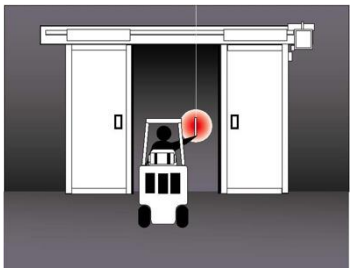
Manual Actuators

Manual actuators give personnel control over the operation of the door. Manual actuators include:



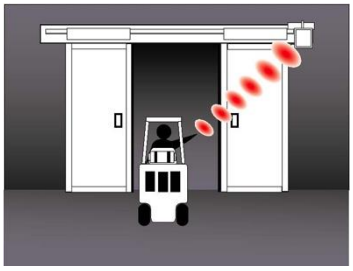
Push buttons are suitable for foot traffic such as "walkie" style vehicles, though these actuators are not recommended for high volume warehouses as their use requires forklift drivers to dismount the vehicle.

Pull cord switches are preferred for motorized traffic. The operator can work the cord without leaving the vehicle. Usually two switches are provided with each door.



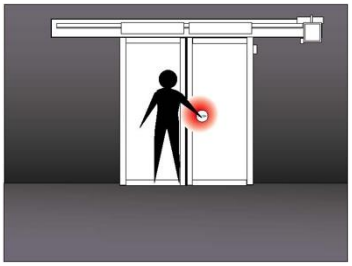
For freezers, one switch will be on the warm side of the door and a low temperature switch will be provided for inside the freezer at operation under 32°F. The area near the freezer's ceiling is the most prone to icing. Pull cords on the freezer side should have a heater cartridge to prevent freeze up of the switch.

Radio transmitter actuators enable the driver to open the door from any point on the floor. Transmitters are generally specified when the dock or cold storage area is too tight to use a pull cord or other actuator. Some warehouses have switched to radio transmitters after a number of accidents in which forklifts pull dangling cords out of the ceiling. This type of actuation is also more common in a facility with a low number of fork trucks and doors.



The receiver on each door is set to an individual frequency. Transmitters are available with up to eight frequencies for large warehouses with multiple doors. Be sure to use a clear numbering system so the operator is aware of which door he is actuating.

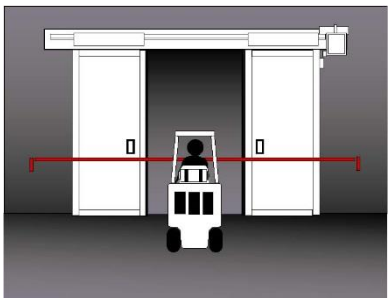
Pedestrian openings are one way to conserve energy for doors accessed by high levels of foot traffic. With the push of a wall-mounted button, door opens to a predetermined width (for horizontal doors) or height (for vertical doors) allowing just enough space for personnel to walk through to minimize infiltration into the cold storage room. The door will close automatically after a set time delay.



<u>Automatic Actuators</u>

The wide variety of automatic actuation devices takes the door operation out of the hands of the drivers and are available in a variety of designs. Most of them detect the presence of the vehicle (or any other object) to open or close the door:

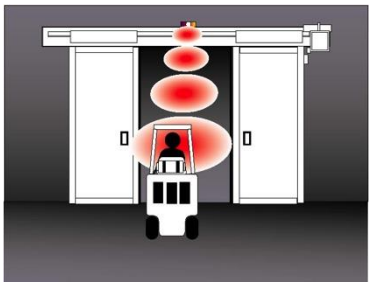
Photo eyes send a beam of light across the doorway which is broken by passing vehicles to cause actuation. Two types are available. One model transmits an infrared beam across the doorway to a reflector to then receive the beam. Another type transmits a beam to a receiver at the other side of the doorway. The single side transmitter/receiver models require less wiring than the two-sided units but can be more prone to problems with moisture and frost buildup.



Primarily, photo eyes are used as safety devices along with other door opening actuation devices to prevent closing of the door on an object in the doorway. Over the past

number of years, photo eyes have been made more durable and better able to withstand cold. One primary disadvantage is that photo eyes can be affected by fog. However, if the door system has been properly specified for the doorway, fog will not be a problem. It is also important to periodically inspect the surface of the cells to be sure that they are clean and avoid stacking objects in the path of the cell.

Motion detectors are combination transmitting and receiving microwave /infrared devices. As with photo eyes, movement will interrupt the signal, causing actuation of the door. The difference is that motion detectors can cover areas of varying widths and heights at the approach to the doorway.

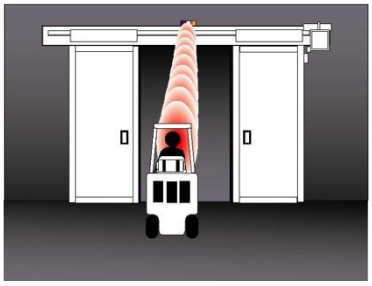


Motion detectors are available that sense movement coming both towards and away from the door, and models that sense movement coming towards the door only. With detectors positioned on both sides of the doorway, the door will open for an approaching vehicle and time out, causing the door to close. As the vehicle enters the opposite side of the doorway, the sensor will not detect the vehicle and continue to close.

The motion detector's area of detection can be adjusted to conform to the wall/rack pattern and sense the vehicle as it approaches the doorway from a desired distance. Motion detectors can be aimed to sense over a multitude of sizes. Bear in mind, however, the larger the pattern, the greater the opportunity for unintended door openings from cross traffic. As faster operating door will allow a tighter operating pattern for fewer unnecessary door openings.

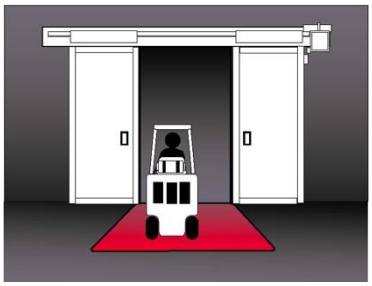
Today's more advanced sensors are capable of screening out the majority of cross traffic and also have settings to eliminate the sensing of personnel traffic.

Presence sensors are similar in operation to motion detectors in that the vehicle or other object is detected when a transmission pattern is disturbed. The difference is that motion detectors detect motion, presence sensors sense presence. So, long as the object is in the presence sensor's detection area, the door will remain open.



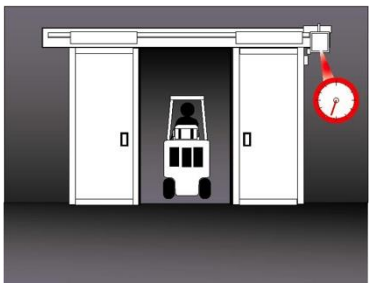
Consequently, presence sensors will be specified when it is anticipated that traffic often has to pause in front of the door without reaching the threshold. The presence sensor broadcast pattern is not as far ranging as the motion detector, making the presence sensor ideal for very tight areas. The disadvantage of a presence sensor is that typically it has a smaller range than a motion detector.

Loop detectors consist of energized loops of wire buried in the floor. As the vehicle passes over the loop, metals in the vehicle disturb the loop's magnetic field, signaling the door to activate. The loop detector is more selective in its response to the presence of objects and will not pick up the presence of, for example, people. The floor area encompassed by the loop is not considerable - about 40 sq. ft. of floor space. To minimize the effect on cross traffic in needlessly causing the door to open, indicate the loop position on the floor.



Some warehouse owners are averse to cutting their floor to install a loop, especially for renovation. The cut involves a mere 1/2" groove which can be covered by a layer of the same durable epoxy that is the standard sealer for their floor. With the advancements in motion/presence detector technology, loops are not as commonly applied.

Time delays are another type of automatic actuator, that differs in principle from those that sense presence. Used to close the door once it has been opened after a set number of seconds, the time delay will work with manual or automatic actuators. The time delay requires no maintenance, although it is a good idea to occasionally verify if the unit is holding true.



Use of time delays without a photo-eye is not recommended. Once the driver activates the actuator, causing the time delay to reset and begin its countdown, the likelihood is too great that the driver may have to pause either before the door or in the doorway (perhaps to wait for cross traffic to pass), resulting in the door closing on the vehicle and damaging itself or the vehicle. The time delay could also cause the door to close in front of vehicles following after the first vehicle going through the doorway. By having the electric eye positioned across the doorway, the door will remain open so long as the vehicle breaks the electric eye's beam.

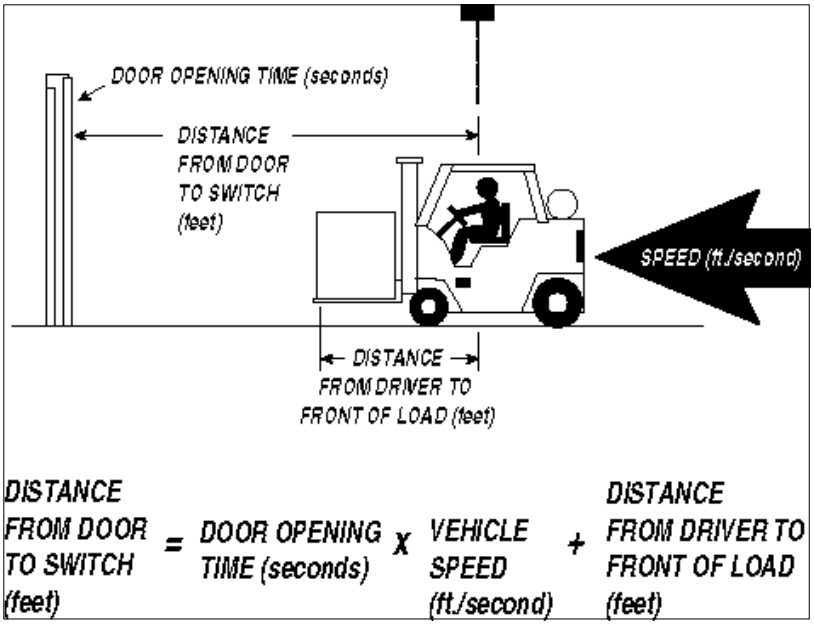
Actuator Placement

As mentioned in previous sections, actuator position is important for efficient door operation. Setting the pull cord - and other actuators - far enough away from the door will enable the forklift to drive through the doorway without stopping and prevent many of the forklift/door collisions that frequently occur.

Often, the decision of actuator placement is left up to the electrician at the job-site who has no idea of the actuator's function. The switch will end up at the closest convenient location. Putting the actuator near the door will defeat the purpose of an automated, high-speed door system. It is not surprising that door collisions happen with so-called automated door systems as the doors are unable to open fast enough for traffic heading towards the door.

Proper placement of the actuator, with the help of your local cold storage door distributor, should be specified on the prints by the facility manager who knows the traffic

pattern. He can be assisted by a door specialist. Adequate distance for actuator placement is based upon the speed of the material handling vehicle and the opening speed of the door. ***Refer to the drawing below*** to determine actuator distance from the doorway based upon forklift speed.



Also, when looking at the doorway, determine the direction of traffic. Multiple actuators can be used on either side of the doorway, depending upon the direction where traffic will be coming from. If traffic is approaching directly in front of the door due to, for example racking, then only one actuator is required. On the other hand, if traffic is expected from both sides and the front of the door, then actuators on three sides are recommended.

Actuator Applications

Actuator approaches that can be devised are numerous and depend upon the goals in mind for the doorway. For optimal material handling efficiency and infiltration protection, automatic open and close is an ideal strategy. Though the cost of such a system may average $1,000, the payback in terms of your ability to hold down energy costs and handle more product through your facility can justify a fully automated doorway.

The simplest type of open/close system is presence sensors on either side of the door and a time delay. After the vehicle passes through the door, actuates the device on the other side of the door, and the time delay has timed out, the door will close. Again, the addition of a photo-eye at the doorway will prevent the doors closing in on vehicles.

Today's actuators give cold storage warehouse owners and designers flexibility in matching door systems to fit the needs and budget of any operation. With possible energy savings, increases in material handling efficiency and the minimization of all-to-common door accidents, cost of the actuation system should not be the only determining factor in the specification of the device. The door system payback achieved though these actuation devices can help the attainment of your profit and volume maximizing goals.

8.2 Maintenance

A study performed in 2003 by the BHI Group analyzed the cost to own cold storage doors. The finding was that the initial cost of buying and installing a hard panel door may represent only about 10% of the total cost of the door over a 10-year period when the cost

of energy consumed in the opening, the downtime, maintenance/repair and safety of the operation's personnel are also quantified. This analysis emphasizes the importance of buying the appropriate high quality doors for each opening and placing the highest priority on maintaining the doors. Not properly maintaining any kind of door will result in significantly higher operating costs including greater energy consumption, higher repair expense and quicker replacement of the door.

Here are some general recommendations for all cold storage doors:

1. Train all employees in the safe and proper operation of your cold storage door equipment – including emergency escape procedures. Make sure that someone having authority is responsible for training and compliance of your personnel regarding the safe, proper operation of your doors.
2. Take immediate steps to correct any damage, wear or malfunction which could lead to improper door operation or affect employee safety.
3. Encourage employees to perform routine daily visual inspections. Good working habits each day involve the willingness to report and act on signs of damaged, unusually worn or improperly operating equipment.
4. Establish a written safety and maintenance inspection plan with specific dates for accomplishment and a log to record completion of required actions.
5. Have all safety and maintenance procedures performed by trained personnel.
6. The overall operating environment will have a material impact upon the repair and maintenance costs of doors. If fork truck drivers operate in a disciplined culture and environment the amount of damage to doors will be significantly less than is otherwise the case.

All companies that make doors for this industry supply maintenance schedules and information for their products. The importance of following their recommendations cannot be overemphasized.

Also, the manufacturers have telephone assistance available when specific problems arise. This is an important resource to use to keep the doors operating efficiently and effectively.

The following points are representative of the general guidelines which manufacturers recommend.

All Doors

- Visually inspect each shift/day for obvious damage or operating problems
- Watch each door operate at least one cycle

Hinged Doors

- Latch & back handle – check for binding, proper alignment, lube
- Hinges – check for lube, binding, cracked parts, wear
- Gaskets – check for tearing, cracking, wear
- Frame or door heaters – check for no heat, damaged covers

- Frame to wall caulking
- Loose bolts, nuts and screws
- Door sag
- Overall door condition
- If locking is an option, test the mechanism and apply lubrication to the treaded components

Manual Horizontal Sliding Doors

- Track – check for damage or wear
- Trolley wheels – check for undue wear, nicks, bearing roughness
- Carriers and rods – check to see if they are bent or loose
- Gaskets – check for any tearing, cracking or signs of wear
- Floor stay rollers – any damage or are they not contacting the door?
- Head sealing wedge – is it bent or cracked?
- Frame or door heaters – check for lack of heat or damaged covers
- Any loose bolts, nuts or screws?
- Is head sealing wedge bent or cracked?
- If locking is an option, test the mechanism and apply lubrication to the treaded components.

Manual Overhead and Vertical Sliding Doors

- Track – check for damage or wear
- Side guide wheels – check for rough rollers, undue wear a dirt
- Door guide wheel brackets – are any bent, damaged or cracked?
- Gaskets – look for tearing or cracked gaskets
- Lifting cables – examine for fraying, signs of wear and failure
- Overhead torsion spring – look for rust and cracks and adequate lube
- Door to counterweight balance – examine for rust, balance and secure cable connections
- Make sure counterweight does not spin while the door is going up or down
- If locking is an option, test the mechanism and apply lubrication to the treaded components

Power Units – Sliding Doors

- Reversing edge – depress to reverse travel
- Drive chain – check lube, tautness and evidence of rust
- Manual release – check for adequate lube, any rust and whether bent
- "V" belts – frayed or worn?
- Gear box – check oil level; is operation noisy and/or rough?
- Brake and solenoid – check for slipping; also, worn discs
- Reversing contactor and relays – check for lack of contact, any sparks and wear

- Limit switches – check for smooth operation, evidence of wear
- Leaf power cords – are they frayed or broken

Roll-Up Doors

- Door fabric and frame – check for any visible damage or unusual wear
- Actuators – check for automatic operation of the door
- Hardware – check for proper tightness
- Limits – observe both open and close door limits; ensure that a proper floor seal is intact when door is fully closed – no visible light seen between reversing edge and floor
- Cables and pulleys – ensure that cable is not slack, misaligned or fraying

Air Doors

- By their very nature air doors are less susceptible to physical damage than other doors. They also require less maintenance than other doors. The downside is that sometimes less maintenance is interpreted to be no maintenance. Here are the basics of required steps:
    - On an ongoing basis – constantly – remove any debris accumulation from intake screens
    - Blower belts (not present on direct drive units) – replace annually but examine for slack regularly
    - Blower wheel – check for foreign material accumulation
    - Blower bearings – grease monthly
    - If unit has a condenser coil, check for correct heat output and clean as needed
    - Amp check the electric heater if so equipped.
    - Verify humidistat or temperature controller and heater relay works
    - Hot gas coil (if present) – keep clean

Chapter 9: Lighting

Acknowledgements

Michael Lynch, United States Cold Storage, Inc., Voorhees, New Jersey, USA

9.1 Design

9.1.1 Introduction

Refrigerated warehouse facilities have specific lighting design considerations because of their function and spatial characteristics. These characteristics include high open spaces, a pattern of tall storage units and open aisles, and the need to easily identify stored items. In addition, low operating temperatures present a distinct lighting design challenge.

Relationship between Light Source and Task

The relationship between the light source, the tasks and employee is very important in a warehouse because the tasks are usually on vertical plan, and above eye level. Searching for an elevated pallet is a task subject to direct glare (looking into the light source) or veiling reflections which obscure labels or writing on shiny surfaces.

Glare Control

The most common glare problems in warehouses occur from "veiling reflections" (i.e. reflections of lights sources on shiny surfaces such as shrink wrapped pallets) on objects or their labels, and direct glare from luminaries when seeking objects above eye level.

Uniformity

A wide range of illumination is unavoidable in most warehousing applications because of the difficulty of distributing light from top to bottom on vertical surfaces. This is acceptable as long as the transition is gradual. Harsh shadows make the job of identification and retrieval difficult for the employee. Luminance ratios should be no more than 20:1 between the top and bottom surfaces, or between the darkest and lightest surfaces in view.

Three-Dimensional Modeling of Objects

Lighting to enhance the modeling of objects is only important when the correct selection of an object is dependent on its shape or texture more than its labeling. In a refrigerated warehouse this type of selection is not common.

Luminance of Surfaces

To reduce the contrast and promote inter-reflections, surfaces in view should be as lightly colored as possible. Refrigerated warehouses typically do not have finished ceilings tending to diffuse the light. Pallet racking finish should be of eggshell or semi-gloss finish. Avoid metallic or shiny finishes. If natural metal is preferred or required, use a heavily brushed finish.

Flicker

Lamp flicker can be dangerous in a warehouse, especially in high fork lift traffic areas. Use high-frequency electronic ballasts to prevent fluorescent or metal halide sources from flickering. Defective or failing ballasts that create lamp flicker should be replaced immediately.

Color

Color can play an important role in object identification and good color rendering light sources will aid in visibility and identification. It is recommended to use lamps with a color rendering index (CRI) of 70 or higher. A correlated color temperature of 3500 to 6500 Kelvin is appropriate for warehousing functions.

The foot-candle level of lighting is defined as the lumens per square foot. For warehouses, the values are as follows:

Function	FC
Shipping and Receiving Areas	50 to 60 fc
Active Storage, Fine Objects	40 to 50 fc
Active Storage, Medium Objects	20 to 40 fc
Active Storage, Bulky Objects	10 to 20 fc
Inactive Storage	5 to 10 fc

Source: IARW Maintenance and Modernization Manual, 2008

9.1.2 Lighting Technologies

Lamp Basics

The lamp is the source of electronic light. This device converts electric power into visible light. Selecting the correct lamp type is at the heart of a high-quality lighting plan, and central to visual performance, energy conservation and the appearance of a space. Various light sources have different characteristics, but the basic performance principles include the following:

- **Lumen Output** – The amount of light emitted by a lamp.
- **Delivered Foot-Candles** – Delivered foot-candles describes usable light on both horizontal and vertical work surfaces. While lumen output describes the total output of a lamp, it takes properly designed optics to deliver that light efficiently to the floor, where equipment must be safely operated, and to rack face

and product, where items must be properly identified and handled. The correct optical package is normally application specific, for both aisles and open areas.

- **Efficacy** - Efficacy is the amount of light (lumens) produced relative to the electric power expended, and is measured in lumens/watt. A lighting system using high efficacy sources will provide the light needed while conserving more energy. Because of their methods for converting electricity to light, various lamps create light with different efficiencies, with incandescent or halogen at less than the 25% of the efficacy of linear fluorescents or LED. Efficacy is most accurately determined for lamp-ballast combinations.
- **Rated Lamp Life** – Rated lamp life is provided by the manufacturer and, for fluorescent and high-intensity discharge lighting, represents the point in time when 50% of a group of lamps have burned out under controlled testing with lamps switched on 12 hour intervals. Rated lamp life is useful in comparing different sources, in developing a maintenance plan for group relamping, and for life cycle cost analyses. There is not a usually significant variation in rated life between manufacturers of similar lamps. There can be significant variations in rated life between lamps types and use. Frequent switching will greatly reduce lamp life unless the cathodes are protected by a "programmed-start" ballast. The rated lifetime of an LED fixture described the L70 time, where the total luminous output of the fixture has decreased to 70% of the initial rating. This data should be provided by lamp manufacturers from 3rd party laboratories, per the LM-80 and TM-21 testing standards. It is important to understand the rated lifetimes and warranties associated with all components of the light fixture and system. There may be different ratings and warranties associated with lamps, ballasts, drivers, LEDs, sensors, and controllers.
- **Lamp Lumen Depreciation** - Lamp lumen depreciation (LLD) represents the decrease in light output of a lamp over time. Lamp manufacturers provide both "initial lumens" and "mean lumens", the former measured after 100 hours, and the later occurring at 40% of the rated lamp life. Mean lumens can be used in calculations to determine maintained luminance.
- **Color Rendering** - Color rendering indicates how "realistic" the colors will appear, compared to how we expect them to look. The measure is the Color Rendering Index (CRI), which ranges from 0 to 100. Objects and people viewed under lamps with a high CRI look more natural. The color rendering index of a lamp is compared to reference source of the same color temperature. At the two extremes, incandescent lamps have a CRI of 100 and low pressure sodium, under which everything looks yellow, has a CRI of 0.
- **Heat** – Lamps convert only a portion of electricity into light. Lamps that produce less heat contribute to less heating and, thus, to lower cost.

9.1.3 Lamp Types

High Intensity Discharge (HID) Lamps

The most common type of high bay freezer warehouse light currently in use is the High Intensity Discharge (HID) lighting fixture. HIDs use a gas-filled tube to generate

light using an arc current to vaporize metal at relatively high temperatures and pressures. There are two main types commonly used in refrigerated warehouse-metal halide (MH) and to a lesser extent high-pressure sodium (HPS). Their light characteristics are determined by the gas. Metal halide provides a white light with a CRI of 65-95, while high-pressure sodium emits a yellowish light with a CRI of 22-65.

HID lamp advantages include:

- High lumen output – up to 1000 wattage lamps available.
- Medium to high efficacy - MH: 51-85 lumens per watt; HPS: 60-115 lumens per watt.
- Long Lamp Life – MH: 10,000 to 20,000 hours; HPS: 12,000 to 24,000 hours.
- Insensitivity to ambient temperatures; operate down to -40 °F.
- 50% and 100% bi-level switching ballast available.

HID lamp disadvantages include:

- Lamps have a warm-up period before reaching full output and color; typically, 2-4 minutes in freezer environment.
- If power is interrupted, lamps must cool before restriking. Instant restrike lamps are available.
- Inappropriate for some control strategies, such as occupancy sensors with high frequency switching.
- Yellow output and low CRI of high pressure sodium.

Fluorescent Lamps

Advancement s in fluorescent lamp technology has made them suitable for high bay freezer warehouse applications. Fluorescent lamps generate their light by using electricity to excite a conductive vapor or mercury and inert gas. The resultant ultraviolet light strikes a phosphor coating on the inside of the tube, causing it to glow. The elements used in the phosphor coating control the lamp's color.

Fluorescent lamp advantages include:

- Very high efficacy – T8/T5 lamps are 80 to 89 lumens per watt.
- Very long lamp life, from 20,000 to 30,000 hours.
- Cool operation.
- Low diffused surface brightness.

Fluorescent lamp disadvantages include:

- Require a compatible ballast.
- Dimming requires a more expensive ballast.
- Low temperatures can affect start-up, lumen output, and lamp life. Insulated enclosures required for high bay freezer applications. Switching lamps with sensors diminish lifetime and can invalidate the warranty if the on/off intervals are too frequent.

9.2 Maintenance

Improve the maintenance factor by regularly cleaning fixture lenses and reflectors and instituting a relamping program. Clean a fixture, at least, every time it is relamped, as the additional labor is nominal when these two activities are combined.

Cleaning

If activities in the warehouse generate a high proportion of dust, the output of the lamps and luminaries may be significantly depreciated due to dirt accumulation. Open glass lamps should not be utilized in and around the storage of food product so lamps should be enclosed in a shatter proof lens material. Annual cleaning and scheduled group relamping at 70% of rated lamp life can offset these losses. Avoid using excessively conservative light loss factors and over lighting the space. Use an antistatic cleaning compound to reduce electrostatic dirt collection on the lens and reflector.

Relamping

Lamp burnout clearly reduces your lighting system effectiveness, but lighting systems begin to deteriorate before they burn out completely. Lamp average rated life, the figure used in all supplier catalogs to compare lamp life, is the number of hours elapsed when 50% of the lamps in a large test group are burned out and 50% are still burning. If you replace your lamps one by one when they burn out, or when they have been burning their average rated life, you may have as little as 50% of the original designed lighting level.

The loss of lighting effectiveness described above can be reduced with a well-organized preventive maintenance program. Group relamping, the replacement of all lamps in an area, can save up to 10 times the cost as compared to replacing lamps one by one. It is recommended that group relamping occur at 70% of the rated average lamp life.

Group relamping increases the material costs because you will replace lamps more often when they are still brighter and more of them are still burning, however, this is only part of the total life cycle cost with labor being the other major cost. Since all lamps are changed in the area at one time, you can clean during the lamp changing, saving a lot of setup time such as travel, material handling to and from the job and ladder/scissor lift handling.

9.3 Modernization

Light Emitting Diodes (LEDs)

LEDs are the new mainstream for lighting in the refrigerated warehousing industry, as they offer many advantages over conventional HID and fluorescent lighting technologies. LEDs are made of an advanced semi-conductor material that emits visible light when current passes through it. Different conductor materials are used, each emitting a distinctive wavelength of light. Lamps that produce white lights are using multiple color LEDs to generate white light; there is no white LED

LED advantages include:

- Impact resistant.
- Operate best at colder temperatures (some down to -30°F).
- Very long average lamp life; 50,000+ hours.
- Instant-on capability (even at cold temperature).
- Unlimited dimming capability; effective for rapid or frequency switching applications.
- Standard efficacy is greater than 70 lumens/watt
- Highly controllable for maximum energy efficiency.
- Available for every required color quality, from 74 to 90 CRI and from 2700 to 5000 degrees Kelvin
- Significant lower heat emission than any other technology, for example, 50% and less of the heat compared to a fluorescent lamp.
- Significant longer warranty than other technologies, typically 5 years.
- Significant lower operation cost including lamp purchase and electricity cost than any other technologies
- Some utilities award exchanging fluorescent lamps with LED, for example, PG&E in California has a special rebate program for exchanging fluorescent systems with LED for refrigerated and frozen food

LED disadvantages include:

- High bay warehouse application is maturing application.
- LED unit cost is still higher than other technologies.

Lighting Controls

Lighting controls serve the dual purpose of enhancing lighting quality and reducing energy consumption. Controls can be simple, e.g. bi-level switching, or complex and integrated into the buildings management system.

Bi-level Switching

Motion/occupancy sensors can be integrated into HID, fluorescent and LED lighting fixtures. Bi-level switching controls two (or more) light levels within a space. Typically lights levels range from a "high" mode of 100% to a "low" mode of 50%. In the case of LED, the "low" mode can be as low as 0% with instantaneous re-strike capability. Appropriate ballast selection is important when integrating bi-level switching onto HID and fluorescent fixtures.

In addition to setting the high and low lighting levels, the sensor delay, or sensor timeout can be set as well. With longer sensor delays, more lights stay on for longer periods of time. Shorter timeouts drive better energy savings. It is important to choose settings appropriate for the application in order to properly manage safety and productivity with energy management. Different technologies have different thresholds for how short a sensor timeout can be set, so it is important to consult manufacturers specifications for guidance.

Advanced Control and Monitoring

Advanced lighting control systems are available for cold storage warehouses, and if properly designed and applied, can increase the level of control as well as energy savings. Lighting control systems can offer time-based scheduling of light settings, as well as the ability to manually override motion sensors and turn on lights in portions of the facility for emergent needs such as maintenance, inspections, or emergencies.

Many advanced control systems also include integrated energy monitoring and reporting, to provide insight into the actual energy usage patterns of the facility. These systems can track kW-h usage from the lighting system in discrete control zones of the warehouse.

Chapter 10: Material Handling

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Jay Easterling, Freezing in Florida, Valrico, Florida, USA

Thomas J. Fox, Arbor Material Handling, Inc., Willow Grove, Pennsylvania, USA

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Lift trucks are designed to operate in many different environments. One of the most difficult environments is cold storage and freezer applications. This is an environment between 40 degrees Fahrenheit and minus 20 degrees Fahrenheit. In the past, trucks had to be specially prepared to resist these conditions. Heaters were added to electronic panels and displays, cold-storage grease was placed on connectors and special fluids were used in the hydraulics and drive train.

Today, circuit cards are conformal coated, connectors have water-tight gaskets and heaters are integrated into the components often governed by a thermostat to turn them on as needed. All-temperature and synthetic fluids can be used for many types of environments. These changes and improvements have allowed the maintenance interval to increase — in some cases double from the traditional 250-hour interval. Alternating current (AC) controls and motors have been implemented, as opposed to direct current (DC) controls. This is especially important for cold storage.

First, AC runs cooler — less heat transmitted from the trucks means the cooler/freezer does not have to dissipate this heat, resulting in less energy usage to maintain the environment's temperature. Second, the energy efficiency of the truck allows more run time on the battery. This is important because even well-maintained batteries provide less run time in cold storage. This is because the cold temperatures affect the chemical process within the battery, reducing the amount of energy it can provide.

10.1 Design

10.1.1 Lift Trucks for Cold Storage

Various kinds of equipment are used to transport products and raw materials in a cold-storage environment. Push carts and lift trucks are the most common vehicles used.

Lift trucks are used extensively in cold storage. While various specialized types of lift trucks are available, several features are common to most or all lift trucks

manufactured today. Warehouse managers should work closely with materials handling professionals to determine the equipment/options best suited for the environment or operation. As part of this consultation, managers also should ensure that appropriate operator training programs, scheduled maintenance programs and fleet management programs are put in place.

The basic components of an industrial lift truck include:

- **Baselegs** - A structural member of a high-lift truck, containing load wheel(s) that extend in front of the mast from both sides, also referred to as outriggers.
- **Counterweight** - A weight, typically made of iron, is incorporated into the rear portion of a counterbalanced lift truck or reach truck. It offsets the weight of the load the trucks lifts on its forks. The counterweight is important to truck stability.
- **Forks** - Horizontal tine-like projections, normally suspended from the carriage, engage and support loads the lift truck carriers.
- **Fork Carriage** - A support structure for the forks or other attachments, generally roller mounted, travels vertically within the mast of the truck.
- **Load Backrest** - This load-supporting structure is attached to the carriage and forks and supports the load when the carriage or mast is tilted rearward or upward, or elevated.
- **Load Wheels** - The wheels located in the baselegs of a reach or straddle-type narrow aisle lift truck assist the movement of the truck over the travel surface.
- **Mast** - This support structure permits the vertical movement of the fork carriage on the lift truck. The mast consists of pairs of interlocking uprights that are elevated by a hydraulic lift cylinder.
- **Overhead Guard** - This protective framework, fitted to the truck over the top of the operator compartment, is designed to help protect the operator material that might fall from above.
- **Operator Compartment** - This is the area of the lift truck within which the operator normally works. The compartment contains all the truck control functions and provides protection for the operator.
- **Tires** - Tires provide cushioned contact with the floor surface or ground and permit the smooth movement of the lift truck on the travel surface. Tires are typically made from rubber or polyurethane components. Tires can be pneumatic (filled with air) or solid. Pneumatic tires generally provide greater cushioning and a smoother ride. Trucks used in cold-storage facilities with smooth floors are most often equipped with solid tires and siped tires that allow for better traction.
- **Lift Truck Uses** - Lift trucks perform many important jobs in cold-storage material handling. Pallet trucks and counterbalanced lift trucks are used to move material horizontally over long and short distances. Reach trucks and counterbalanced lift trucks are used to store material vertically in bulk stacks. Lift trucks also can be used to retrieve materials stored in racks, either by the piece or as complete loads. Orderpickers, reach trucks, turret trucks and counterbalanced trucks perform these functions. Counterbalanced and pallet trucks are used to

load and unload over-the-road trucks and trailers. Reach trucks also can operate in trailers, depending on their configurations.

- **Electric and Internal Combustion** - There are two basic power sources for industrial lift trucks — internal combustion engines and industrial lead-acid batteries. Internal combustion engines, fueled by liquefied propane gas, diesel fuel or gasoline, power a substantial number of lift trucks. These trucks generally are used outdoors because their exhaust fumes are undesirable or even hazardous in indoor environments. Industrial lead-acid batteries are the other major lift truck power source. Battery-powered lift trucks are most often found working in indoor environments and common in freezers. The batteries are typically 24 or 36 volts, although some might be 48 or even 72 volts. Batteries can weigh from 500 to 3,000 pounds.
- **Lift Truck Classification** - Because of the great variety of lift truck uses and significant differences in design, the Industrial Truck Association (ITA) developed a classification system. The ITA is an organization whose members are lift truck manufacturers and suppliers in the U.S., Canada and Mexico. The ITA classification system divides lift trucks in to seven categories.

Table 10. 1 ITA Lift Truck Classifications

Class I	Electric motor, rider, counterbalanced trucks (solid and pneumatic tire). This class consists of counterbalanced lift trucks that include both stand-up and sit-down versions. It also includes 3-wheel and 4-wheel truck designs.
Class II	Electric motor, narrow aisle trucks (solid tire). This class consists of reach-type, narrow aisle lift trucks, narrow aisle orderpicker trucks, and very narrow aisle turret-type trucks.
Class III	Electric motor hand trucks. This class consists of pallet trucks of different designs, including low-lift, horizontal transport and high-lift stacking models.
Class IV	Internal combustion engine trucks (solid tire). This class consists of counterbalanced internal combustion trucks that use solid or cushion tires.
Class V	Internal combustion engine trucks (pneumatic tire). This class is similar to Class IV except that the trucks use air-filled tires.
Class VI	Electric and internal combustion engine tractors (solid and pneumatic tire). These trucks are used to tow carts or trains of products. They do not lift loads.
Class VII	Rough-terrain forklift trucks (pneumatic tire). This class works strictly in outdoor, construction-type applications.

10.1.2 General Overview of Lift Truck Types

Counterbalanced and Narrow Aisle Lift Trucks

Lift trucks are traditionally differentiated as either counterbalanced or narrow aisle trucks. Counterbalanced lift trucks use the fulcrum principle to support a load. The fulcrum, or pivot point, is located at the front axle of the truck. The load weight in front of the truck on one side of the fulcrum point is balanced by the weight of the truck and counterweight on the other side. A counterbalanced lift truck remains stable as long as the load weight being carried does not exceed the counterbalancing weight of the lift truck.

Narrow aisle lift trucks handle loads using a different principle of support. These trucks have baselegs (also called outriggers) that change the load-handling characteristics of the truck. Narrow aisle lift trucks with a smaller footprint than the typical sit-down counterbalanced truck can support a comparable load and operate in smaller spaces while still doing the same job as a counterbalanced truck. These trucks can elevate higher than counterbalanced trucks and can carry more weight, making them ideal for high rack freezer storage.

Deep-Reach Trucks

Deep-reach trucks are used to increase storage density in narrow aisle applications such as in cold storage. The double reach mechanism allows applications to store pallets that are two pallets deep with the aid of an extended reach. This two-deep storage accommodates higher volume product or longer-storage-life products. Deep-reach trucks also can lift to higher heights than counterbalanced. The loads also can be placed two deep, increasing the pallet storage due to less space lost to aisles.

Operator-Up and Operator-Down Lift Trucks

Lift trucks also can be distinguished based on the basic orientation of the operator to the truck and the load. In some lift trucks, the operator always remains on the ground when storing, retrieving or transporting loads. These trucks, called operator-down vehicles, include pallet trucks, reach trucks and many counterbalanced lift trucks.

In operator-up lift trucks, the operator can travel up to the load location when storing and retrieving and when transporting the load. These trucks include order-picking vehicles and turret-type lift trucks. Most types of trucks perform a specific function in cold-storage materials handling systems.

Operator-down vehicles typically transport and store full pallet loads of materials. Operator-up vehicles typically store and retrieve materials that need to be accessed in less than full pallet quantities. Turret trucks can store and retrieve both full pallet loads and individual items.

10.1.3 Commonly Used Lift Trucks in Cold Storage

Five types of lift trucks are commonly used in cold-storage applications. Here are basic descriptions of each type:

Reach Trucks and Deep-Reach Trucks

Reach trucks are widely used in cold-storage applications. Reach trucks store and retrieve loads in narrow aisles where increased storage capacity, selectivity and productivity are needed and also can operate in trailers depending on their configurations. Operators can face forward or tractor first when traveling. The deep-reach truck uses a double-reach mechanism to achieve two-pallet-deep storage capabilities, allowing for increased storage density.

- Maximum throughput needs
- Heights up to 42 feet
- Designed for rack interface
- Pallet storage and retrieval
- Load capacity pounds (kg):
    - Up to 4,500 (up to 2,041)

With the ability to reach heights up to 42 feet, lowering speed can be a consideration for reach trucks in cold storage environments. Newer reach trucks can offer lowering speeds up to twice as fast as older models without increasing energy consumption. Some reach trucks also now feature regenerative technology that allows lost energy during lowering to be captured and returned to the battery to increase efficiency.

Figure 10.1: Reach & Deep Reach Truck



Pallet Trucks

Pallet trucks are used for horizontal transport of product from one part of the warehouse to another, for floor-level order picking, for general dock work and for loading and unloading trailers. The operator can walk along with the vehicle or, with some models ride on the vehicle. New automation options also now allow the operator to advance the truck from the aisle using **wearable technology** (mobile automation), eliminating the need to get on and off the truck when advancing to the next pick location and saving valuable seconds per pick.

- Longer travel distances
- Heavy-duty cycles
- Handle multiple pallets per trip
- Horizontal transport and order picking
- Load capacity pounds (kg):
    - Up to 8,000 (up to 3,629)

Figure 10.1: Pallet Truck Automation

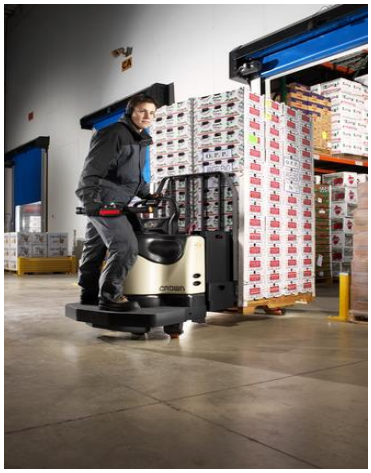


Figure 10.3: Pallet Truck with Mobile



Orderpickers

Orderpickers are operator-up, in-aisle trucks used for filling individual customer orders that require piece or case picking — rather than full pallet retrieval. The trucks work in very narrow aisles and provide high-level picking capabilities in limited storage spaces.

- Multiple shifts
- Heights up to 30 feet
- 24, 36, 48 volt
- Case or piece picking
- Load capacity pounds (kg):

- Up to 3,000 (up to 1,361)

Counterbalanced Lift Trucks

Counterbalanced lift trucks are multipurpose trucks typically used in heavy-duty dock operations — unloading and loading trucks, transporting loads to and from the dock and interfacing with trucks that are working in aisles. These trucks also can be used for special handling applications that require attachments.

Stand-up Counterbalanced

- Frequent on/off
- Loading/unloading trailers and containers
- Dock-to-stock transport
- Attachments
- Load capacity pounds (kg):
  - Up to 5,000 (2,268)

Sit-down Counterbalanced (three or four-wheel)

- Long runs
- Infrequent on/off
- Attachments
- Dock-to-stock/staging
- Load capacity pounds (kg):
  - Up to 6,000 (2,722)
  -

Very Narrow Aisle Lift Trucks

Transtackers

A transtacker is an aisle-dedicated operator-up truck that can store and retrieve in aisles as narrow as 54 inches, maximizing space for high density storage.

- Very narrow aisle storage up to 58 feet
- Guided applications
- Storing and retrieving full pallets or case picking
- More weight to higher heights up to 58 feet
- Load capacity pounds (kg):
  - Up to 4,000 (1,814)

Turret

Turret trucks work in very narrow aisles (typically 66 to72-inch aisles) where an application calls for denser storage. These trucks are designed for full pallet and case picking, offering access to both sides of the storage aisle without the truck having to turn 90 degrees. The turret mechanism also allows the forks to traverse from side to side and rotate 180 degrees. Vehicle guidance systems (wire guidance in aisles) normally are installed with turret trucks for maximum efficiency. In addition, auto positioning capabilities can enable turret trucks to take the most efficient route to the next rack

location, increasing productivity up to 25 percent and reducing the time operators spend in cold storage environments.

- Typically wire-guided applications
- Storing and retrieving full pallets or case picking
- Heights up to 56 feet
- Load capacity pounds (kg):
    - Up to 3,300 (1,500)

Figure 10.2: Very Narrow Aisle Lift Truck



10.1.4 Special Cold-Storage Modifications

Lift trucks operating in refrigerated warehouses, blast freezers and other cold-storage applications require a few special modifications. The trucks require robust control systems, and a cold-storage conditioning package that protects the truck systems is advisable. The energy efficiency of AC-powered trucks is also beneficial.

For comfort and productivity in refrigerated environments from 31 degrees Fahrenheit to minus 20 degrees Fahrenheit, accessories like heated control handles allow operators to wear lighter gloves for enhanced mobility and easier data entry. Heated floor pads also provide added warmth.

Additionally, certain lift truck options are specifically designed for cold-storage or freezer applications:

- Control handles with coned auxiliary buttons are used on reach trucks and stand-up counterbalanced trucks. This allows operators wearing freezer gloves to have greater control without having to remove their gloves. The convex design of the standard handle makes it difficult to manipulate auxiliary functions when wearing gloves.
- Handle heaters, seat heaters and floor heaters are available for some vehicles to provide greater operator comfort and aid in productivity in freezer applications.

- Corrosion protection is included with the cold storage option for some trucks.
- An on-board power hookup option is available for some trucks. Certain configurations of the on-board power hookup may be required if the warehouse information communication terminal is equipped with heaters for cold storage use.

10.2 Modernization

Electronic tools now enable cold-storage warehouse managers to extract more efficiency, higher performance and greater uptime from lift truck fleets. Two noteworthy advances include digital fleet management systems and battery management systems.

10.2.1 Fleet Management

Vehicle monitoring systems allow cold-storage warehouse managers to acquire, analyze and act upon information about their lift truck fleet operations, enabling them to control and reduce costs. The technology helps them stay globally competitive by measuring productivity and finding ways to improve continuously. Truck-based fleet management technology can be integrated as standard equipment on the truck or added to trucks as an option or retrofit. This enables lift trucks to benefit from IoT technology, helping managers get more productivity from lift truck operators and service technicians, diagnose service issues remotely, comply with regulations and optimize lift truck capital.

Figure 10. 3: Fleet Management



The systems operate by sending information wirelessly from the lift trucks' on-board vehicle manager to a central data bank. Information is reliably accurate because it comes directly from the truck operating system. The information is available not just to

warehouse management, but also to anyone in the organization to whom it might have value. For example, maintenance technicians, service technicians and operators all can review the information when making fleet decisions. A service center dispatcher can use alert codes and lift truck data to help ensure that service is completed on the first call.

By collecting and analyzing real-time lift truck data, companies can see how their lift trucks are being used and how many hours each truck operates. This information can be used to maximize fleet productivity and reduce costs. For example, this data can help determine if a lift truck is being used for the wrong job. Data may show that a reach truck is being used primarily for long horizontal transport, putting unnecessary wear on that truck. In that instance, a company can allocate a more appropriate lift truck in its place.

Vehicle monitoring systems also help managers determine whether lift trucks are being used efficiently. If some trucks are in operation most of the day and others are sitting idle, it may be time to reduce the number of trucks or reallocate trucks for other applications. A regional warehouse manager can use fleet information to compare one facility with another for benchmarking, while a national organization can generate a fleet overview across multiple regions. The ability to monitor fleets regionally or nationally aids in decisions about truck replacement, fleet rightsizing, employee staffing and budgeting.

Opportunities to improve efficiency and productivity can also be identified by vehicle-monitoring-system consultants provided by various lift truck manufacturers.

Vehicle monitoring systems include a variety of modules to meet specific needs. The functions include:

- **Alerts** — Automatically sending alert code notifications to service technicians to identify required maintenance or provide warning of maintenance issues.
- **Control** — Configuring specific operator profiles based on skill level to limit truck lift speed and acceleration. The parameters are set automatically when the operator signs in to use the truck.
- **Certification** — Control operator access to trucks based on training level and automate certification management.
- **Impact** — Notifying warehouse and service managers if there is an impact or other significant event while the truck is in motion.
- **Verification** — Requires the operator to review the OSHA-mandated daily checklist before the truck will start and notifying the service manager if an item needs service.
- **Metrics** — Tracking truck usage data to help facility managers determine whether the best truck was used for a specific application. The data helps managers evaluate operator productivity and optimize lift truck fleets.
- **Reporting** — Generating reports on fleet data by truck, facility, region and company. The data can reveal opportunities to save time and costs across the enterprise.
- **Energy** — Monitor battery or fuel consumption and efficiency, depending on truck type.

Battery Management

Digital battery management systems help cold-storage operations extend service life, increase uptime and reduce costs in the power sources of electric lift trucks. Again operating through the lift truck's on-board vehicle manager, the systems automatically notify warehouse managers of key battery parameters, such as charge/discharge cycles, high and low temperatures, and low battery water levels.

If electric lift trucks are to operate at peak efficiency, their batteries must be maintained in peak condition. This depends on timely charging, cooling and watering, and periodic inspection. The key to performing these tasks well is to monitor the battery consistently — not just to react when damage already has been done. The ultimate goal is to maintain a state of health as close as possible to 100 percent throughout the battery's life span. This is best accomplished by battery management system that integrate information about the truck, operator and battery to provide a broader perspective on battery performance. This allows for tracking of the battery as a wireless asset and monitoring of battery health while the truck is operating.

Lead-acid batteries almost can cost as much as a small lift truck, and yet the batteries rarely are optimized and can be misused in high-volume warehouses. A battery typically lasts about five years, or roughly 1,500 charge/discharge cycles, but if not maintained properly, the life of the battery can be reduced by 20 percent or more.

A battery management system delivers essential information on every battery on every truck. The information is available both to lift truck operators (to help them make timely day-to-day decisions) and to warehouse supervisors (who can see the big picture and monitor and adjust operating practices when appropriate. The system automatically monitors key battery parameters and provides hard data that helps users:

- Reduce battery replacement and save dollars
- Minimize electricity consumption
- Avoid overheating, overdischarge and other conditions that could cause battery damage or void warranties
- Accurately gauge fuel readings to help ensure timely charging
- Ensure that only the appropriate battery is placed on a given truck
- Collect and analyze data for record keeping and fleet management

As lift trucks' power plants, batteries are essential contributors to warehouse productivity, cost-efficiency, performance and profit. Digital management brings tools that help manage batteries, and thus lift truck fleets, with more precision and certainty.

10.2.2 Mobile Automation

Automated lift trucks provide the potential to minimize or eliminate the exposure of operators to cold storage environments. While full automation of the lift trucks most commonly used in cold storage environments is still in the future, capabilities, such as

auto positioning and assisted picking demonstrate the potential. Auto positioning allows turret trucks to take the most efficient path to its next location while assisted picking allows the operator to advance the truck from the aisle while picking, eliminating the need to get on and off the truck for each location change. Forklift manufacurers are building on technologies such as these to enhance forklift intelligence and develop more sophisticated positioning systems that will enable increased vehicle automation in the future.

Lift trucks will increasingly connect to equipment and systems beyond the fleet management system. The "connected forklift" will gather data on its environment and connect to material handling equipment, other forklifts and, through the fleet management system, to warehouse management and labor management systems. This increased connectivity will provide deeper insight into operations, enable productivity gains and support semi-automated and automated vehicle operation.

10.3 Maintenance

Properly planning a lift truck fleet and implementing a service schedule are critical to optimizing the fleet's uptime and productivity. To maximize efficiency and uptime, it is essential to follow a few steps to ensure the long-term health of any lift truck fleet, including planning for scheduled maintenance, considering who will conduct scheduled maintenance and what other resources — such as warranties and fleet management technologies — are available to aid in maintaining the health of the lift truck fleet.

10.3.1 Scheduled Maintenance

A quality scheduled maintenance program is essential to the longevity of a lift truck. This can include changing fluids and filters, adjusting lift chains, tightening hardware parts and ensuring proper lubrication. An electronic fleet maintenance management system provides a convenient platform for tracking and scheduling maintenance activities across a fleet of lift trucks. This helps ensure consistent execution of maintenance across the fleet, centralizes visibility into parts and service costs, and provides insight into reliability trends.

It is important to schedule maintenance based on hours of usage and level of activity. For example, a lift truck operating in certain applications may need scheduled maintenance every 500 hours of operation, while a lift truck in heavier-duty applications (such as a refrigerated environment) may require scheduled maintenance every 250 hours of operation. As part of regular maintenance practices, several other factors also should be considered:

- **Tires and Floors** — There are many different compounds for lift truck tires, and each is designed for a different application. Consider load weights, floor types and travel distances when choosing a tire. A properly chosen tire may not be the least expensive one, but it will be the most cost-effective in the long term because it will last longer. Anti-slip technology integrated into the truck controls can also

improve safety and extend tire life by reducing tire spin during acceleration, plugging and braking. This can be particularly valuable in cold environments where floors may be damp or wet. A simple way to prevent damage to tires, wheels and bearings is to keep floor conditions clean. Pallet pieces, debris and shrink wrap can get caught in lift truck wheels, causing damage and downtime. Repair damaged and uneven flooring to prevent damage to wheels and tires and to prevent trucks from damaging the undercarriage. Nevertheless, truck tires will wear over time and require replacement. Quick-change wheels are now available on some forklift models that reduce the time for wheel replacement from approximately 25 minutes to less than three minutes.

- **Batteries and Chargers** — An unmaintained or incorrectly sized battery can lead to additional maintenance. Ensure that each lift truck has the correct battery, and charge it only when necessary. Today's technology will indicate when the battery needs to be charged. Opportunity charging can shorten battery life, so it is best to follow a recommended charging schedule. To comply with battery warranty requirements, it may be necessary to keep detailed reports on the interval of charges, temperature, watering and equalization to validate battery maintenance. Operating a truck with a damaged battery or a battery with damaged cells can result in erroneous truck fault codes or even impact the reliability of the truck's electronics. Also, be certain that the correct battery charger is being used. If a charger isn't built to charge a larger battery, that battery will never fully charge, which ultimately will reduce the battery life and result in the need for more frequent charges.
- **Energy Efficiency** — A lift truck that is not energy efficient can create unnecessary cost and lead to reduced productivity. There are ways to ensure a lift truck is operating at peak energy efficiency. First, make sure the battery is operating at maximum capacity. When a lift truck battery is operating at low voltage, it makes up for the lost power by drawing more amps from the battery. The result is excessive heat and current draw, which can damage electronics and make a freezer or cooler work harder to maintain a consistent temperature. Second, make sure parts are properly fitted and lubricated to prevent unnecessary resistance, which can draw extra energy from the battery. A fleet management program can help evaluate energy efficiency by comparing battery draw and work performed.
- **Fluids** — The fluids used in the lift system and the drive unit differ based on the temperature of the environment. Applications with full-time freezer or cooler environments may use different fluids than those where the lift truck is moving from freezer/cooler to room temperature throughout the shift.
- **Electrical Omponents** — Some electrical components use sealants as a barrier/shield on connections to prevent condensation and malfunction resulting from moisture (condensation). Additionally, circuit cards are conformal coated and heaters are placed on LCD displays to ensure they operate properly within the environment.

- **Cold-Storage Applications** - Scheduled maintenance requirements are different for cold-storage applications. More frequent service intervals are required for constant freezer operations or when the application has sudden changes in temperature, such as going from freezer to room temperature as material is stored or retrieved.

10.3.2 Repair and Maintenance of Pallets

Start with Quality

Regardless of the types or sizes of pallets you use, proper care and maintenance will pay dividends in reduced commodity damage, safer handling and longer pallet life.

The first step is to be sure that you obtain quality pallets built to good specifications. Such pallets will

- use hard wood of low moisture content,
- contain boards free of defects, such as large knots, etc., and
- be assembled with drive screw nails.

Cost Considerations

Without question, pallets will get damaged and require repair or replacement. The decision to repair or replace is of paramount importance since excessive labor time can easily exceed the replacement cost of the pallet. To combat this dilemma, it is important to establish a Pallet Repair Program which, if properly maintained, can extend the life of your pallets and keep replacement costs low.

As a minimum, a well lighted, permanent work station should be established. Said station should contain all necessary tools required to support the program. Additionally, definite locations should be established for replacement parts which will minimize repair costs since on-hand-inventory can easily be seen and action taken when reorder time occurs. Finally, any damaged pallets encountered during the course of the work day should be sent into this area — at a designated spot — for further processing.

Repair

Repair of pallets should be part of your regular repair and maintenance program so that it does not become a haphazard procedure.

- Set aside all broken or damaged pallets in a special area reserved for this purpose.
- Don't let excessive numbers of unrepaired pallets accumulate. This makes the repair job much bigger and may result in a shortage of good pallets.
- Keep an adequate inventory of repair parts at all times. Buy extra deckboards, stringers and nails from your pallet manufacturer. He will probably sell them cheaper than you can buy them elsewhere and boards and stringers are cut to size.
- Pre-drill staggered nail holes in deckboards. This makes drive screw nails easier to drive and prevents split boards.

- Always replace split boards. To remove broken deckboards use a wrecking bar or a modified crowbar. Don't try to pull out remaining drive screw nails. They are usually hardened and can, therefore, be snapped off by hitting them sideways with a hammer.
- If a stringer is broken, a pallet can sometimes be repaired by leaving the broken stringer in place and nailing a new stringer along side of the broken one.

Proper Care

- Much repair work can be avoided by taking proper care of pallets. Here are some suggestions:
- Avoid rough handling. A good place to start is with stacks of reserve pallets. These stacks should not be so high that employees tend to drop them to the floor when removing them.
- Train pallet truck and fork truck operators in proper handling. Some common causes of accidents and damage are (a) careless insertion of forks, (b) turning too soon when removing loads from piles, failure to set loads down gently.
- Avoid dropping heavy loads such as barrels, drums, etc., on pallets.
- Keep hammers handy at reserve pallet stacks for hammering loose nails tight before use.
- Don't push or drag loaded pallets.
- Load pallets properly. Use a pallet pattern which will give a stable load. Avoid excessive overhang.
- See that aisle width and lighting are adequate for proper and safe operation of handling equipment.
- Keep pallets clean.
- If you use pallet trucks be sure the bottom end boards of pallets are well chamfered to permit easy access.

Additional Suggestions

Here are some additional suggestions which may be helpful in special situations where loss or damage is unusually severe:

Attach end deckboards to stringers with 3/8" diameter carriage bolts, making sure that the bolt head and nut are sunk flush with deckboards.

Rounding the outside corners of end deckboards may help reduce certain types of damage to both pallets and commodities.

Use steel strapping to reinforce pallets.

If you ship out loaded pallets for subsequent return or under an interchange program, identify your pallets with a stenciled code or company name or paint them with an identifying color.

Fork Truck Bumpers Can Lengthen Pallet Life

Fork truck tines can unnecessarily damage and shorten the Iife of pallets. Leading edge damage can be reduced by distributing the load across a wide surface, or by cushioning the fork's tines. A strip of 3/4 inch plywood, notched to fit over the tines, can be easily bolted to the forks. Bumpers cut from a rubber tire or discarded fire hose can be bolted or glued to the tines. Although this method does not distribute the load, the bumpers will cushion the leading edge of the pallet at the point of greatest impact.

10.3.3 Trained Technicians

Technicians who are well-trained on a piece of equipment will know how to repair it correctly and quickly. Many factory-trained technicians have access to software that can remotely identify a problem so a technician can quickly diagnose the problem and find the solution even before arriving at the facility.

An untrained technician may use the wrong parts or unnecessary parts, adding downtime and cost. A technician with proper understanding of the equipment can service the truck quickly and get the truck back up on service, often completing the work on the first visit.

If maintenance is being performed by internal resources, those in-house technicians should be trained by factory technicians and continue to have regular updates to stay on top of the latest products and technologies.

Whether internal or external resources are being used, it's important to ensure that all technicians comply with safety requirements and only use approved equipment for diagnostics and repair.

10.3.4 Vehicle Monitoring systems

Work with a lift truck provider to design a tailored fleet management program. By collecting and analyzing real-time lift truck data, companies can see how their lift trucks are being used and how many hours each truck operates. This information can be used to maximize fleet productivity and reduce costs. For example, this data can help determine if a lift truck is being used for the wrong job. Data may show that a reach truck is being used primarily for long horizontal transport, putting unnecessary wear on that truck. In that instance, a company can allocate a more appropriate lift truck in its place.

Vehicle monitoring systems also can help managers determine whether lift trucks are being used efficiently. If some trucks are in operation most of the day and others are sitting idle, it may be time to reduce the number of trucks or reallocate trucks for other applications. Opportunities to increase efficiencies and productivity can be identified by vehicle-monitoring-system consultants, who are provided by various lift truck manufacturers.

Another way that fleet management can reduce long-term costs is by enabling the evaluation of ongoing maintenance expenses for each truck. Once an older lift truck's maintenance costs exceed its usefulness, it becomes more cost-effective to invest in a new lift truck.

A well-maintained lift truck will provide reliable, long-lasting productivity at a low operating cost. Ongoing scheduled maintenance by trained technicians and real-time data analysis of the fleet will keep lift trucks working hard to contribute to the company's bottom line.

Chapter 11: Batteries

Acknowledgements

J.C. Marrella, United States Cold Storage, Inc., Cherry Hill, New Jersey, USA

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B.D. Tackett, United States Cold Storage, Inc., Cherry Hill, New Jersey, USA

Bill Wood, Battery Handling Systems, Inc., St. Louis, Missouri, USA

11.1 Introduction

A battery has three key components that allow electrical energy to be stored as chemical energy. The three components are a positive plate, negative plate, and electrolyte. All batteries undergo reduction / oxidation reactions in order to store electrons that will later be used to power the piece of equipment. There are several types of commercial batteries available which include, but are not limited to: alkaline, lithium, lead acid, and nickel-metal hydride. The lift truck industry is currently dominated by lead acid batteries for two reasons: the power they can generate and the cost they can be manufactured. Another good reason to use lead acid battery technology is the fact that the lead acid battery is 100 % recyclable.

11.2 Battery Room Design

11.2.1 Battery Room Overview

The battery room is an integral part of the day-day operations, and it is imperative to include its layout in the original floor plan of any warehouse. The location of the battery room should minimize the time spent traveling to and from the battery room and work areas. If the industrial lift truck fleet is dispersed throughout the warehouse or distribution center (DC), a centrally located battery room would be most efficient. For companies where industrial lift truck usage is primarily isolated to a specific area, it is recommended to locate the battery room near the area of highest usage. In larger environments, multiple battery rooms should be considered.

Figure 11. 1



The battery room should be located in an area that allows adequate space for traffic flow in and out of the room. Traffic aisles should be wide enough to allow industrial lift trucks to pass one another as required and should stay clear of obstructions. The size of the battery room is important. The planned area must be sufficient for the size of fleet it is servicing and should allow room for expected future growth.

Figure 11. 2



The battery room must have adequate electrical service and should be located near a main power feed, as distance from the power feed will increase costs. Chargers, ventilation, heating, cooling, and battery handling equipment all require electricity and should be considered when calculating the power requirements for the battery room. Plumbing, including drainage, will also be needed inside the battery room for battery filling and washing, as well as safety eye washes and showers.

11.2.2 Battery Handling Equipment

Weight is a significant safety concern with industrial lift truck batteries. Incorporating handling equipment to move, store, and maintain the batteries must be a priority in the planning of any battery room. Even the smallest battery fleet should have battery handling equipment available for maintenance purposes.

The ideal battery changer will efficiently handle battery changes as often as required. Eliminating a line of industrial lift trucks waiting for changes increases productivity. Considerations for selecting the appropriate battery handling equipment include:

- Overhead Extraction vs. Side Extraction
- Daily number of battery change-outs
- Space available for the system

Overhead Extraction

A fork attachment and lifting beam along with sufficient charging racks and/or service stands are suitable for the following applications:

1. Fleets requiring overhead extraction
2. Limited battery changes
3. Removal for maintenance

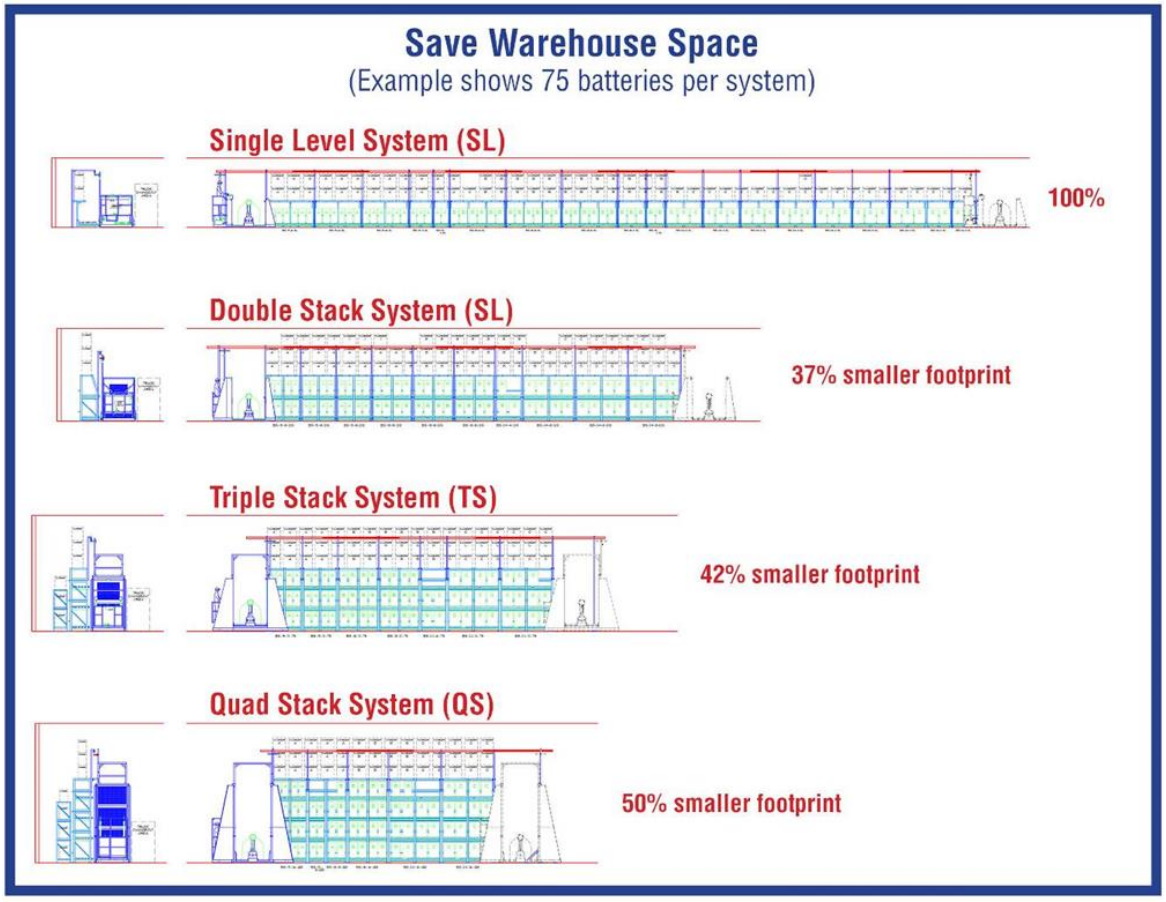
As an alternative, a small portable gantry crane would increase efficiency by eliminating the need for a second available industrial lift truck. Larger systems requiring multiple changes per day would benefit from a track mounted, powered gantry crane.

Side Extraction

For fleets with side extraction, choices are similar, but more options are available. Small park and charge operations may only require a manual transfer carriage and battery service stand for battery maintenance purposes. Multi-shift operations with a small fleet and minimal battery changes per day may find that a powered transfer carriage will make the battery changing process more efficient and then the manual transfer carriage.

For maximum efficiency in larger fleet operations, a fully powered Operator Aboard Battery Extractor will be required. Operator Aboard Battery Extractors are available in multi-level systems. Deciding which system is right depends on space availability and the number of batteries to be stored. Ceiling height of the battery room may eliminate some options. Depending on the charger quantities, specifications, and stackability, the system layout may require additional charger storage stands. Increasing the system height can save between 10% and 50% of floor space *(see figure 11.3 below)*.

Figure 11. 3



It is common for an industrial lift truck and battery fleet to consist of multiple types and sizes. It is important that the battery handling equipment is designed to safely transport all of the batteries in your fleet.

BHS Equipment Application Guide

The following chart may assist in determining the proper battery handling safety (BHS) equipment according to the number of stored batteries in the warehouse.

Number of Stored Batteries	BHS Equipment Recommendation	Change-out Time	Type of Extraction
1 – 49	BE-SL (Single Level)	2 – 3 minutes	Operator Aboard Side Extraction
40 – 139	BE-DS (Double Stack)	2 – 3 minutes	Operator Aboard Side Extraction

140 – 299	BE-TS (Triple Stack)	2 – 3 minutes	Operator Aboard Side Extraction
300 – 619	BE-QS (Quad Stack)	2 – 3 minutes	Operator Aboard Side Extraction
Up to 50 Batteries	MBE (Mobile Battery Extractor)	3 – 5 minutes	Side Extraction
15 – 18	ATC (Automatic Transfer Carriage)	3 – 5 minutes	Side Extraction
2 – 3	BTC (Battery Transfer Carriage)	5 – 8 minutes	Side Extraction



BHS BE-DS BHS ATC BHS MBE BHS BTC

11.2.3 Maintenance

Daily inspections by trained operators along with planned maintenance are vital to the battery handling equipment's functionality and operator's safety.

Frequent inspections support the prevention of system malfunctions while planned maintenance, such as lubrication and cleaning, ensure proper system operation. It is imperative that all battery handling equipment sustain a scheduled maintenance program. The battery handling equipment's owner and operator manual should be referenced for maintenance checklists and intervals. In addition, the BHS Service School is offered as an excellent tool to advance the knowledge of the battery handling equipment's operators and technicians.

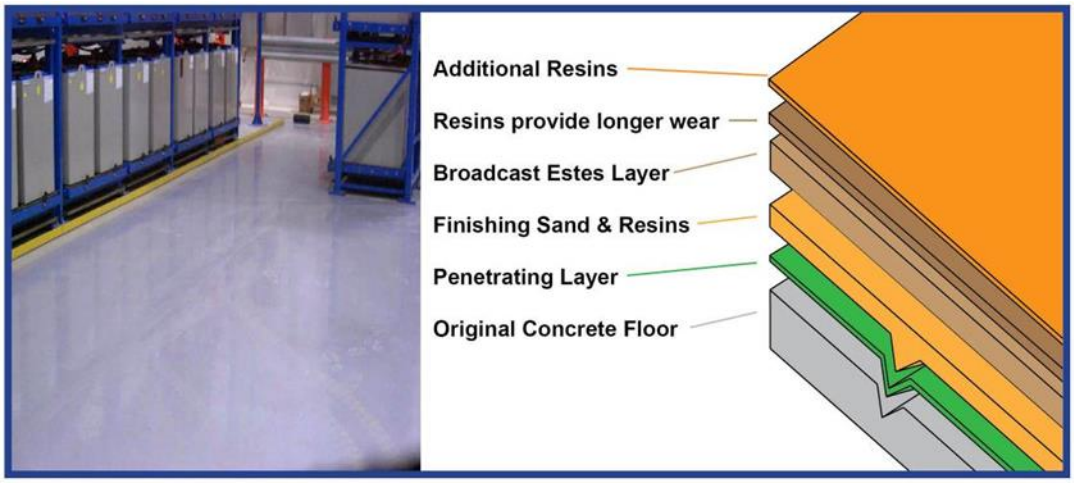
11.2.4 Battery Room Floors

The floor of the battery room should be code approved flooring which resists acid damage. Consult applicable building codes and regulations issued by the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the National Fire Protection Association (NFPA), and others. The BHS Operator Aboard Battery Extractor operates on a fixed travel path that requires a defined specification.

An uneven floor in a fixed travel path causes vibration, flexing, and stress on equipment resulting in decreased productivity of the Operator Aboard Battery Extractor. Lift heights of battery extractor systems magnify the effect of an uneven floor. As elevation increases, so does the amount of flex and strain on the machine. A floor with an

appropriate F-min rating provides for safe and proper operation of your equipment. Consequently, you will save money with fewer repairs, fewer parts purchased, less downtime, and less potential for personal injury or equipment damage.

Figure 11. 4 Recommended floor layers in a battery room



A single number, F-min, is used to measure the floor flatness and levelness for defined traffic paths. F-min rating results from four different F-numbers representing the floor's longitudinal levelness, longitudinal flatness, transverse levelness, and transverse flatness. The floor is measured along the exact travel path that each wheel of the Operator Aboard Battery Extractor follows. Changes in elevation along each wheel path are used to determine whether the floor meets the specified F-min requirements. Any area of the path that falls outside of the specification is identified for correction as part of the measurement process. As systems increase in height, any defects in the floor further amplify both static and dynamic shifts of the load while traveling.

Defined Traffic Floor Requirements for Operator Aboard Battery Extractor Travel Path

Table 11. 1 Minimum F-min requirements to ensure satisfactory operation.

American Concrete Institute 117 (ACI 360)	
Machine Type	**F-min**
SL, DS	40
TS	60
QS	85

Note: Contact factory if seismic certification is needed.

11.2.5 Battery Management

Improper battery rotation is a leading cause of reduced battery run time and reduced battery life. Tests have shown that when battery selection is left to an operator, thirty percent of batteries will be underutilized while another 20% will be overused.

Underutilized batteries will lose capacity due to corrosion on the plates. Over utilized batteries do not have time to cool and become over-heated, causing corrosion which leads to a shortened life. Proper rotation of all batteries is required in order to ensure maximum battery life and run time. Selecting the battery that has the longest cool down time since charging ensures proper rotation.

First-in-first-out systems, such as BHS' FleetTracker, select the next available battery based on the battery's time on the rack. The battery which has been on the rack the longest will be logically selected, as it is the battery which has had the longest cool time after charging. This type of system requires no input from the chargers or the batteries, so there is no additional wiring, or modules to connect. The system can track multiple battery types. The addition or removal of batteries, racks, or trucks can be done simply at any time. The FleetTracker system also alerts operators when batteries require equalization, washing, or watering based on parameters set by the user during setup. Unauthorized use of the extractor can be prevented by requiring a user to login to the FleetTracker in order to activate machine travel. All transactions are recorded and all information is available for review in a variety of reports. These reports track battery and truck usage, maintenance intervals, and operator performance. Review of the battery and truck usage may identify shortages or overages in fleet availability. This allows the battery room to be "right-sized", avoiding costly wastes of time, space, and energy.

Figure 11. 5 FIFO BHS FleetTracker Battery Tracking System



Multiple charger monitoring systems, like the BHS NAB-2000, utilize the same first-in-first-out theory, but do so by monitoring the charge state of all of the batteries on charge. Remote modules on each charger monitor charger output and queue the batteries in the order charging was completed. Again, the battery with the longest cool down time is shown as the next available. If no batteries have completed charge, batteries are displayed in order of most fully charged. By monitoring the charger output, the NAB-2000 can also alert operators when a charger does not come on, when chargers shut off prior to the battery reaching an 80% charge, or when chargers do not shut off after 15 hours of runtime.

Figure 11. 6 Multiple Batter Charger Monitoring System



Regardless of the system chosen, ensuring that batteries are properly rotated, even by simply recording information manually, will not only increase the lifespan of the batteries but also the overall efficiency of the battery room.

11.2.6 Charger Storage

To save floor space and comply with OSHA regulations, chargers should be mounted to shelves or stands designed for that purpose. Many charger layout variations are available depending on the size of the fleet and space requirements. The chargers must be mounted securely in all four corners, regardless of the quantity. Chargers can often be stacked, but it is important to follow all manufacturer's instructions and recommendations. Manufacturer's instructions must also be followed when spacing the chargers to allow adequate ventilation during use.

When positioning battery charger cabinets, consideration should be given to the charger DC cable lead length. It is important to design the battery charger layout in a manner that enables the charger DC cable leads to connect to the battery, yet ensures that the charger manufacturer DC cable lead length specification is not exceeded.

Accommodations should be made for charger maintenance during the design of the battery room layout. The incorporation of a catwalk and/or multi-level charger shelves into the overall system design allows for easy accessibility to the chargers.

11.2.7 Safety

Safety equipment is essential in the design and planning of the battery room. Proper planning is necessary in order to provide a safe and productive environment for those operating and maintaining the equipment. Hydrogen gas can reach dangerous levels in the warehouse. It may be required to install hydrogen gas detectors which will activate ventilation and alarms when this occurs. Installation of emergency wash equipment is imperative. Personal protective equipment must be available to machine operators and maintenance personnel. This equipment includes acid-resistant face shield, goggles, gloves and apron. Nonconductive tools for maintenance must also be supplied. It is necessary to keep spill kits on site to control spills of dangerous materials such as battery acid.

As part of all safety programs, it is important that warehouse management properly train personnel. Operators must be trained on the proper operation of the battery handling equipment. This training includes daily inspections which help to determine that the equipment is in proper operating condition and safe for use. Personnel must also be trained on the use of the personal protective equipment. Appropriate signage denoting locations of safety equipment must be present. Other signage marking travel paths, pedestrian warnings and other safety related information are also recommended.

11.2.8 Personnel

The proper training and management of the battery handling equipment is crucial in determining its lifespan and efficiency. It is recommended to assign a dedicated battery handling equipment operator to manage all industrial lift truck battery change-outs as well as the battery handling equipment's maintenance. A dedicated operator is responsible for performing the daily inspections, planned maintenance, and all repairs thus heightening his or her familiarity with the battery handling equipment and its functions. Implementation of a dedicated operator increases productivity and ensures the battery handling equipment's preservation.

11.3 Battery Design

This section provides basic information to understand how batteries and chargers react and perform during their daily use in a warehouse. This section will also discuss effective ways to charge batteries to get the longest life.

11.3.1 Design Overview

What is a lead acid battery? Lead acid batteries were invented in 1859 by Gaston Plante. It is the oldest form of a rechargeable battery. It is a unique battery in the fact that both the positive and negative plates become lead sulfate when the battery is discharged, most batteries have two different types of material for their positive and negative plates. The electrolyte used in all lead acid batteries is sulfuric acid. Because two of the major components of the battery are made of lead, a lead acid battery has two major disadvantages to other battery technologies: low energy to weight and energy to volume ratios. The first is not as much of a disadvantage when used in forklift trucks because most batteries are a significant part of the counterbalance requirement of the forklift truck. However, these disadvantages mean that the batteries need to be fairly large and very heavy to supply the energy needed to run a forklift truck.

Battery charging is typically done one of two ways. It is either done in a two-stage process, or a three-stage process. The two-stage process is much easier for charger manufactures to write controls and algorithms, so early on this type of charge dominated the market. They soon realized that this type of charge had some detrimental effects to batteries if the charger was under or oversized. Usually the charger was under sized to save money and hence the battery would not get enough ampere-hours returned to bring the battery to a full state of charge. This undercharge would cause a significant reduction

in battery life. The over sizing of a charger also causes a significant reduction in battery life do to over charging the battery which creates heat and excess sediment to deposit on the bottom of the cell or cover the sides of the plate (mossing.) In either case this sediment would then cause a short between the positive and negative plate and cause the battery to not perform. As control boards and circuitry technology improved, the charger manufactures realized they could help prevent these two problems by going to a three-stage charge. The three-stage charger has a constant current portion to top off the battery once it reaches about 80 to 90 percent state of charge. This allows the battery to get the right amount of over charge so that the life of the battery is not significantly affected.

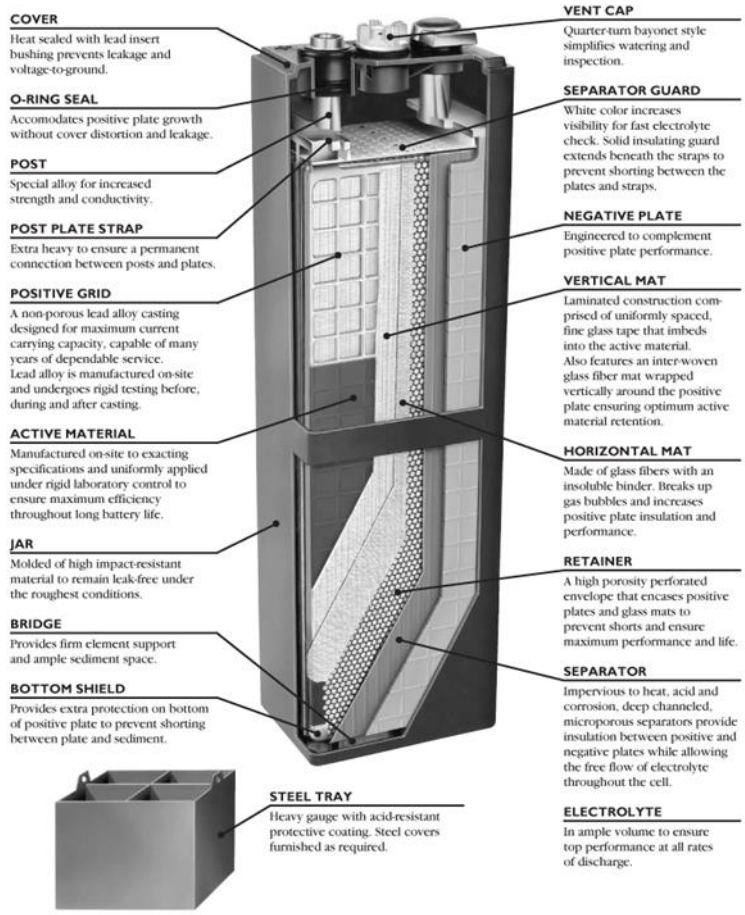
11.3.2 Terms and Definitions

- **Battery Rating** - The amount of power a battery can give over a specific time period. In order to get more power, either cells need to be added, or plates per cell need to be increased.
- **Battery Voltage** - The number of cells is determined by the required nominal operating voltage of the equipment. Since each cell has a nominal of two volts, a thirty-six-volt industrial lift truck will require an eighteen-cell battery (2 volts/cells * 18 cells = 36 volts.)
- **Ampere-hour (AH)** - The electrical capability of a storage battery is usually expressed in ampere-hours. The ampere-hour capacity is the number of ampere-hours which can be delivered under specified conditions of temperature, rate of discharge, and final voltage. Basically, ampere-hours are determined by multiplying the number of amperes which the battery will deliver by the number of hours during which the current is flowing.
- **Positive Plate Capacity** - Positive plate capacity is the ampere delivery for a fixed period of time (usually six hours) for a particular size positive plate. Example: A Deka D100 type positive plate has the capability of delivering 16.66 amperes for six hours or hundred ampere-hours (16.66 amperes * 6 hours = 100 ampere-hours) to a final voltage of 1.70. Increasing or decreasing the number of positive plates in the cell can vary this ampere-hour rating or capacity. To determine the battery capacity, take the total number of plates and subtract one. The answer is then divided by two and multiplied by the rating of the plate.

Example: The previous example is an 18-D100-13 battery. So, 13 plates – 1 plate / 2 = 6 plates * 100 ampere-hours / plate = 600 Ampere-hours.

- **Specific Gravity** - The term specific gravity describes the ratio of the density of electrolyte to the density of water. Electrolyte weighing 1.2 times as much as the same value of water has a specific gravity of 1.200. The full charge specific gravity of a cell is a matter of design and depends on several factors. The specific gravity must be high enough to contain the amount of sulfuric acid necessary to meet the chemical demand of the cell. If the sulfuric acid content is too high, damage may result to the cell. Since the acid content of the electrolyte decreases linearly as the cell is discharged, a decrease in the specific gravity is directly proportional to the amount of ampere-hours removed.

Figure 11. 7 Basic components of a battery cell and their functions



11.4 Battery Maintenance

There are several keys steps that should be followed when receiving a new battery to put into service. First, if there are any signs of rough handling, damage to the battery, or electrolyte leakage file a claim with the carrier immediately and advice your battery consultant. Once the battery is received check each cell and insure that the electrolyte level is above the separator protector. In taller cells, enough gas may have been displaced during shipment to drop the level just below the separator protector, but should be visible with a flash light through the holes in the protector. If the electrolyte is not visible contact your battery consultant. If the electrolyte level is ok the battery may be given its initial charge.

Check the nameplate of your charger against the nameplate of the battery to ensure that they both show the same voltage and that the six-hour ampere-hour capacity falls within the eight-hour recharge range of the charger. If both of these items do not match,

contact your battery consultant. The next step is to ensure the battery is the proper type for the industrial lift truck in which it will be installed. The voltage of the battery and the truck should agree as well as the "Battery Type Identification" (E, EO, EE, or EX). The service weight of the battery which is stamped on the side of the tray below the lifting hole must fall within the battery weight range on the truck nameplate. This is necessary so the truck has enough counterbalance so as not to tip over when lifting. Finally, give the battery an equalize charge and ensure the electrolyte levels are visible above the separator protector and the specific gravity is between 1.280 – 1.295 when temperature corrected to 77° F (25° C).

Upon installation in the truck, all the battery restraints should be adjusted so that the battery moves no more than ½ inch in the horizontal direction. An insulated spreader bar should be used any time the battery is lifted or hoisted. Batteries should not be discharged more than 80 % of their rated capacity to achieve longest battery life.

All batteries must be properly maintained, or there will be a significant reduction in battery life and efficiency. A good battery maintenance program needs to keep accurate records of battery cycles and repair / maintenance work done to all batteries. Another part of the maintenance program is regular battery inspections. A visual inspection of the battery every time the battery is put into or out of service will help maintain a proper battery. Keys things to look for during the battery inspection are: Corrosion on the tray, terminals, or intercell connectors; leaks or damage to the cell; damaged cable leads, terminals, or connectors; and damaged, clogged, or missing vent caps. All of these items should be repaired as soon as they are found to ensure long battery life and efficiency. A major hurtle for battery maintenance is to water the battery cells on a weekly basis (1 time per 7 days) unless the application requires more frequent watering. A battery should be watered either during or just after an equalize charge. Only approved water should be used to water cells because certain impurities reduce battery life and efficiencies. The last general rule is to equalize your battery on a weekly basis to ensure that all sulfates are removed from the plates and thoroughly mixed into the electrolyte. An equalize charge also is responsible for evening out the cells. There is always a weak cell in a battery that requires a little more charge than the others to get the voltage back, or the specific gravity into nameplate rating. This additional charge every week at or close to the finish rate is able to do that and keep the battery healthier for a longer period of time.

Table 11. 2 Suggested battery inspection schedule

	Daily	Weekly	Monthly	Quarterly
Visual Inspection	X			
Electrolyte Level		X		
Addition of Water		X		
Equalize		X		
Specific Gravity			X	
Clean Top of Battery			X	
Battery Cables			X	
Charger output				X
Water System Injectors				X
Battery Cell Voltage				X

To determine the health of a battery or whether or not the battery should be replaced, a discharge test (capacity test) should be performed. The test is conducted by discharging a fully charged battery at the six-hour rate until the battery voltage drops to a final voltage of 1.70 volts per cell, times the number of cells in the battery. The six-hour rate in amps is a number equal to the rated capacity at the six-hour rate divided by six hours. By noting the elapsed time when the battery reaches the final voltage, you can determine if the battery is delivering its rated capacity. Take the elapsed time in minutes and divide by 360 and then multiply by 100. This calculation is the battery's capacity. A battery should deliver at least 80 percent of its rated capacity or should be replaced.

In order to receive the longest life of a battery, a pilot cell should be chosen upon receipt of the battery. This cell should be near the middle of the battery and can be marked in some way to distinguish it. Before and after every charge cell this pilot cell should have its voltage, temperature, and specific gravity recorded. This data should be recorded and trended over time to help determine the battery health. If any of these readings start to deviate from the original reading your battery consultant should be contacted immediately. The remaining cells of the battery should be compared to this cell on a monthly basis in order to determine their health. If any of these cells deviate from the pilot cell, your battery consultant should be contacted immediately. It is much easier to correct an issue the earlier it is detected, and there is less loss of life on the battery with the issue being corrected as quickly as possible. For instructions on the best practices to obtain these readings contact your battery consultant.

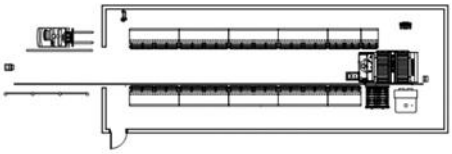
11.5 Power Lift Technologies

This section will act as a guide to various power technologies and their impact on the building design. The most common forms of power technology are lead acid batteries, fuel cells, and lithium ion. Various charging methods for lead acid batteries will also be explored. The selection of a power technology will have a direct impact on operations, work flow, and power cost. Traditional lead acid batteries and battery charging methods for material handling equipment have changed in recent years. The traditional means of

centralized charging of lead acid batteries is also being challenged. Charging methods of lead acid batteries now ranges from traditional battery rooms to opportunity and fast charge systems. Fast charging utilizes newer power electronics to provide energy to industrial batteries very quickly. Challenging lead acid batteries are other technologies influencing conventional material handling equipment including newer battery technology with lithium ion batteries and the use of hydrogen fuel cells. Selection of a power technology has long term effects on the building design, operation, and energy costs of a facility.

11.5.1 Lead Acid Batteries

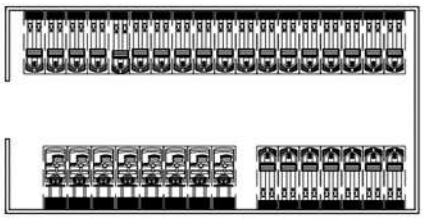
Figure 11. 8



CENTRAL BATTERY
HANDLING/ CHARGING

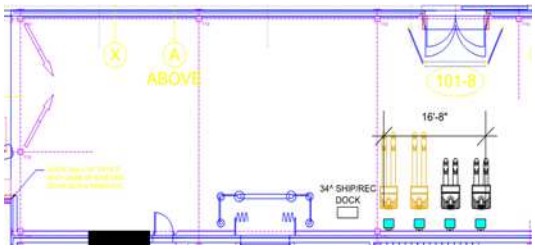
Lead Acid Battery Fast Charge

Figure 11.9



CENTRALIZED
PARK & CHARGE

Figure 11.10 Fast Charge on a Dock



Lead acid batteries are the most common power technology used in the cold storage warehouses. Large industrial batteries are charged with electric current. These batteries serve as the primary power source for most material handling equipment.

The motive power battery/industrial lead acid battery is an assembly of cells used for the primary purpose of propelling a vehicle.

Discharge Process: As the cell discharges, the acid separates from the electrolyte in the pores of the plate and attaches itself to the plate material changing it into lead sulfate. The process continues throughout the discharge and as it proceeds, the remaining solution becomes more water than acid. The acid is the conductor and the water is an insulator causing the energy transfer process to become less and less efficient between the plates.

Charge Process: When the cell is placed on charge the process is reversed. The SO_4 (Acid) is driven out of the active plate material back into solution thus increasing the specific gravity in the solution. As the charge is completed all components of the battery are back to their original make up (positive is lead peroxide (PbO_2); Negatives, sponge lead (Pb)) and the acid is back into the electrolyte solution.

Battery Life Expectancy: Except for lightly-worked or infrequently-cycled batteries whose life is likely to exceed normal expectancy, most battery applications are sized to run one shift for 5-6 years in typical change out applications and 3-5 in opportunity or fast charge applications. Other factors influencing battery life are: operating temperature, quality and design of battery, quality of charging, watering practice, cleanliness, acid loss, and grounding.

Normal Life Expectancies: Assuming 300 cycles per year and discharges limited to 80% of rating, good charging and proper care, the normal life expectancies are five years for flat-plate and six years for tubular. Whenever a shortened battery life is detected, examine the life-influencing factors as noted above, as well as the cycle rate and depth of discharge. In claims of short life, it is often found that the battery was short-life in time only, but delivered a normal number of cycles or amp hours

When operating in cold environments, the average lift truck battery life cycle and rate of charge can decline by 20% - 50%, meaning a battery rated for an 8-hour cycle in ambient warehouses might only last 4 to 6 hours in the cold. The capacity of a lead acid battery is reduced at low temperatures due to the increased viscosity and resistance of the electrolyte.

An approximation of this reduction in capacity for batteries of these types is shown below:

Internal Temperature of Cell (°F) Percent Capacity

77° = 100%

60° = 095%

40° = 087%

20° = 073%

In the coldest freezer applications, it may be necessary to exchange the battery up to 5 times in one day. Batteries operating at sub-normal temperatures, due either to climate or to working in cold-storage plants, will have their electrical capacity reduced. This in turn will impair vehicle performance.

Charging: Batteries that are cold are harder to charge and the charger must be set to put out more current to get the job done. Some chargers will have a setting for temperature correction in cold storage environments. It is imperative that all batteries being used in Freezer Applications are charged on a charger with a specific charge profile developed to deal with heavier acid densities and higher battery resistances (i.e. - Cold Storage Charger). It is advised that when looking at charging equipment being used in these applications that the charger have the capability to have the ambient average

temperature as an adjustable setting in the program to arrange the proper charge profile for the operations batteries.

A lead-acid motive power battery can be an extremely useful, safe, source of electrical power. On the other hand, if improperly used, it can be an extremely dangerous piece of equipment. The difference between the two conditions is determined by the care and safety procedures exercised in handling batteries. Before considering the safety procedures, first consider the hazards inherent to a lead-acid battery.

Safety Hazards: A lead-acid battery, by its very construction, exposes working personnel to four potentially dangerous elements: sulfuric acid, explosive gases, electricity and heavy weight.

A sulfuric acid solution is used as the electrolyte in lead-acid storage batteries and has a concentration of approximately 40% by weight of sulfuric acid in water. Even in this diluted state, sulfuric acid is a strong oxidizing agent and can burn the skin and eyes and "eat" holes in clothes made of many common materials.

An explosive mixture of oxygen and hydrogen is produced in a lead-acid storage battery during the charging process. The two gases can combine explosively if a spark or flame ignite them. Because hydrogen is so light, it normally floats away and disperses into the air before it can collect into an explosive mixture. However, if it accumulates into gas pockets, it will explode when ignited.

A lead-acid battery is capable of discharging at extremely high rates and under conditions of direct shorting, which can cause much damage and serious injury. The weight of these heavy batteries can crush hands and feet if care is not taken when charging and handling them. Adequate and proper handling equipment should be provided. The average lift truck battery weighs over 2000 pounds.

Ventilation and Fan cost can be as high as $8 per square foot and depending on location may need to meet specific codes. Reference Mechanical Ventilation and Institute of Electrical and Electronic Engineers (IEEE) Standard 484-2002. Additionally, Fire Suppression guidelines may need to be followed Such as NFPA-13.

Battery Costs: Operators using electric vehicles will need to add the battery and charger to the cost of the lift truck. Continuing to compare the 2,000-hour per year operation or 167 hour per month, data suggests electric lift trucks use 3 to 4 kWh per hour. In that operation, the expected monthly usage on the electric vehicle would be 500 – 700 kWh per month. Assigning the proper battery for that operation depends on the client's operation and available time to recharge the battery. These constraints will affect the price of the power because of the amount of the power needing to be returned. If the operator has more time to charge the batteries, a smaller charger may be used resulting in decreased costs.

Monthly Cost of a Forklift's Battery and Charger: Using 167 hours per month over a five-day workweek, the daily usage of approximately eight hours yields a 24 to 32 kWh usage by the electric lift truck. In this example, a 40-kWh battery would provide the necessary power to complete the daily usage. In smaller footprint vehicles, two 20 kWh

batteries could fulfill the energy requirement. The estimated price for a 40-kWh battery and high efficiency charger at the end of 2016 is approximately $ 10,000.

Note: (Specify specific scenario to be used for comparison on all power methods)

Cost to Charge an Electric Forklift Battery: Assumptions of the higher energy usage of the Electric vehicle will be calculated at 40 kWh per day or 700 kWh per month. According to the Department of Energy estimates the national cost of energy at $ 0.09 cents per kWh. Accounting for the recharge efficiencies of forklift chargers in lead acid batteries, a conservative estimate of 25 % can be added for estimations. Monthly estimates of 700 kWh + 25% = 875 kWh used each month. At $ 0.09 cents per kWh, the operator would see a monthly cost of $ 79.00 in electricity costs per battery.

Peak Demand: In some locations Monthly Peak Demand Charges could be increased due to concurrent multiple batteries charging. Care should be taken to schedule charging during off peak times when refrigeration load is at its lowest point to avoid setting a new peak demand while charging multiple batteries at the same time.

Maintenance Costs: PM Costs are approximately $80 per year per battery and charger, excluding parts costs.

Battery Watering: Lead acid batteries need weekly maintenance. As the cell approaches full charge it cannot absorb all the charging current. The excess charge breaks up the water which passes off the battery as the gases of hydrogen and oxygen. This lowers the water content of the cell which typically requires the function of replacing the water on a weekly basis.

Operator Costs: When a battery suffers a loss of charge it must be swapped out with a fully charged battery. A single battery change takes somewhere between 10-15 minutes. In a large warehouses a battery handling system operator may be required, resulting in an additional full time position at the approximate cost of $35,000-$50,000 per year per shift.

Battery Room: A battery room with an extractor is typically 1,500-2,000 sq. ft. Construction of the dedicated charging room is an expected cost of $65,000 – $140,000

- Construction of the dedicated charging area- $30-$40 per square foot
- Ventilation fan and duct work- $5-$8 per square foot
- Special floor coating to protect against acid spills- $9-$12 per square foot
- Additional cost: roll up door $20,000

Cost of Ownership: Based on a facility having 100 Batteries and 50 Chargers the following costs could be expected to purchase and operate lead acid batteries. It would be expected that you would need to replace the Batteries sometime between year 5 and year 10.

Lead Acid Battery Central Battery Charging/ extractor	
Construciton Cost	$ 140,000
Equipment Cost	$ 797,500
Operation and Energy Cost	$ 427,750
Year 1 Cost	$ 1,365,250
1 year cost per battery	$ 13,653
5 year cost per battery	$ 30,763
10 yer cost per battery	$ 60,125

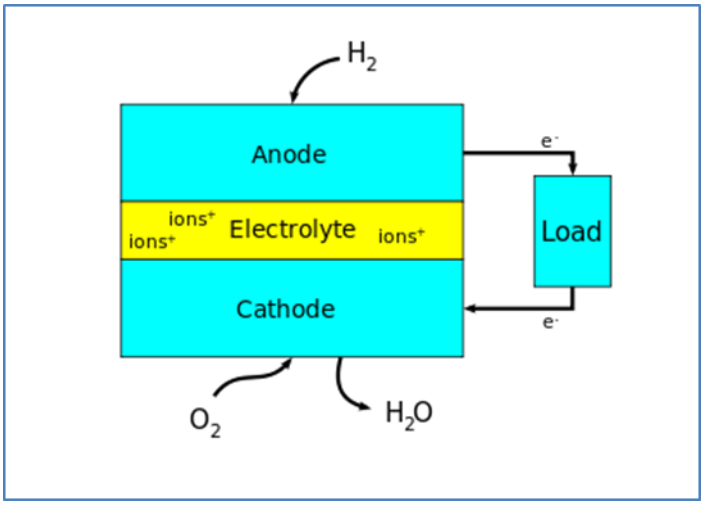
Lead Acid Battery Centrelized Park and Charge	
Construciton Cost	$ 350,000
Equipment Cost	$ 747,500
Operation and Energy Cost	$ 427,750
Year 1 Cost	$ 1,525,250
1 year cost per battery	$ 15,253
5 year cost per battery	$ 32,363
10 yer cost per battery	$ 61,225

11.5.2 Fuel Cells

Fuel Cell Technology

Fuel cells, or more specific hydrogen driven fuel cells, combine chemically hydrogen and oxygen, generating electricity and heat.

Figure 11.9 Fuel Cell, Block Diagram



There are different types of fuel cell technologies. The best selection for fork lift application is based on operating temperature, the lower the better, see Figure 11.12. We also can exclude methanol powered fuel cells because carbo dioxide is the product of the process and will be release into the environment. Conclusion: PEM Polymer Electrolyte Membrane Fuel Cells are the preferred fuel cells for forklifts.

Figure 11. 10

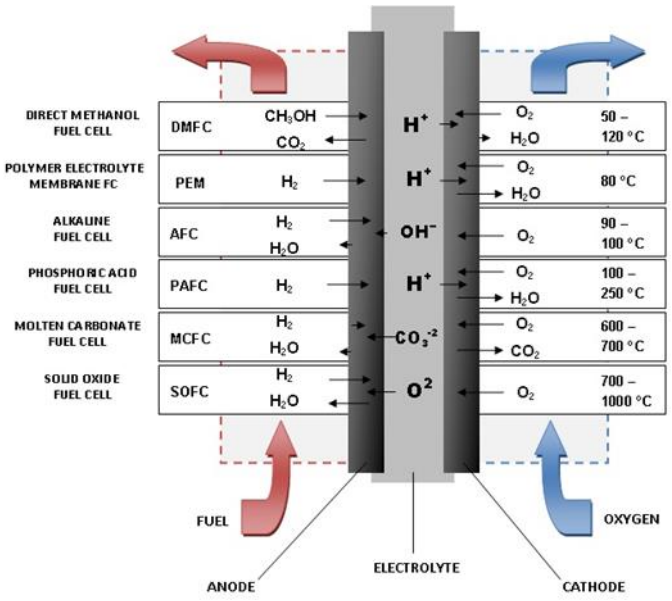
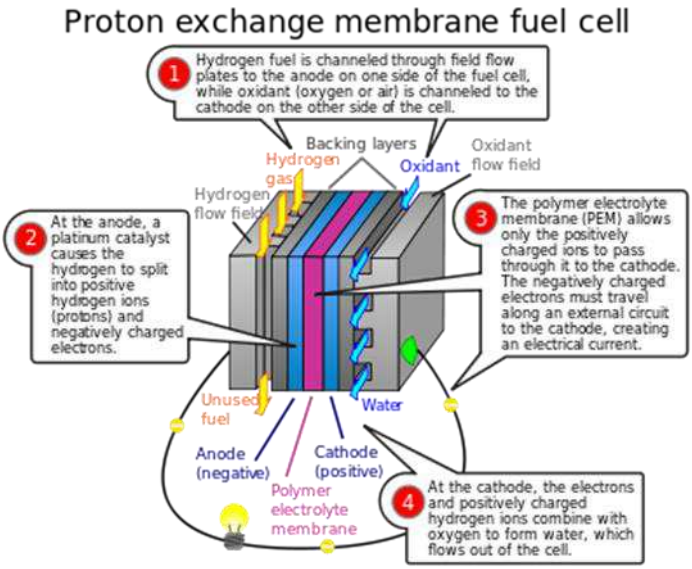


Figure 11.13 shows more details of a PEM fuel cell. Typical efficiency of PEM FC is between 50% and 70%.

Figure 11. 11 Proton Exchange Membrane Fuel Cell



Operation

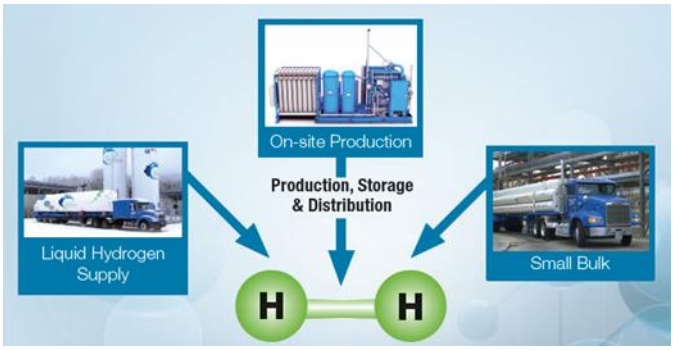
Fuel cells can work in low temperature refrigerated warehouses. The typical operating temperatures are from -40°C (-40°F) to +50°C (122°F). Thus, fuel cell powered material handling equipment (MHE) is an alternative to battery powered MHE. While batteries have to be recharged with long recharging times fuel cells will be reloaded in a

few minutes. Fuel cells also have a longer operating time between refueling compared to batteries.

Figure 11. 12



Figure 11. 13



The necessary infrastructure consists of dispensers and either hydrogen storage or hydrogen generator at the facility (figure 11.15). Existing MHE's can be retrofit with fuel cells. The small foot-print dispensers or refueling stations can be conveniently located into existing space (figures 11.16 & 11.17). For smaller facilities and where there is no space for onsite hydrogen generation storage cabinets can be distributed to meet facility requirements (figures 11.18 & 11.19). Where applicable onsite hydrogen generators may be a good alternative to being dependent on hydrogen suppliers, in particular when installed before the end of 2016, because the cost can be reduced by a 30% federal investment credit. It is estimated that an onsite hydrogen generator is financial feasible for fleets of 40 forklifts and more (figure 11.19).

Figure 11. 14



Figure 11. 15



Figure 11. 16 Hydrogen Storage Cabinet



Figure 11. 17 Outside Hydrogen Generator and Storage Unit

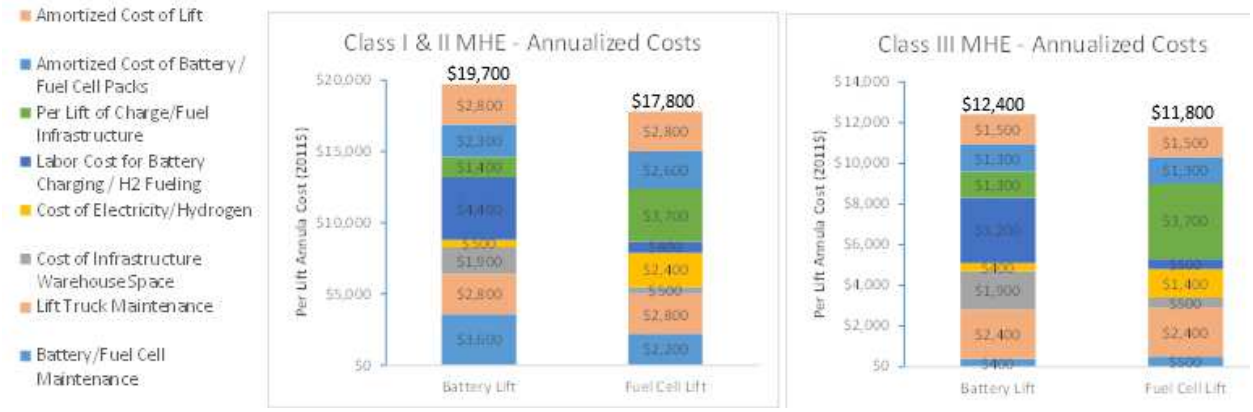


Cost of Operation

Typical cost for fuel cell is estimated to be between $14,000 and $30,000. The average fuel cell system lifetime is 10 years, with the fuel cell stacks refurbished every 3 years. The cost of hydrogen (including delivery and storage) is priced at $8.00 per kilogram.

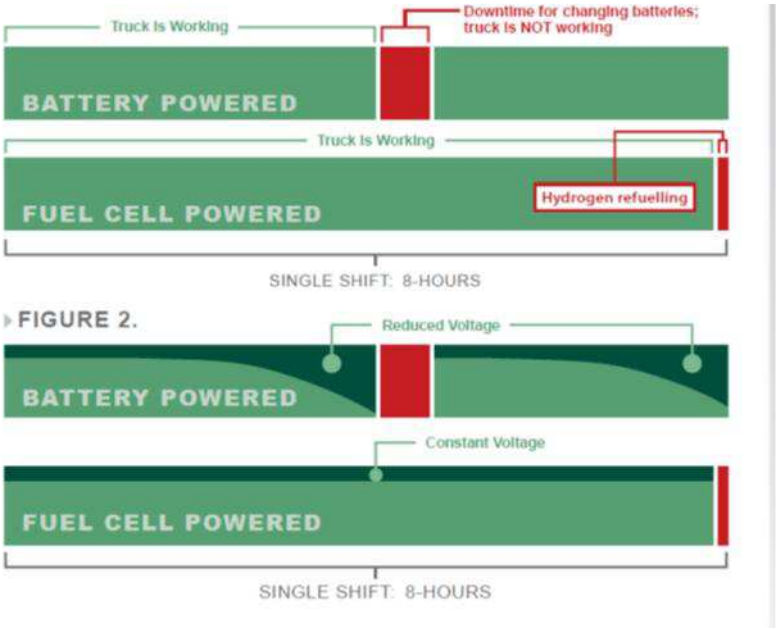
NREL published a report called "An Evaluation of the Total Cost of Ownership of Fuel Cell-Powered Material Handling Equipment" in April 2013. The evaluation was done for a fleet of about 60 lifts for 2 -3 shifts per day, 6 – 7 days a week. NREL found that for Class I and II forklifts (three- and four-wheel, sit-down, counter-balanced forklifts) used in multi-shift operations, fuel cell could reduce the overall cost of ownership by 10%, from $19,700 per year per lift truck to $17,800 per year per lift truck. The cost of ownership of Class III forklifts (also known as pallet jacks) can be reduced by 5% from $12,400 per year to $11,800 per year for each lift truck. Details are shown in figure 11.20.

Figure 11. 18 Total annual cost of ownership of battery & fuel cell Material Handling Equipment. Source: NREL/TP-5600-56408



NRELs evaluation doesn't include potential benefits of fuel cell MHE – Material Handling Equipment such as improved productivity. It is expected that fuel cell powered forklifts deliver a 2 – 5% productivity gain versus battery-powered vehicles, since there is no need for battery recharging and servicing. Hydrogen-powered vehicles can be refueled from conveniently located fueling stations in less than four minutes, reducing down time and elimination the need for dedicated battery-charging area and support. A major advantage over batteries is the 100% power availability, while the power of batteries starts to drop typically after 6 hours.

Figure 11. 19 Driving Productivity.



Source: Ballard "Economics of Fuel Cell Solutions for Material Handling"

Maintenance

Fuel cells are low maintenance. Fuel cells operate maintenance free. Typically, they require maintenance every three years or 10,000 hours refurbishing the fuel cell stacks. The expected lifetime is ten years or more.

Safety

Most fuels have high energy content and must be handled properly to be safe. Hydrogen is no different. In general, hydrogen is neither more nor less inherently hazardous than gasoline, propane, or methane. As with any fuel, safe handling depends on knowledge of its particular physical, chemical, and thermal properties and consideration of safe ways to accommodate those properties. Hydrogen, handled with this knowledge, is a safe fuel. Hydrogen has been safely produced, stored, transported, and used in large amounts in industry by following standard practices that have been established in the past 50 years. These practices can also be emulated in non-industrial uses of hydrogen to attain the same level of routine safety.

11.5.3 Fast Charging & Opportunity Charging

This section is currently under revision and will be added at a later date.

11.5.4 Lithium Ion Batteries

This section is currently under revision and will be added at a later date.

11.6 Battery Modernization

The future holds a lot of advances in technology both to batteries and forklifts. Fuel cells are an interesting addition to the forklift environment. So far, they have not made a significant impact because of power limitations, the inability to supply high rates for short periods of time, and costs. As costs come down and technologies improve the fuel cell may be a viable option for some companies, but only time will determine the reliability and the cost of ownership.

Automated Guided Vehicles (AGV's) are another technical advancement that has brought about significant changes to how warehouses operate. An AGV only needs to stop working long enough to charge its battery, or in some cases change its battery. AGV are changing the way warehouses staff people and get work done. They are increasing efficiencies which in term cuts costs. Battery life on an AGV is still undermined, because the application for some of the AGV is very hard on batteries which causes a shorten battery life. Each application will need to be evaluated to determine if AGV are a good fit for your application.

Chapter 12: Fire Prevention

Acknowledgements

George W. Stanley, Wiginton Corporation, Orlando, Florida, USA

Don Wiginton, Wiginton Corporation, Orlando, Florida, USA

12.1 Introduction

Fire sprinkler systems were first developed around the mid to late 1800s. Henry Parmalee invented the first practical automatic fire sprinkler in 1864. In 1894, NFPA (National Fire Protection Association) was founded and four years later the first installation standard (now known as NFPA 13) was published. These early systems were mostly designed to protect factories and the workers within those facilities.

Today, you will find fire sprinkler systems in a wide range of properties from mega storage warehouses to single family homes. The success of controlling fires and protecting lives with a properly designed and maintained fire sprinkler system is well documented. In most cases, it only takes a few fire sprinklers to control a fire. The evolution of the fire sprinkler technology continues to develop. The development of the ESFR (Early Suppression Fast Response) sprinkler in the late 1980's revolutionized storage protection with the elimination of in-rack sprinklers. Another significant development was in the CMSA (Control Mode Specific Application) sprinklers and the reduction or elimination of in-rack sprinklers in a cold storage application. The classification of the hazard is a primary factor in the proper design of a fire sprinkler system. The role of the Fire Protection Engineer is very important when it comes to determining the proper protection scheme based on the hazard analysis, the water supply to be used, and the type of system to be employed. Other factors in the proper design of a sprinkler system are the appropriate water application that must be delivered and the options related to sprinkler head temperature ratings, orifice sizing, orientation and spacing. It is also necessary to specifically identify special materials appurtenances that will be used for reliability, redundancy, environmental and insurance reasons, as well as consideration for future expansion and adjacent structures and hazards.

All fire sprinkler systems are designed using prescriptive standards such as NFPA 13 (Installation of Sprinkler Systems), other applicable NFPA standards or Factory Mutual Data Sheets, including specific application test reports. Since the owner is responsible for what goes on in the building long after engineers, contractors and public safety officials are gone, NFPA requires an owner's certificate to document the intended use and occupancy of the building. The engineer of record, who has specific knowledge of the code and owner's requirements, helps the owner fill out this certificate. This

information should be posted on the riser. Once the engineering decisions are made, contractors knowledgeable in the NFPA standards are then able to "layout" and hydraulically calculate the specified fire sprinkler systems using a variety of products and configurations with an emphasis on reducing costs through creativity and experience.

While fire protection engineering is recognized as a special discipline within the engineering community, most states allow any professional engineer with specific training and experience in fire sprinklers to act in the capacity of Fire Protection Engineer. It is also this engineer's responsibility to coordinate with other engineering disciplines under the supervision of the prime professional to make sure questions relating to civil, structural, mechanical and electrical issues work together.

12.2 Fire Sprinkler Design

12.2.1 Site

Water Supply

The water supply for the fire sprinkler system may consist of municipal or private water mains, hydrants, fire pumps (electric or diesel), ground storage tanks, elevated storage tanks, wells, ponds or any combination thereof.

Hydrant

A valved connection on a water supply system having one or more outlets and that is used to supply hose and fire department pumpers with water on private property. Where connected to a public water system, the private hydrants are supplied by a private service main that begins at the point of service designated by the authority having jurisdiction, usually at a manually operated valve near the property line.

Fire Pumps

Fire pumps are either electric motor driven requiring a direct power supply or diesel engine driven with a double wall diesel fuel tank. Fire pumps are sized based on the required pressure for the system at approximately a 100% capacity. The pump house or room must have a minimum temperature of at least 40°. The cost to install an electric fire pump is greater than a diesel driven fire pump. However, the cost to maintain a diesel driven fire pump is greater than an electric fire pump.

Ground Storage Tanks

The use of an above ground water storage tank that is correctly sized for the application may be required by local fire code as a secondary on-site water supply for automatic fire sprinkler systems or the primary supply when the city main is not capable of supplying the necessary pressure and GPM.

Riser Locations

System Riser: The aboveground horizontal or vertical pipe between the water supply and the mains (cross or feed) that contains a control valve, drain and alarm. It

should be located in an area that will be protected from fork lifts along with other moving equipment and has a temperature maintained at a minimum of 40°.

Flushing

After underground piping installation it is required that these mains be flushed and tested. In accordance with NFPA #13 the minimum flow rate shall be not less than one of the following:

1. Hydraulically calculated water demand rate of the system including any hose requirements
2. Flow in accordance with Table 10.10.2.1.3 (see below)
3. Maximum flow rate available to the system under fire conditions.

Additionally NFPA #20, Standard for the Installation of Stationary Fire Pumps, indicates that Underground Suction pipes be flushed at a flow rate not less than that indicated in figure 1 or at the Hydraulically Calculated water demand of the system; whichever is greater.

Flow Required to Produce a Velocity of 10 ft/sec (3 m/sec) in Pipes

Pipe Size		Flow Rate	
in.	mm	gpm	L/min
2	51	100	379
2½	63	150	568
3	76	220	833
4	102	390	1,476
5	127	610	2,309
6	152	880	3,331
8	203	1,560	5,905
10	254	2,440	9,235
12	305	3,520	13,323

Flow Rates for Stationary Pumps

U.S. Customary Units		Metric Units	
Pipe Size (in.)	Flow Rate (gpm)	Pipe Size (mm)	Flow Rate (L/min)
4	590	100	2,233
5	920	125	3,482
6	1,360	150	5,148
8	2,350	200	8,895
10	3,670	250	13,891
12	5,290	300	20,023

Flush Rates for Positive Displacement Pumps

U.S. Customary Units		Metric Units	
Pipe Size (in.)	Flow (gpm)	Pipe Size (mm)	Flow (L/min)
1½	100	40	378.50
2	250	50	945.25
3	400	80	1514.00
4	450	100	1703.25
6	500	150	1892.50

12.2.2 Construction

Roof Construction

There are two groups of roof construction that NFPA 13 defines.

Obstructed Construction - Panel construction and other construction where beams, trusses, or other members impede heat flow or water distribution in a manner that materially affects the ability of sprinklers to control or suppress a fire.

Unobstructed Construction - Construction where beams, trusses, or other members do not impede heat flow or water distribution in a manner that materially affects the ability of sprinklers to control or suppress a fire. Unobstructed construction has horizontal structural members that are not solid, where the openings are at least 70 percent of the cross-section area and the depth of the member does not exceed the least dimension of the openings, or all construction types where the spacing of structural members exceeds 7½ ft (2.3 m) on center.

Building Height – Building height has effects on the sprinkler performance. Certain storage sprinklers can provide adequate protection at roof heights of 48’ without requiring in-rack sprinklers.

Temperature - Above 40 degrees - Wet Pipe Sprinkler System

Below 40 degrees - Dry Pipe Sprinkler System or Preaction Sprinkler System

12.2.3 Occupancy

The occupancy is defined by the intended use of the building including the storage arrangement and the commodity being stored. A list of storage commodities and storage definitions for various storage arrangements are listed below. The owner's information certificate is the communication vehicle between the owner and the designer.

Classification of Commodities as defined in NFPA 13, 2010 Edition…

- **Class II.** A Class II commodity shall be defined as a noncombustible product that is in slatted wooden crates, solid wood boxes, multiple-layered corrugated cartons, or equivalent combustible packaging material, with or without pallets.
- **Class III.** A Class III commodity shall be defined as a product fashioned from wood, paper, natural fibers, or Group C plastics with or without cartons, boxes, or crates and with or without pallets. A Class III commodity shall be permitted to contain a limited amount (5 percent by weight or volume or less) of Group A or Group B plastics.

Figure 12. 1 Paper cups in compartmented cardboard cartons on wood pallets



- **Class IV**. A Class IV commodity shall be defined as a product, with or without pallets, that meets one of the following criteria:
  - Constructed partially or totally of Group B plastics
  - Consists of free-flowing Group A plastic materials
  - Contains within itself or its packaging an appreciable amount (5 percent to 15 percent by weight or 5 percent to 25 percent by volume) of Group A plastics

The remaining materials shall be permitted to be metal, wood, paper, natural or synthetic fibers, or Group B or Group C plastics.

Plastics: Group A.

The following materials are examples of a Group A plastic:

- EPDM (ethylene-propylene rubber)
- FRP (fiberglass-reinforced polyester)
- PET (thermoplastic polyester)
- Polycarbonate

- Polyester elastomer
- Polyethylene
- Polypropylene
- Polystyrene
- Polyurethane
- Plastic materials
- Cartoned vs. Uncartoned (Exposed)
- Expanded vs. Unexpanded

Figure 12. 2 16-oz (454 g) Polystyrene Plastic Jars in compartmented cardboard cartons



Figure 12. 3 Exposed Expanded Polystyrene Trays

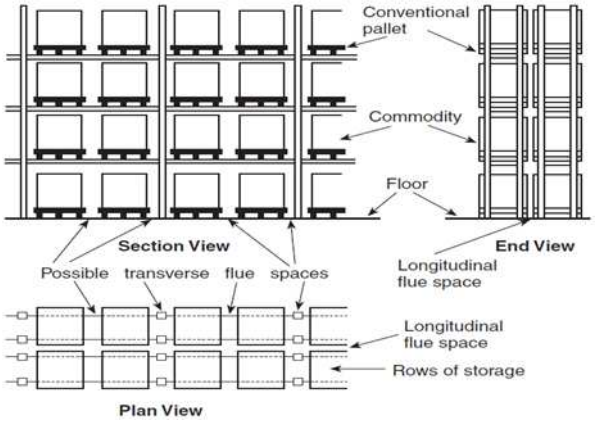


NFPA 13, 2010 edition – Storage Definitions

- **Wood Pallet.** A pallet constructed entirely of wood with metal fasteners.
- **Plastic Pallet.** A pallet having any portion of its construction consisting of a plastic material.
- **Reinforced Plastic Pallet.** A plastic pallet incorporating a secondary reinforcing material (such as steel or fiberglass) within the pallet.
- **Aisle Width.** The horizontal dimension between the face of the loads in racks under consideration.
- **Longitudinal Flue Space**. The space between rows of storage perpendicular to the direction of loading with a width not exceeding 24 in. (610 mm) between storage. Rack. Any combination of vertical, horizontal, and diagonal structural members that support stored materials or commodities.

- **Double-Row Racks.** Racks less than or equal to 12 ft. (3.7 m) in depth or single-row racks placed back to back having an aggregate depth up to 12 ft. (3.7 m), with aisles having an aisle width of at least 3.5 ft. (1.1 m) between loads on racks.
- **Movable Racks.** Racks on fixed rails or guides. They can be moved back and forth only in a horizontal, two-dimensional plane. A moving aisle is created as abutting racks are either loaded or unloaded, then moved across the aisle to abut other racks.
- **Multiple-Row Racks.** Racks greater than 12 ft. (3.7 m) in depth or single- or double-row racks separated by aisles less than 3.5 ft. (1.1 m) wide having an overall width greater than 12 ft. (3.7 m).
- **Portable Racks**. Racks that are not fixed in place. They can be arranged in any number of configurations.
- Single-Row Racks. Racks that have no longitudinal flue space and that have a depth up to 6 ft. (1.8 m) with aisles having a width of at least 3.5 ft. (1.1 m) between loads on racks.
- **Rack Shelf Area.** The area of the horizontal surface of a shelf in a rack defined by perimeter aisle(s) or nominal 6 in. (152 mm) flue spaces on all four sides, or by the placement of loads that block openings that would otherwise serve as the required flue spaces.
- **Open Rack.** Racks without shelving or with shelving in racks that are fixed in place with shelves having a solid surface and a shelf area equal to or less than 20 sq. ft. (1.9m2) or with shelves having a wire mesh, slatted surface, or other material with openings representing at least 50 percent of the shelf area, including the horizontal area of rack members and where the flue spaces are maintained.
- **Slatted Shelf Rack**. A rack where shelves are fixed in place with a series of narrow individual solid supports used as the shelf material and spaced apart with regular openings.
- **Solid Shelf Rack.** A rack where shelves are fixed in place with a solid, slatted, or wire mesh barrier used as the shelf material and having limited openings in the shelf area.
- **Solid Shelving**. Solid shelving is fixed in place, slatted, wire mesh, or other type of shelves located within racks. The area of a solid shelf is defined by perimeter aisle or flue space on all four sides. Solid shelves having an area equal to or less than 20 sq. ft. (1.9m2) shall be defined as open racks. Shelves of wire mesh, slats, or other materials more than 50 percent open and where the flue spaces are maintained shall be defined as open racks.
- **Transverse Flue Space.** The space between rows of storage parallel to the direction of loading.

Figure 12. 4



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12.2.4 Plastic Pallets

- If there is any plastic in the pallet, it will be classified as a plastic pallet.
- In order for plastic pallets to be classified the same as wood pallets they must meet UL 2335 or FM 4995 test and be marked as such.
- All plastic pallets are to be considered reinforced unless specifically marked nonreinforced.
- When using reinforced plastic pallets, all commodities except Group A plastics shall be increased by two classifications.
- When using nonreinforced plastic pallets and they are marked as such, all commodities except Group A plastics shall be increased by one classification.
- No increase in classification required where minimum K 16.8 spray sprinklers are used for ceiling-only sprinkler protection.
- Factory Mutual, according to their data sheets, only requires one classification increase for plastic pallets. They do not distinguish between reinforced and nonreinforced plastic pallets.

Plastic Pallet Types

Un-reinforced plastic pallets

- Melt fairly easily in a fire and are less of a fire challenge
- Material
  - Polypropylene
  - high-density polyethylene

Figure 12.5 Un-Reinforced Plastic Pallets



Reinforced plastic pallets

- Hold their structure and integrity longer allowing air gaps to remain longer within the pallet, which fuels the flames and creates a more intense fire
    - Material
        - Polypropylene
        - high-density polyethylene

Figure 12. 5 Reinforced Plastic Pallet



12.2.5 Owner's Information Certificate

An example of an Owner's Information Certificate is below:

Owner's Information Certificate

Property Name: _____

Property Address: _____

Name of Owner: _____

Existing or planned construction is:

- ☐ Fire resistive or noncombustible
- ☐ Wood frame or ordinary (masonry walls with wood beams)
- ☐ Unknown

Intended use of the building _____

_____

Is the system installation intended for one of the following special occupancies?

Aircraft hangar ☐ *Yes* ☐ *No* - Fixed guide way transit system ☐ *Yes* ☐ *No* - Race track stable ☐ *Yes* ☐ *No* - Marine terminal, pier, or wharf ☐ *Yes* ☐ *No* - Airport terminal ☐ *Yes* ☐ *No* - Power plant ☐ *Yes* ☐ *No* - Aircraft engine test facility ☐ *Yes* ☐ *No* - Water-cooling tower ☐ *Yes* ☐ *No*

Indicate whether any of the following special materials or conditions are intended to be present:

Expanded Plastics	☐ Yes	☐ No
Cartoned	☐ Yes	☐ No
Exposed	☐ Yes	☐ No
Non- expanded Plastics	☐ Yes	☐ No
Cartoned	☐ Yes	☐ No
Exposed	☐ Yes	☐ No
Bin Box	☐ Yes	☐ No
Shelf storage	☐ Yes	☐ No
Rack storage	☐ Yes	☐ No
Palletized storage	☐ Yes	☐ No
Flammable or combustible liquids	☐ Yes	☐ No
Aerosol products	☐ Yes	☐ No
Nitrate film	☐ Yes	☐ No
Pyroxylin plastic	☐ Yes	☐ No
Compressed or liquefied gas cylinders	☐ Yes	☐ No
Liquid or solid oxidizers	☐ Yes	☐ No
Organic peroxide formulations	☐ Yes	☐ No
Encapsulation of palletized products	☐ Yes	☐ No
Roll paper	☐ Yes	☐ No
Tire Storage	☐ Yes	☐ No
Record Storage	☐ Yes	☐ No

If the answer to any of the above is "yes", describe type, location, arrangement, and intended maximum quantities.

_____

_____

Indicate whether the protection is intended for one of the following specialized occupancies or areas:

Spray area or mixing room	☒ Yes	☒ No
Solvent extraction	☐ Yes	☐ No
Laboratory using chemicals	☐ Yes	☐ No
Oxygen-fuel gas system for welding or cutting	☐ Yes	☐ No
Acetylene cylinder charging	☒ Yes	☒ No
Production or use of compressed or liquefied gases	☐ Yes	☐ No
Commercial cooking operation	☐ Yes	☐ No
Class A hyperbaric chamber	☐ Yes	☐ No
Cleanroom	☒ Yes	☒ No
Incinerator or waste handling system	☐ Yes	☐ No
Linen handling system	☐ Yes	☐ No
Industrial furnace	☐ Yes	☐ No
Water-cooling tower	☒ Yes	☒ No
Glass walls or doors	☐ Yes	☐ No

Storage:

Storage of Products ☐ yes ☐ no If "yes", then fill out the following information.

Palletized Storage: Total sq. ft. _____ Top of storage height _____

Rack Storage: Total sq. ft. _____ Top of storage height _____

Single Row ☒ Double Row ☐ Multi-Row ☐ Open Shelves ☐ Solid Shelves ☒

Plastic Pallets ☐ yes ☒ no Idle Pallets Storage ☐ yes ☐ no Height _____

Cantilever Racks ☐ Movable Racks ☒ Aisle Width _____ Flue Space Width _____

Carton Record Storage: ☒ yes ☒ no Total sq. ft. _____ Top of storage height _____

Depth of Racks _____ Catwalks ☐ yes ☐ no Conveyors ☒ yes ☒ no

Compact Record Storage: ☐ yes ☒ no Total sq. ft. _____ Top of storage height _____

Mobile High Bay Record Storage: ☒ yes ☒ no Total sq. ft. _____ Top of storage height _____

Fixed High Bay Record Storage: ☒ yes ☒ no Total sq. ft. _____ Top of storage height _____

Additional Information: _____

I certify that I have knowledge of the intended use of the property and that the above information is correct.

Signature of owner's representative/agent: _____ **Date:** _____

Name of owner's representative/agent completing certificate (print): _____

Relationship and firm of agent (print): _____

12.2.6 Design Schemes

Protection schemes for storage occupancies are based on classification of commodity, storage arrangement, roof construction, roof height, storage height, and ambient temperatures.

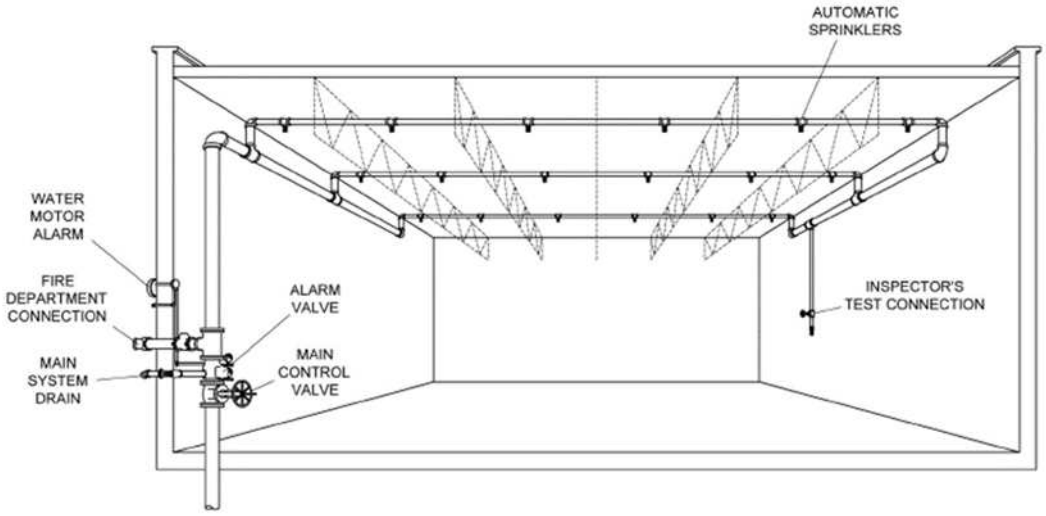
- Control Mode Density Area (CMDA) – Wet, Dry, and Preaction systems
- Control Mode Specific Application (CMSA) – Wet, Dry, and Preaction
- Early Suppression Fast Response (ESFR) – Wet systems only.

12.2.7 Types of Systems

Wet Pipe Sprinkler System.

A sprinkler system employing automatic sprinklers attached to a piping system containing water and connected to a water supply so that water discharges immediately from sprinklers opened by heat from a fire.

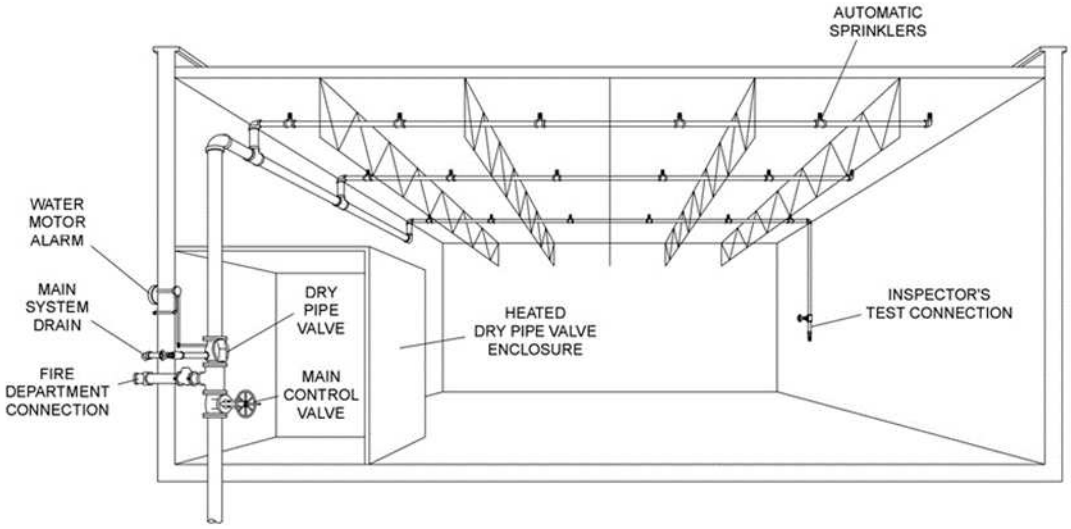
Figure 12. 6 Wet Pipe Sprinkler System



Dry Pipe Sprinkler System.

A sprinkler system employing automatic sprinklers that are attached to a piping system containing air or nitrogen under pressure, the release of which (as from the opening of a sprinkler) permits the water pressure to open a valve known as a dry pipe valve, and the water then flows into the piping system and out the opened sprinklers.

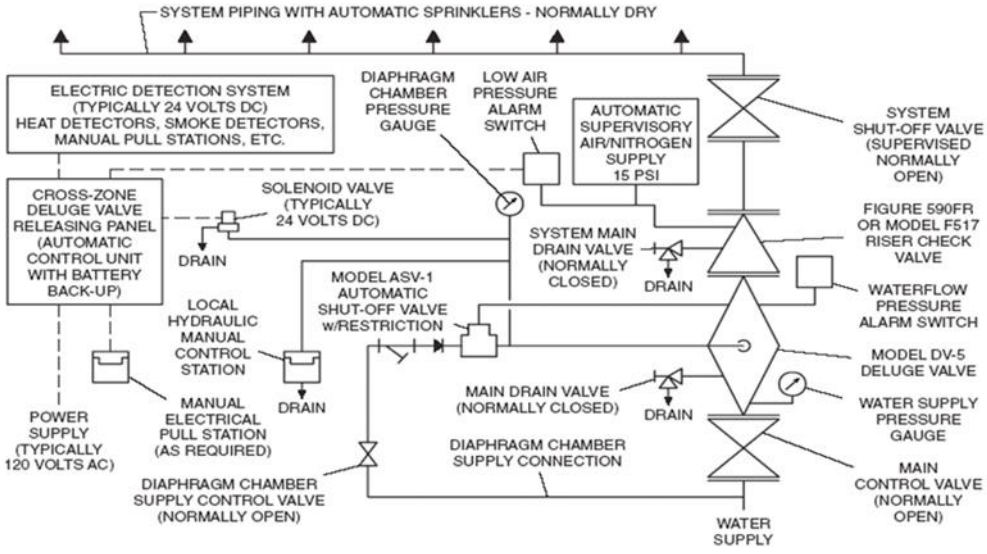
Figure 12. 7 Dry Pipe Sprinkler Systems



Pre-action Sprinkler System.

A sprinkler system employing automatic sprinklers that are attached to a piping system that contains air that might or might not be under pressure, with a supplemental detection system installed in the same areas as the sprinklers.

Figure 12. 8 Double-Interlock Pre-action System. Source: TYCO Fire Suppression & Building Products

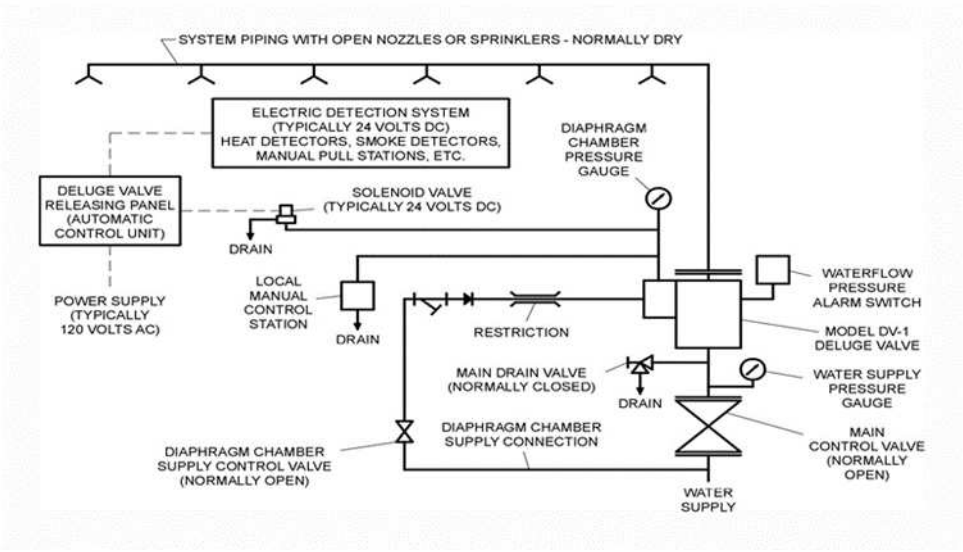


Deluge Sprinkler System.

A sprinkler system employing open sprinklers that are attached to a piping system that is connected to a water supply through a valve that is opened by the operation of a

detection system installed in the same areas as the sprinklers. When this valve opens, water flows into the piping system and discharges from all sprinklers attached thereto.

Figure 12. 9 Deluge Sprinkler System. Source: TYCO Fire Suppression & Building Products



12.2.8 Penthouses

Penthouses present a particular challenge for protecting storage below. Penthouse configurations vary considerably, and as such there is no typical solution for providing protection beneath these areas. An engineering evaluation should be provided. The evaluation should consider: Storage below penthouse, Volume of penthouse, Area of openings, Air distribution ductwork.

12.2.9 Seismic Protection

Based on your seismic zone, using the IBC tables 1613.5.6 (1) & (2) find your SDS & SD1 values. If your seismic design category has a value of C or D, then seismic bracing is required. There are many seismic programs on the market to determine the specifics of the seismic protection designs.

12.2.10 Corrosion Protection

Wet Sprinkler Systems- Internal Corrosion / Pinhole Leaks and Contributing Factors

- **Trapped air at high points in the system (*Most Common)***

  Solution: Remove trapped air by installing a properly designed ventilation system. Avoid filling the system without utilizing a ventilation method. (Note: commercially available air venting systems do not necessarily remove all trapped air.)

- **Ambient temperature**

  Higher temperature increases corrosion rate of steel.

- **Frequent draining and re-filling of sprinkler systems**

  Solution: Design sprinkler systems so that overhead systems are isolated from auxiliary systems (offices, racks, hose stations, etc., "hot spots"). Only drain systems when absolutely necessary. Design and install features that isolate "hot spots" to eliminate excessive draining and refilling.

- **System pressure**

  Fluctuating system pressure can have varying affects on corrosion. Ensure that each riser has a check valve installed and pressure relief valves as necessary.

- **Foreign matter in piping (i.e. metals, minerals)**

  Solution: Ensure that underground pipe is properly flushed prior to introducing water into sprinkler systems. Periodic flushing of existing sprinkler systems is also necessary. However, the procedures outlined in NFPA 25 Annex D need to be included as part of the overall removal of foreign matter in the sprinkler system.

- **Microbiologically Influenced Corrosion (M.I.C.)**

  Solution: Currently, the only solutions involve chemicals that introduce biocides into the sprinkler system. In many jurisdictions, this may require an upgraded backflow preventer. M.I.C. is now thought to be responsible for a low percentage of pipe failures in the United States.

Dry/Preaction Systems – Internal Corrosion/Pinhole Leaks and Contributing Factors

- **Trapped water – lack of low point drains, poor pitch (*Most Common)***

  Solution: Reconfigure pipe to drain and/or add drum drips at low points with a maintenance plan that includes draining water at regular intervals.

- **Pipe coating (i.e. Zinc, Galvanized, Black mill coating, etc.)**

Solution: Use nitrogen for supervisory air in addition to removing trapped water.

- **Oxygen content of supervisory air**

  Solution: Same as above. (Note: Slight modification to sprinkler systems is often necessary to ensure the effectiveness of nitrogen.)

External Piping - Rust and Pitting and Contributing Factors

- **Condensation (*Most Common)***

  Solution: In areas subject to condensation, consider coating pipe and fittings with high quality paint, powder coating, etc. to avoid repeated corrosion cycles caused by condensation. Ensure that pipes serving cold areas are properly insulated.

Areas with acidic gasses (battery charging areas, etc.) are particularly vulnerable during condensation corrosion cycles.

- **Chemical processes**

  Solution: Pipe coatings work well above acid baths, battery manufacturing, fertilizer storage, etc. (Note: Don't forget to evaluate the sprinkler heads as some may contain metals that corrode faster than others.)

- **Outdoors**

  Solution: Assuming that trapped air is removed in wet systems and nitrogen is used in dry systems, galvanized pipe offers suitable protection from external corrosion. Galvanized pipe used in conjunction with a quality coating is the best line of defense.

- **Galvanic Corrosion**

  Solution: Ensure that connections of differing metals are electrically isolated from one another wherever possible. Copper and steel pipe are notorious for corroding without using a dielectric union between them.

12.2.11 Pipe

- **Wall Thickness** – Schedule 7,10,30, and 40
- **Black steel and galvanized pipe** - Specification for black and hot-dipped zinc-coated (galvanized) welded and seamless steel pipe for fire protection use ASTM A 795. Specification for welded and seamless steel pipe ASTM A53. Specification for electric resistance-welded steel pipe ASTM A 135. Galvanized pipe should only be used in corrosive environments such as a battery charging room.

12.2.12 Fittings

All fittings shall be listed for the application:

- Malleable iron threaded fittings, Class 150 and 300 steel- ASME B16.3
- Factory-made wrought steel buttweld fittings - ASME B16.9
- Buttwelding ends for pipe, valves, flanges, and fittings - ASME B16.25
- Flush seal or tri-seal groove couplings shall be used in areas subjected to temperatures below 0o.

12.2.13 Detection System

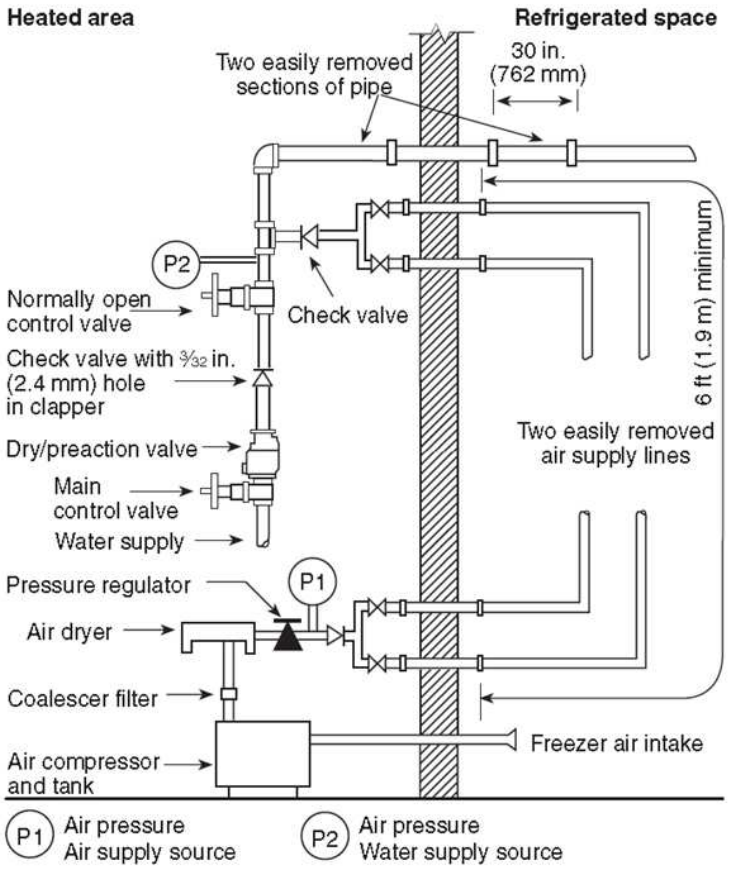
There are two types of prefer detection systems. The first is a linear heat detection system that is used with an approved addressable or conventional panel. The wire detects heat and sends a signal to the panel. The second is an air sampling detector system which analyzes the air in the freezer for smoke particles. This method eliminates the need for any wires.

12.2.14 Air Supply

To eliminate ice blocks in dry and preaction systems the air supply must be properly sized for the systems they are filling. A standard air compressors properly sized for the system it is filling is adequate for small dry systems. General's Dry Air Pac's are designed to provide sprinkler systems with a moisture free air to a -40°F dew point. They are used in conjunction with double-interlock preaction systems to provide the maximum in protection. Nitrogen tanks or generators are also used to eliminate moisture from the system.

The air intake for the compressor or dry air pac must be taken from the protected area as designed below with dual intake for servicing.

Figure 12. 10



Notes:

1. If pressure gauge P1 and P2 do not indicate equal pressures, it could mean the air line is blocked or the air supply is malfunctioning.
2. Air dryer and coalescer filter not required when system piping capacity is less than 250 gal (946 L).

Per NFPA 13, 2010 Edition – **Refrigerator Area Sprinkler Systems Used to Minimize the Chances of Developing Ice Plugs.**

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12.3 Inspection, Testing, and Maintenance

All inspections should be in accordance with NFPA 25 - Current Edition - Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems

Inspection, testing, and maintenance shall be performed by personnel who are qualified through training and experience.

Owner's Responsibilities per NFPA 25, 2011 Edition

- **Buildings** – The building owner shall ensure that all areas of the building containing water-filled piping shall be maintained at a minimum temperature of 40°F (4.4°C) and not exposed to freezing conditions. Inspection, testing, maintenance, and impairment shall be implemented in accordance with procedures meeting those established in NFPA 25 and in accordance with the manufacturer's instructions. Inspection, testing, and maintenance shall be performed by personnel who are qualified through training and experience.
- **Accessibility** – The property owner or designated representative shall provide ready accessibility to components of water based fire protection systems that require inspection, testing, and maintenance.
- **Notification of System Shutdown** – The property owner or designated representative shall notify the authority having jurisdiction, the fire department, if required, and the alarm receiving facility before testing or shutting down a system or its supply. The notification of system shutdown shall include the purpose for the shutdown, the system or component involved, and the estimated time of shutdown. The authority having jurisdiction, the fire department, and the alarm-receiving facility shall be notified when the system, supply, or component is returned to service.
- **Corrections and Repairs** – The property owner or designated representative shall correct or repair deficiencies or impairments that are found during the inspection, test, and maintenance required by NFPA 25. Corrections and repairs shall be performed by qualified maintenance personnel or a qualified contractor.
- **Changes in Occupancy, Use, Process, or Materials** – The property owner or designated representative shall not make changes in the occupancy, the use or process, or the materials used or stored in the building without an engineering evaluation of the fire protection systems for their capability to protect the new

occupancy, use, or materials. The engineering evaluation is not part of a normal inspection.

The engineering evaluation shall consider factors that include, but are not limited to, the following:

- Occupancy changes such as converting office or production space into warehousing
- Process or material changes such as metal stamping to molded plastics
- Building revisions such as relocated walls, added mezzanines, and ceilings added below sprinklers
- Removal of heating systems in spaces with piping subject to freezing

All of the above NFPA 25 referenced material is reprinted with permission from NFPA 25-2011, *Inspection, Testing and Maintenance of Water-Based Fire Protection Systems,* Copyright© 2010, National Fire Protection Association, Quincy, MA. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

12.3.1 Wet Pipe Sprinkler Systems – Inspection and Testing Tasks

A quality scheduled maintenance program is essential to the longevity of a lift truck. This can include changing fluids and filters, adjusting lift chains, tightening hardware parts and ensuring proper lubrication.

Quarterly Inspection Tasks

‰ System is in service on inspection

‰ Reduced pressure backflow assembly not in continuous discharge

‰ Gauges:

- ‰ In good condition
- ‰ Normal pressure being maintained

‰ Control valves are in the open position

‰ Alarm valve:

- ‰ Free of physical damage
- ‰ All valves in the appropriate open or closed position
- ‰ Retarding chamber or alarm drains are not leaking
- ‰ Alarm device appears free from physical damage

‰ Hydraulic nameplate attached and legible

‰ FDC is visible and accessible

‰ FDC swivels/couplings undamaged/rotate smoothly

‰ FDC plugs/caps in place/undamaged

‰ FDC gaskets in place and in good condition

‰ FDC identification sign in place

‰ FDC check valve not leaking

‰ FDC automatic drain valve in place and operating properly

‰ FDC clapper in place and operating properly

‰ FDC interior inspected where caps are missing

‰ FDC obstructions removed as necessary

Quarterly - Main Drain Test:

‰ Water flow alarm (other than vane type) tested and is operational

‰ A test conducted per manufacturer's instructions

‰ A main drain test conducted downstream from backflow preventer

‰ Supply water gauge reading before flow (static)

‰ Gauge reading during stable flow (residual)

‰ Time for supply pressure to return to normal

Semi-Annual Inspection and Tests:

Inspection: Same as quarterly

Main Drain Test:

‰ All quarterly test items included

‰ All vane type devices tested

Supervisory Switches:

‰ Supervisory switch initiates distinct signal during first two hand wheel revolutions or before

‰ Valve stem moved one-fifth from normal position

‰ Signal restored only when valve returned to normal position

Annual Inspection and Tests:

‰ All quarterly inspection items

‰ Hangers and seismic bracing appears undamaged and tightly attached

‰ Piping appears free of mechanical damage

‰ Piping appears free of leakage

‰ Piping appears free of corrosion

‰ Piping appears properly aligned

‰ Piping appears free of external loading

‰ Sprinklers appear free of leakage

‰ Sprinklers appear free of corrosion

‰ Sprinklers appear free of foreign materials

‰ Sprinklers appear free of paint

‰ Sprinklers appear free of physical damage

‰ Sprinklers appear properly oriented

‰ Sprinklers' spray patterns appear free of obstructions within 18" of the deflector and of obstructions over 4' wide

over 18" below the deflector

‰ Glass bulbs appear full of liquid

‰ Spare sprinklers are of proper number (at least six), type and temperature rating

‰ Spare sprinklers stored where temperature maximum is 100° F

‰ Wrench available for each type of sprinkler

‰ Building is secure such as not to expose piping to freezing conditions

‰ Adequate heat is provided maintaining temperatures at 40° F or higher

Main Drain Test: Same as semi-annual

Valve Inspection:

‰ Control valves (including backflow and PIV's) operated through full range and returned to normal position

‰ PIV's opened until spring or torsion felt in rod

‰ PIV's and OS&Y's backed ¼ turn from full open

Backflow Preventer Test:

‰ Backflow preventer assembly forward flow test conducted

‰ System demand flow was achieved through the device or

‰ Forward flow test conducted at maximum rate possible (only where connections do not permit full flow test) or

‰ Forward flow test conducted without measuring flow (device</=2" and outlet sized to flow system demand) or Backflow prevention assembly internal inspection conducted (where water shortages last more than 1 year and rationing enforced by AHJ) or

‰ Forward flow test satisfied by annual fire pump flow test

‰ Backflow preventer performance test conducted as required by the AHJ

12.3.2 Dry Pipe Sprinkler Systems – Inspection and Testing Tasks

Quarterly Inspection and Tests:

‰ System is in service on inspection

‰ Valve enclosure (during cold weather) shall maintain 40° F

‰ Reduced pressure backflow preventer assembly not in continuous discharge

‰ Gauges

- ‰ Supply side indicates normal supply water pressure
- ‰ System side indicates proper air or nitrogen pressure

‰ Quick-Opening device indicates same as system side

‰ Control valves are in the open position

‰ Dry pipe valve

- ‰ Free of physical damage
- ‰ Trim valves in appropriate open or closed position
- ‰ Intermediate chamber not leaking

‰ Alarm device appears free from physical damage

‰ Hydraulic nameplate attached and legible

‰ FDC is visible and accessible

‰ FDC swivels/couplings undamaged/rotate smoothly

‰ FDC plugs/caps in place/undamaged

‰ FDC gaskets in place and in good condition

‰ FDC identification sign in place

‰ FDC check valve not leaking

‰ FDC automatic drain valve in place and operating properly

‰ FDC clapper in place and operating properly

‰ FDC interior inspected where caps are missing

‰ FDC obstructions removed as necessary

Main Drain Test:

‰ Water flow alarm (other than vane type) tested and is operational

‰ A test conducted per manufacturer's instructions

‰ A main drain test conducted downstream from backflow preventer

‰ Supply water gauge reading before flow (static)

‰ Gauge reading during stable flow (residual)

‰ Time for supply pressure to return to normal

‰ Priming water level correct and low air pressure passed test

‰ Quick opening device passed test

Semi-Annual Inspection and Tests:

Inspection: Same as quarterly

Main Drain Test:

‰ All quarterly test items included

‰ Supervisory Switches:

‰ Supervisory switch initiates distinct signal during first two hand wheel revolutions or before

‰ Valve stem moved one-fifth from normal position

‰ Signal restored only when valve returned to normal position

Annual Inspection and Tests:

‰ All quarterly inspection items

‰ Hangers and seismic bracing appears undamaged and tightly attached

‰ Piping appears free of mechanical damage

‰ Piping appears free of leakage

‰ Piping appears free of corrosion

‰ Piping appears properly aligned

‰ Piping appears free of external loading

‰ Sprinklers appear free of leakage

‰ Sprinklers appear free of corrosion

‰ Sprinklers appear free of foreign materials

‰ Sprinklers appear free of paint

‰ Sprinklers appear free of physical damage

‰ Sprinklers appear properly oriented

‰ Sprinklers' spray patterns appear free of obstructions within 18" of the deflector and of obstructions over 4' wide over 18" below the deflector

‰ Glass bulbs appear full of liquid

‰ Spare sprinklers are of proper number (at least six), type and temperature rating

‰ Spare sprinklers stored where temperature maximum is 100° F

‰ Wrench available for each type of sprinkler

‰ Building is secure such as not to expose piping to freezing conditions

‰ Adequate heat is provided maintaining temperatures at 40° F or higher

Main Drain Test: Same as semi-annual

Valve Inspection:

‰ Control valves (including backflow and PIV's) operated through full range and returned to normal position

‰ PIV's opened until spring or torsion felt in rod

‰ PIV's and OS&Y's backed ¼ turn from full open

Dry Pipe Valve

‰ Partial flow trip test

‰ Air pressure maintenance device passed test

Backflow Preventer Test:

‰ Backflow preventer assembly forward flow test conducted

‰ System demand flow was achieved through the device or

‰ Forward flow test conducted at maximum rate possible (only where connections do not permit full flow test) or

‰ Forward flow test conducted without measuring flow (device</=2" and outlet sized to flow system demand) or

‰ Backflow preventer assembly internal inspection conducted (where water shortages last more than 1 year and rationing enforced by AHJ) or

‰ Forward flow test satisfied by annual fire pump flow test

‰ Backflow preventer performance test conducted as required by the AHJ

12.3.3 Pre-Action Sprinkler Systems – Inspection and Testing Tasks

Quarterly Inspection and Tests:

‰ System is in service on inspection

‰ Valve enclosure (during cold weather) shall maintain 40° F

‰ Reduced pressure backflow preventer assembly not in continuous discharge

‰ Gauges

- ‰ Supply side indicates normal supply water pressure
- ‰ System side indicates normal air pressure
- ‰ Detection system indicates normal air pressure (if applicable)

‰ Control valves are in the open position

‰ Pre Action valve

- ‰ Free of physical damage
- ‰ Trim valves in appropriate open or closed position
- ‰ Valve seat is not leaking
- ‰ Electrical components in service

‰ Alarm device appears free from physical damage

‰ Hydraulic nameplate attached and legible

‰ FDC is visible and accessible

‰ FDC swivels/couplings undamaged/rotate smoothly

‰ FDC plugs/caps in place/undamaged

‰ FDC gaskets in place and in good condition

‰ FDC identification sign in place

‰ FDC check valve not leaking

‰ FDC automatic drain valve in place and operating properly

‰ FDC clapper in place and operating properly

‰ FDC interior inspected where caps are missing

‰ FDC obstructions removed as necessary

Main Drain Test:

‰ Water flow alarm (other than vane type) tested and is operational

‰ A test conducted per manufacturer's instructions

‰ A main drain test conducted downstream from backflow preventer

‰ Supply water gauge reading before flow (static)

‰ Gauge reading during stable flow (residual)

‰ Time for supply pressure to return to normal

‰ Priming water level correct and low air pressure passed test

Semi-Annual Inspection and Tests:

Inspection: Same as quarterly

Main Drain Test:

‰ All quarterly test items included

‰ Supervisory Switches

‰ Supervisory switch initiates distinct signal during first two hand wheel revolutions or before

‰ Valve stem moved one-fifth from normal position

‰ Signal restored only when valve returned to normal position

Annual Inspection and Tests:

‰ All quarterly inspection items

‰ Hangers and seismic bracing appears undamaged and tightly attached

‰ Piping appears free of mechanical damage

‰ Piping appears free of leakage

‰ Piping appears free of corrosion

‰ Piping appears properly aligned

‰ Piping appears free of external loading

‰ Sprinklers appear free of leakage

‰ Sprinklers appear free of corrosion

‰ Sprinklers appear free of foreign materials

‰ Sprinklers appear free of paint

‰ Sprinklers appear free of physical damage

‰ Sprinklers appear properly oriented

‰ Sprinklers' spray patterns appear free of obstructions within 18" of the deflector and of obstructions over 4' wide over 18" below the deflector

‰ Glass bulbs appear full of liquid

‰ Spare sprinklers are of proper number (at least six), type and temperature rating

‰ Spare sprinklers stored where temperature maximum is 100° F

‰ Wrench available for each type of sprinkler

‰ Building is secure such as not to expose piping to freezing conditions

‰ Adequate heat is provided maintaining temperatures at 40° F or higher

Main Drain Test: Same as semi-annual

Valve Inspection:

‰ Control valves (including backflow and PIV's) operated through full range and returned to normal position

‰ PIV's opened until spring or torsion felt in rod

‰ PIV's and OS&Y's backed ¼ turn from full open

Pre-Action Valve

‰ Trip test passed

‰ Air pressure maintenance device passed test

Backflow Preventer Test:

‰ Backflow preventer assembly forward flow test conducted

‰ System demand flow was achieved through the device or

‰ Forward flow test conducted at maximum rate possible (only where connections do not permit full flow test) or

‰ Forward flow test conducted without measuring flow or

‰ Backflow prevention assembly internal inspection conducted (where water shortages last more than 1 year and rationing enforced by AHJ) or

‰ Forward flow test satisfied by annual fire pump flow test

‰ Backflow preventer performance test conducted as required by the AHJ

12.3.4 Fire Alarm Systems – Inspection and Testing Tasks (Annual)

Control Panel

‰ Accessible and no mechanical or water damage

‰ Alarm, supervisory and trouble signal (inputs) function properly

‰ Evacuation signals and auxiliary signal (outputs) function properly

‰ Circuit supervision including ground fault and power supply supervision function properly

‰ Fuses – supervised and rating is correct

‰ Interfaced equipment – Circuit integrity verified

‰ Lamps and LEDs illuminated

‰ Primary power supply – functions properly

Disconnect switches

‰ Intended function verified

Batteries

‰ No corrosion or leakage

‰ Connections checked and ensured

‰ Within acceptable date range

‰ Battery charger operating properly

‰ Load test acceptable

‰ Voltage level acceptable

Transient Suppressors

‰ In good condition and functioning properly

Remote Annunciators

‰ Accessible, no mechanical damage and operates properly

Alarm Notification Devices

‰ No obstructions to impair effectiveness

‰ No physical damage

‰ No changes in building conditions that render the appliance ineffective

‰ Viewing paths to visible notification devices clear

‰ Devices operate as intended

Initiating and Supervisory Devices

‰ No mechanical or water damage

‰ Heat detectors not painted

‰ Devices operate as intended

‰ Radiant energy detectors not obstructed, lenses clear and unit directed toward intended hazard

‰ Smoke detectors have no covers, bags or tape

‰ Devices operate as intended

‰ Emergency Communications Equipment

‰ No mechanical damage

‰ Correct operation verified

‰ Interface Equipment

‰ Signals required to be transmitting, receiving and verifying at control unit

‰ AHU shutdown verified

‰ Access control interface verified

‰ Aux power supply, etc. verified

‰ Special Hazard Systems

‰ Detection circuits operate per original design verified

‰ Releasing circuit operation verified

‰ Supervision of devices and circuits verified

‰ Supervising Station Monitoring

- ‰ Alarm signal and restoration verified
- ‰ Trouble signal and restoration verified
- ‰ Supervisory Signal and restoration verified

12.3.5 Fire Extinguisher – Inspection and Maintenance Tasks

Annual Inspection:

‰ Location in designated place

‰ No obstruction to access or visibility

‰ Operating instructions on nameplate legible and facing outward

‰ No safety seals and tamper indicators missing or broken

‰ Fullness confirmed by weighing or “hefting”

‰ No obvious physical damage, corrosion, leakage or clogged nozzle

‰ Pressure gauge in normal range

‰ HMIS label in place

Annual Maintenance:

‰ Examination of mechanical parts

12.3.6 Fire Pump Assemblies – Inspection and Testing Tasks

Quarterly Inspection:

‰ System is in service on inspection

‰ Pump house conditions

- ‰ Check pump room or house for proper heat and ventilation

‰ Pump system conditions

- ‰ Piping if free of leaks
- ‰ Suction line and system line pressure gauge is reading normal
- ‰ Suction reservoir is full
- ‰ Wet pit suction screens are unobstructed and in place

‰ Electrical system conditions

- ‰ Controller pilot light and transfer switch normal pilot light are illuminated
- ‰ Isolating switch is closed – standby (emergency) source
- ‰ Reverse phase alarm pilot light is off or normal phase rotation pilot light is on
- ‰ Oil level in vertical motor sight glass is normal

‰ Diesel engine system conditions

‰ Fuel tank is two-thirds full

‰ Controller selector switch is in auto position

‰ Battery's voltage and charging current readings are normal

‰ Battery's pilot lights are on or battery failure pilot lights are off

‰ All alarm pilot lights are off

‰ Engine running time meter is reading

‰ Oil level in right angle gear drive is normal

‰ Crankcase oil level and cooling water level is normal

‰ Electrolyte level in batteries is normal

‰ Battery terminals are free from corrosion

‰ Water-jacket heater is operating

‰ Control valves in normal open or closed position

‰ Control valves properly locked or supervised

‰ Control valves accessible

‰ Control valves free from external leaks

‰ Control valve identification signs in place

‰ Backflow preventer assembly valves are locked or electrically supervised in open position

‰ Reduced pressure backflow preventer assembly not in continuous discharge

‰ Battery case corrosion removed

‰ Circuit breakers or fuses checked

‰ Isolating switch exercised

‰ Circuit breaker exercised

Quarterly Main Drain Test:

‰ One main drain test conducted downstream from the backflow preventer

‰ One main drain test conducted downstream from pressure reducing valve

‰ Supply water gauge reading before flow (static)

‰ Gauge reading during stable flow (residual)

‰ Time for supply pressure to return to normal

Quarterly No Flow Pump Test:

‰ Record system and discharge pressure

‰ Check pump packing gland for slight discharge

‰ Check for unusual noise or vibration

‰ Check packing or pump casing for overheating

‰ Electric Pumps:

‰ Observe the time for motor to accelerate to full speed

‰ Record the time controller is on first step for reduced voltage starters

‰ Run pump for 10 minutes

‰ Diesel Pumps:

‰ Observe the time for the engine to crank

‰ Observe the time for the engine to reach running speed

‰ Observe the engine oil pressure gauge, speed indicator, water and oil temperature

‰ Run pump for 30 minutes

NOTE:

‰ Fuel and oil for diesel engines as needed based on normal pump tests

‰ Strainer, filter, or dirt leg (or combination thereof) cleaned

‰ Crankcase breather cleaned (as necessary)

‰ Crankcase breather changed (as necessary)

‰ Water strainer cleaned

Semi-Annual Inspection and Testing:

Inspection: Same as Quarterly

No Flow Pump Test: Same as Quarterly

Main Drain Test: Same as Quarterly

Supervisory Switches:

‰ Supervisory switch initiates distinct signal during first tow hand wheel revolutions or before valve stem moved one-fifth from normal position

‰ Signal restored only when valve returned to normal position

‰ Manual starting means of electric driven pumps operated

‰ Antifreeze protection level tested

‰ Electrical system safeties and alarms operated

Annual Inspection and Testing:

‰ All Quarterly visible inspection items

‰ Hangers appear undamaged and tightly attached

‰ Piping appears free of mechanical damage

‰ Piping appears free of leakage

‰ Piping appears free of corrosion

‰ Piping appears properly aligned

‰ Piping appears free of external loading

‰ Pump shaft end play within specified tolerances

‰ Pressure gauge and sensor accuracy verified to be within 5%

‰ Pump coupling alignment within specified tolerances

‰ Electrical connections tightened as necessary

‰ Mechanical moving parts lubrication verified (excluding starters and relays)

‰ Pressure switch setting calibration verified

‰ Fuel tank vents and overflow piping free from obstructions

‰ Fuel piping in good condition

‰ Combustion air ductwork and louvers in good condition

‰ Exhaust system hangers and supports in place and in good condition

‰ Electrical control and power working connections checked for tightness

Full Flow Pump Test:

‰ Flow test conducted under minimum, rated and peak fire pump flows

‰ Flow test conducted by controlling quantity of water discharged through test devices

‰ Fire pump operated at maximum allowable discharge (where available suction supplies do not allow flowing of 150 percent of rated pump capacity)

‰ Fire pump suction supply provided required flow at 0 psi or higher gauge pressure at pump suction flange (except installations where NFPA 20 permitted negative suction gauge pressures)

‰ Electric fire pump driver did not overload beyond rating (including service factor allowance) while delivering necessary brake horsepower

‰ Pump suction and discharge pressures and flow measurements at each hose stream used to determine total pump output where hose streams used in testing (must be conducted every 3 years at minimum)

‰ Pump suction and discharge pressures and flow meter measurements used to determine total pump output where flow meter used in testing (not to exceed 2 consecutive annual tests)

‰ Flow meter adjusted immediately prior to testing in accordance with manufacturer's instructions

‰ Test results using flow meter consistent with previous annual test results. If “no” — complete flow test using hose streams OR calibrate flow meter

While Pump is Running:

‰ At churn, circulation relief valve checked for operation and water discharge

‰ At churn, pressure relief valve checked for proper operation

‰ At churn, pressure control valve checked for proper operation

‰ At churn, test continued for minimum of ___ hour

‰ At each flow condition, electric motor voltage and current in all lines recorded

‰ At each flow condition, pump speed recorded

‰ At each flow condition, simultaneous readings of pump suction and discharge pressures and pump discharge flow recorded

‰ Pressure relief valve closely observed during each flow condition

‰ Pressure relief valve functioning properly (pump discharge pressure did not exceed normal operating

‰ Pressure rating of system components)

‰ Pressure relief valve observed closing at proper pressure

‰ Pressure relief valve closed by pilot adjustment during flow conditions (as necessary to achieve minimum rated pump characteristics)

‰ Pressure relief valve reset to normal position at pump test conclusion

Main Drain Test: Same as Quarterly

Supervisory Switches: Same as Semi-annual

‰ Operate emergency manual starting means (without primary power)

‰ Exhaust system tested for back pressure

Note: Fire pump assembly maintenance to be performed in accordance with manufacturer’s recommendations. Diesel engine maintenance to be performed in accordance with manufacturer’s recommendations

12.3.7 Fire Hydrant – Inspection and Testing Tasks

Annual Inspection:

‰ Accessible

‰ No water or ice in barrel

‰ Proper drainage from barrel

‰ No leaks in outlets or at top of hydrant

‰ No cracks in hydrant barrel

‰ No worn nozzle threads

‰ No worn hydrant operating nut

‰ Operating wrench available

Annual Testing:

Hydrant full flow tested until foreign material cleared (flow maintained for at least one minute)

Proper drainage took no longer than 60 minutes

12.3.8 3-Year – Inspection and Testing Items

Inspection:

‰ Interior of all tanks without corrosion protection

Test:

‰ All hoses in accordance with NFPA 1962

‰ Pump flow test through hoses or flow meter

‰ Full flow trip test on all dry and preaction valves

‰ Pressure test on all dry pipe and preaction valves

‰ Hose valves shall be tested by opening and closing the valves

12.3.9 5-Year – Inspection and Testing Items

Inspection:

‰ Internal inspection of pipe for obstructions and corrosion

‰ Internal inspection of all types of tanks

‰ Mainline strainers

‰ Interior inspection of all check valves, alarm valves, dry pipe valves and preaction valves

‰ All strainers, filters, and orifices in valve trims

‰ All pressure reducing and relief valves

Test:

‰ All gauges shall be replaced or tested

‰ All high temperature sprinklers shall be tested

‰ Hoses shall be tested in accordance with NFPA 1962

‰ All underground piping shall be flow tested

‰ Water level indicators for tanks

12.3.10 Owner's Form

Daily, Weekly, and Monthly Fire Protection Inspection Tasks

System No.: Date:

Inspector's Name: Page: 1 of 3

System Inspection Tasks

1) **Daily, or weekly if low temperature alarms are installed:**
   - A. Heating equipment for valve enclosures around dry pipe, preaction or deluge valves maintaining a minimum of 40 deg. F? ☐ Yes ☐ No ☐ N/A

2) **Weekly inspection items:**
   - A. Relief port on reduced pressure and reduced pressure detector backflow prevention assemblies free of continuous discharge? ☐ Yes ☐ No ☐ N/A
   - B. For freezer dry and preaction systems, gauge near the compressor showing same pressureas dry pipe valve system gauge? ☐ Yes ☐ No ☐ N/A

3) **Weekly inspection items which can be performed monthly if the items are electrically supervised or secured with locks:**
   - A. Control valves and isolation valves on backflow prevention assemblies
     - 1. In normal (open or closed) position? ☐ Yes ☐ No ☐ N/A
     - 2. Sealed, locked or supervised? ☐ Yes ☐ No ☐ N/A
     - 3. Accessible? ☐ Yes ☐ No ☐ N/A
     - 4. Provided with appropriate wrenches? ☐ Yes ☐ No ☐ N/A
     - 5. Free from external leaks? ☐ Yes ☐ No ☐ N/A
     - 6. Provided with identification sign? ☐ Yes ☐ No ☐ N/A
     - 7. Provided with sign indicating area served? ☐ Yes ☐ No ☐ N/A

4) **Weekly inspection items which can be performed monthly if air pressure supervision is connected to a constantly attended location:**
   - A. Gauges on supply side of dry, preaction and deluge valves in good condition and showing normal water pressure? ☐ Yes ☐ No ☐ N/A
   - B. Gauges on system side of dry pipe valve indicating proper ratio of air or nitrogen pressure to water supply pressure? ☐ Yes ☐ No ☐ N/A
   - C. Quick opening device gauge (if provided) showing same pressure as dry pipe valve system gauge? ☐ Yes ☐ No ☐ N/A
   - D. Gauge on preaction system supervisory air showing normal air pressure? ☐ Yes ☐ No ☐ N/A
   - E. Gauge on detection system for preaction and deluge systems (if provided) showing normal air pressure? ☐ Yes ☐ No ☐ N/A

5) **Monthly inspection items:**
   - A. Gauges on wet pipe (shotgun, riser check or alarm valve) system in good condition and showing normal water supply pressure? ☐ Yes ☐ No ☐ N/A
   - B. Riser Check:
     - 1. Free from physical damage? ☐ Yes ☐ No ☐ N/A
   - C. Alarm valves:
     - 1. Free from physical damage? ☐ Yes ☐ No ☐ N/A
     - 2. Trim valves in appropriate (open or closed) position? ☐ Yes ☐ No ☐ N/A
     - 3. No leakage from retarding chamber or alarm drain?
   - D. Dry pipe valves:
     - 1. Free from physical damage? ☐ Yes ☐ No ☐ N/A
     - 2. Trim valves in appropriate (open or closed) position? ☐ Yes ☐ No ☐ N/A
     - 3. No leakage from intermediate chamber? ☐ Yes ☐ No ☐ N/A
   - E. Preaction and deluge valves:
     - 1. Free from physical damage? ☐ Yes ☐ No ☐ N/A
     - 2. Trim valves in appropriate (open or closed) position? ☐ Yes ☐ No ☐ N/A
     - 3. No leakage from valve seat? ☐ Yes ☐ No ☐ N/A
     - 4. Electrical components in service? ☐ Yes ☐ No ☐ N/A
   - F. Air Supply Equipment
     - 1. Service Air Compressors and Dry Air Packs in accordance with manufacturer's instructions: Date of last service: _____
     - 2. Change desiccant in accordance with manufacturer's instructions: Last date changed: _____

Daily, Weekly, and Monthly Fire Protection Inspection Tasks

System No.: Date:

Inspector's Name: Page: 2 of 3

Fire Pump - Inspection Tasks

1) Weekly inspection items:

A. Relief port on reduced pressure and reduced pressure detector backflow prevention assemblies free of continuous discharge? ☐ Yes ☐ No ☐ N/A

B. Pump house conditions:

1. Pump house/room at least 40 degree F? ☐ Yes ☐ No ☐ N/A
2. Pump house/room for diesel pumps without engine heaters at least 70 degree F? ☐ Yes ☐ No ☐ N/A
3. Pump house/room adequately illuminated? ☐ Yes ☐ No ☐ N/A
4. Ventilating louvers free to operate? ☐ Yes ☐ No ☐ N/A

C. Pump system conditions:

1. Pump (s) (jockey & fire) free from physical damage? ☐ Yes ☐ No ☐ N/A
2. Suction, discharge and bypass valves are fully open? ☐ Yes ☐ No ☐ N/A
3. Pipe and fittings free from leaks? ☐ Yes ☐ No ☐ N/A
4. Suction pressure gauge reading: _____ psi
5. System pressure gauge reading: _____ psi
6. Gauge readings within acceptable range? ☐ Yes ☐ No ☐ N/A
7. Suction reservoir, if provided, full? ☐ Yes ☐ No ☐ N/A
8. Wet pit suction screens, if provided in place and unobstructed? ☐ Yes ☐ No ☐ N/A

D. Electrical system conditions:

1. Controller (jockey & fire pump)pilot light (power on) is illuminated? ☐ Yes ☐ No ☐ N/A
2. Transfer switch normal pilot light is illuminated? ☐ Yes ☐ No ☐ N/A
3. Isolation switch closed - standby (emergency source)? ☐ Yes ☐ No ☐ N/A
4. Reverse phase alarm pilot light "off"? ☐ Yes ☐ No ☐ N/A
5. Normal phase rotation pilot light "on"? ☐ Yes ☐ No ☐ N/A
6. Oil level in vertical motor sight glass is normal? ☐ Yes ☐ No ☐ N/A

E. Diesel engine system conditions:

1. Fuel:
   a. Tank float switch free of physical damage? ☐ Yes ☐ No ☐ N/A
   b. Solenoid valve free of physical damage? ☐ Yes ☐ No ☐ N/A
   c. Flexible hoses and connections free of physical damage? ☐ Yes ☐ No ☐ N/A
2. Lubrication system:
   a. Oil level in right angle gear drive within acceptable range? ☐ Yes ☐ No ☐ N/A
3. Cooling system:
   a. Water pump(s) free of physical damage? ☐ Yes ☐ No ☐ N/A
4. Battery system:
   a. Batteries' (2) voltage reading within acceptable range? ☐ Yes ☐ No ☐ N/A
   b. Batteries' (2) charging current reading within acceptable range? ☐ Yes ☐ No ☐ N/A
   c. Batteries' (2) pilot lights "on"? ☐ Yes ☐ No ☐ N/A
   d. Batteries' (2) failure pilot lights "off"? ☐ Yes ☐ No ☐ N/A
5. Electrical system:
   a. Electrical system free of physical damage? ☐ Yes ☐ No ☐ N/A
   b. Controller selector switch in auto position? ☐ Yes ☐ No ☐ N/A
   c. All alarm pilot lights off? ☐ Yes ☐ No ☐ N/A
6. Record engine running time meter reading: _____ hours.
   a. Is this appropriately higher than previous reading? ☐ Yes ☐ No ☐ N/A

2) Monthly if the items are electrically supervised or secured with locks:

A. Control valves and isolation valves on backflow prevention assemblies: ☐ Yes ☐ No ☐ N/A

Daily, Weekly, and Monthly Fire Protection Inspection Tasks

System No.: Date:

Inspector's Name: Page: 3 of 3

Fire Pump - Testing Tasks

1) **Weekly test items:**

A. Electric Driven Fire Pumps

1. Pump started automatically? ☐ Yes ☐ No ☐ N/A
2. Pump started manually? ☐ Yes ☐ No ☐ N/A

   Record starting pressure:_____ psi
3. Pump run for at least 10 minutes? ☐ Yes ☐ No ☐ N/A

   Record suction pressure: _____ psi and discharge pressure: _____ psi

   Record time for motor to accelerate to full speed: _____ sec
   For reduced voltage or reduced current starting, record time controller is on first step: _____ sec.

   For automatic stop controllers, record time pump runs after starting: ____ sec.
4. All times and pressures for electric motor driver pumps acceptable? ☐ Yes ☐ No ☐ N/A

B. Diesel engine driver pumps:

1. Pump started automatically? ☐ Yes ☐ No ☐ N/A
2. Pump started manually? ☐ Yes ☐ No ☐ N/A

   Record starting pressure:_____ psi
3. Pump run for at least 30 minutes? ☐ Yes ☐ No ☐ N/A

   Record suction pressure: _____ psi and discharge pressure: _____ psi

   Record time for engine to crank: _____ sec.

   Record time for engine to reach running speed: _____ sec.
4. Engine oil pressure, speed indicator, water and oil temperature indicators all reading within acceptable range? ☐ Yes ☐ No ☐ N/A
5. Cooling water flowing from heat exchanger? ☐ Yes ☐ No ☐ N/A
6. All times and pressures for diesel driver pumps acceptable? ☐ Yes ☐ No ☐ N/A

Notes and Observations:

Signature: _____ **Date:** _____

12.3.11 Ice Plugs

Figure 12. 11



Dry / Preaction Systems – Ice Plugs and Contributing Factors

- **Improperly pitched pipe and low points allowing trapped water to remain.**

  Solution: Reconfigure pipe to drain and/or add drum drips at low points with a maintenance plan that includes draining water at regular intervals.

- **Floor/Wall penetrations through differing temperature zones**
- **Design/condition of pipe insulation through floors/walls**

  Solution: Insulation should be professionally installed and designed to prevent exterior condensation of piping on the warmer side of the penetration.

- **Tees/Elbows installed near wall penetrations**

  Solution: Ice tends to build up wherever there are friction points in the piping. Keeping fittings away from penetrations from warm to cold aids in preventing ice plugs. If there is an elbow installed near a penetration, consider swapping it out for a Tee so it can be inspected easily by removing a cap.

- **Moisture content of supervisory air (*Most Common)***

  Solution: Avoid using shop air in your cold storage sprinkler system. Nitrogen or even dry-air pack style compressors properly designed for your system are most effective at preventing ice plugs. Slight modification to the sprinkler systems is often necessary to ensure the effectiveness of these options.

- **Design/condition of air drying equipment**

  Solution: Ensure that air drying compressor assemblies are properly sized and the correct number used for your application. Note: a 500,000 sq. ft. building may have 12 sprinkler systems, each with a capacity of 1200 gallons. In this

scenario, a minimum of (4) General Dry-Air packs is necessary to provide the moisture control necessary to prevent ice plugs. Dry-air packs need regenerative maintenance regularly and the frequency can be as high as 6 times per year in buildings that experience frequent air leakage due to mechanical damage (i.e. in-rack systems)

- **Leaks in system piping or leaking sprinkler heads**

  Solution: Avoid contact with in-rack piping at all costs! Since most leaks occur in rack systems where forklifts are used, consider designing and installing a modern overhead only system and eliminate in-rack sprinklers. If this is not feasible, consider a bi-annual shut down of overhead blower units while a skilled crew assesses the sprinkler system for leaks. Make repairs as necessary.

- **Dry pipe in warm areas that condensates internally**

  Solution: Convert supervisory air to nitrogen or, depending on temperature, convert the dry system into a wet system permanently.

12.3.12 Required Signs per NFPA 13, 2010 Edition

Hydraulic Design Information Sign

The installing contractor shall identify a hydraulically designed sprinkler system with a permanently marked weatherproof metal or rigid plastic sign secured with corrosion resistant wire, chain, or other approved means. Such signs shall be placed at the alarm valve, dry pipe valve, preaction valve, or deluge valve supplying the corresponding hydraulically designed area.

The sign shall include the following information:

- Location of the design area or areas
- Discharge densities over the design area or areas
- Required flow and residual pressure demand at the base of the riser
- Occupancy classification or commodity classification and maximum permitted storage height and configuration
- Hose stream allowance included in addition to the sprinkler demand
- The name of the installing contractor

General Information Sign

The installing contractor shall provide a general information sign used to determine system design basis and information relevant to the inspection, testing, and maintenance requirements required by NFPA 25, Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems.

Such general information shall be provided with a permanently marked weatherproof metal or rigid plastic sign, secured with corrosion-resistant wire, chain, or other acceptable means.

Such signs shall be placed at each system control riser, antifreeze loop, and auxiliary system control valve.

The sign shall include the following information:

- Name and location of the facility protected
- Occupancy classification
- Commodity classification
- Presence of high-piled and/or rack storage
- Maximum height of storage planned
- Aisle width planned
- Encapsulation of pallet loads
- Presence of solid shelving
- Flow test data
- Presence of flammable/combustible liquids
- Presence of hazardous materials
- Presence of other special storage
- Location of auxiliary drains and low point drains on dry pipe and preaction systems
- Original results of main drain flow test
- Name of installing contractor or designer
- (16) Indication of presence and location of antifreeze or other auxiliary systems

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12.4 Modernization

12.4.1 Changes in Commodities

Any changes in product or packaging could cause an increase in commodity classification which might render your fire sprinkler system inadequate for the hazard it is protecting. If your system is not properly designed to protect the hazard, then the results could be additional property loss as well as business interruption. This increase risk could result in higher insurance premiums.

When any one of the following changes in commodities occurs, then you should have an engineering evaluation preformed on your fire sprinkler system.

- Product changes
- Additional plastics in the product
- Any changes to the packaging

- Any changes to the cartons
- Any changes to the pallets
- Encapsulation of the product

12.4.2 Changes in Storage Arrangements

Any changes in storage arrangements could present a challenge to your fire sprinkler system which may render it ineffective for the hazard it is protecting. If your system is not properly designed to protect the storage arrangement, then the results could be additional property loss as well as business interruption. This increase risk could result in higher insurance premiums.

When any one of the following changes in storage arrangement occurs, then you should have an engineering evaluation preformed on your fire sprinkler system.

- Changes in storage height
- Excessive clearance from top of storage to ceiling sprinklers
- Additional racking
- Changes in racking size and configuration
- Addition of solid shelves in racking
- Changes in double row racks to multi-row racks
- Changes to aisle widths
- Changes to flue spaces inside the rack
- Idle pallet storage
- Using plastic pallets instead of wood
- Using reinforced plastic pallets
- Using non-listed plastic pallets
- Adding automated storage and retrieval systems
- Converting areas from a dry goods to a cooler or freezer
- Using portable or movable racks

12.4.3 Engineering Evaluation - Overview

1. **Owner's Information Certificate**

- Owner to complete Owner's Information Certificate per NFPA 13, 2010 edition (see Annex A, FIGURE A.22.1(b))
- Review any planned future storage commodities and arrangements
- Check for plastics in products and packaging
- Check for flammable and/or combustible liquids
- Check for exposed expanded plastics

2. **Analyze water supply**

- Perform hydrant flow test
- Test fire pumps and compare results to original performance criteria
- Review and inspect ground storage tanks

- Determine underground main sizes and locations
- Verify backflow preventer loss
- Check fire department connection location(s)

3. **Review existing systems**

- Review existing plans if available
- Measure existing system if needed
- Check spacing of sprinklers if needed
- Check pipe sizes if needed
- Check pressures on riser
- Check deflector distances if needed
- Check for obstructions to sprinklers
- Check existing ceiling heights and type of roof construction
- Check for any signs of external corrosion
- Check pipe type and wall thickness

4. **Review existing storage commodities and compare to Owner's Information Certificate**

5. **Determine proper commodity classification of existing commodities**

6. **Review existing storage arrangements**

7. **Research codes and standards for proper protection scheme**

8. **Review all sprinkler options for most effective protection**

9. **Preform hydraulic calculations (if required)**

10. **Recommend any modifications to existing systems (if required)**

11. **Develop a specification for the modification (if required)**

12.4.4 Eliminating In-Rack Sprinklers

The development of certain types of storage sprinklers has eliminated the need for in-rack sprinklers in most cases for dry goods and some cases for cold storage.

Dry Goods: Wet Systems

- **Early Suppression Fast-Response (ESFR) Sprinkler:** The K25 ESFR sprinkler protects storage of cartoned unexpanded plastics in single row, double row and multiple row racks to 40' under a 45' ceiling without in-rack sprinklers.
- **Control Mode Specific Application (CMSA) Sprinkler:** The K25 CMSA sprinkler protects storage of cartoned unexpanded plastics in single row, double row, and multiple row racks to 35' under a 40' ceiling without in-rack sprinklers.

Cold Storage: Preaction Systems with Electric Detection

The following specific sprinklers can protect storage of class III commodity in single row, double row, and multiple row racks with ceiling protection only and no in-rack sprinklers, when using it in a preaction system with electric detection. These systems shall be designed in strict accordance with their listing and specific data sheets.

- **Victaulic LP46:** The Victaulic LP46 upright storage sprinkler was designed for controlling fires in single, double and multiple row open-frame rack storage of commodity hazards up to and including cellulosic products (Class III) under a maximum 45ft./13.7m (40ft./12.2m storage) ceiling height, utilizing a preaction system and an electric detection system with a water delivery time of 20 seconds.

The Victaulic LP46 upright K25 CMSA sprinkler protects storage of a class III commodity in single row, double row, and multiple row racks to 40' under a 45' ceiling without in-rack sprinklers.

- **Tyco QUELL Systems:** The Tyco® QUELL Systems are an innovative approach to addressing a high-challenge fire hazard that departs from previous control mode and suppression mode approaches for addressing high-challenge fires, and instead employs a sprinkler operational area sufficient to surround and drown a high-challenge fire. The QUELL Preaction and Dry Systems provide an alternative method of protecting high challenge storage without the need for in-rack sprinklers.

The TYCO Ultra K17 upright sprinkler specifically designed in accordance with the QUELL design data sheets can protect storage of a class III commodity in a single row, double row, and multiple row racks to 40’ under a 48’ ceiling without in-rack sprinklers.

Note: Always review the latest data sheets and approval guides.

Chapter 13: Racking

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13.1 Introduction

A cursory search on YouTube reveals numerous examples of pallet rack collapses. Some of them result in injury or death; all of them result in substantial product loss, loss of the rack, and a partial or complete shutdown in warehouse operation. OSHA inspectors collect additional rack collapse photographs, most of which are not publicly available. In many of the videos you can observe that the rack does not appear to be very damaged, or collapses from only a minor lift truck impact. This underscores that dangerous rack conditions are not always obvious; even a conscientious facility manager may fail to spot dangerous rack conditions without proper training, which is why many companies outsource their rack inspections and maintenance to outside experts. But regardless of whether you perform rack maintenance internally or on an outsourced basis, it is advisable that your maintenance and/or engineering personnel are familiar as much as possible with the nationally-recognized standards of rack safety, as sometime dangerous conditions can emerge between visits by expert inspectors.

For the most part, pallet rack maintenance standards are applicable in a cold storage environment in the same manner as they are applicable in a dry environment. This article will first discuss general standards applicable to all warehouse environments. Then, it will discuss special maintenance guidelines specific to cold storage environments.

Please note that the purpose of this article is to provide some guidance to warehouse managers who are not rack specialists. This guide is not warranted to be comprehensive, nor to substitute for the expertise of a rack maintenance professional.

13.2 Design

Rack 101: How to Design Your Pallet Rack System has been provided as a courtesy of Frazier Industrial Company of Long Valley, New Jersey. The material contained herein is confidential and proprietary information of Frazier Industrial Company and is to be used by IARW and CEBA for internal, informational purposes only and provided only to

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13.2.1 Engineering & Design Parameters

Prior to selecting the components of the rack system, the parameters for designing a storage system need to be determined. These include: design codes, steel codes, earthquake parameters, building codes, fire system integration, lighting, egress, and floor considerations.

13.2.1.1 Pallet Rack Type

The type of material used in the manufacturer of the storage rack will determine the design specification required to guide the selection of acceptable members. There are two classes of steel that are used in the manufacture of pallet racking: **hot-rolled structural steel** and **cold-formed steel sheet steel**.

Roll-forming was developed as a technique for utilizing a minimal amount of steel by forming thin sheets into complex shapes. Thereby using the shape to add the necessary local stiffness to the thin sheets. This type of roll-forming is used for such applications as automotive trim, secondary building construction applications such as girts and purlins, and light duty shelving and storage racks.

A roll-formed shape starts with a coil of flat steel. The flat material is formed thru a series of rolls (at room temperature or "cold") into shapes very carefully designed to optimize the local buckling (or crinkling) of the thin, flat portions. There are many flat thicknesses, or gages, that allow the designer to further minimize the amount of steel in the final section. Unfortunately, these sections offer little reserve capacity in the event of impact damage of overloading. Further, these sections are highly dependent on the shape for their strength. When a part of the storage rack is damaged, it loses much of its capacity and is very difficult to straighten the material to its original shape and strength. This means that the entire component must be replaced. As a result, unloading the surrounding stored loads, disassembling the components, replacing the damaged parts and reloading the stored loads back into their correct locations make the corrective work time-consuming and costly.

Structural storage racks are made of 100% hot-rolled structural steel – the strongest building material known. Red hot steel is processed through a series of roll stands at the steel mill, to produce heavy-duty channel, angle and I-beam shapes. This hot-rolling allows the steel to be forced into the shape corners and some of the portions of the shape to be thicker or tapered. As required by the hot-rolled steel design specification, the shapes are thicker and have reinforced corners. Because of this structural sections used in storage racks can withstand much greater impact from

material handling equipment. In addition, with damaged, these sections retain 90% of their load-carrying capacity. This translates into greater safety, less downtime and product longevity.

13.2.1.2 Design Codes

The building code adopted by the local jurisdiction (state, region, or local) is the required standard for the design of structures. Currently all jurisdictions have adopted some edition of the International Building Code (IBC). The IBC is a model for use by jurisdictions that is developed by the International Code Council (ICC). Even though each jurisdiction participates in the IBC changes, any jurisdiction may enact their own modifications as they see fit. It is the administering Building Official that has final determination of the building requirements.

The model IBC uses many standards that have been developed independently. Generally these standards have also been reviewed by third-party independent (from the developers) peers in a process supervised by the American National Standards Institute (ANSI). The seismic design requirements for buildings comes from the American Society of Civil Engineers (ASCE), the seismic risk assessment for every location in the United States comes from the United States Geological Society (USGS). The cold-formed steel part design requirements comes from the American Iron and Steel Institute (AISI). The American Institute for Steel Construction (AISC) has developed and maintains the design requirements for structural steel. There are many others such as American Concrete Institute (ACI) for floor slabs and post-installed anchors. Each of these are referenced in the IBC as the standard to be used for the specific design requirements.

For pallet storage racks the Rack Manufacturer's Institute (RMI) has developed, received ANSI approval of the peer review the **"Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks"** (RMI Spec) and is directly referenced , as the storage rack design standard to be used, in the International Building Code. This specification recognizes and recommends requirements for design requirements unique to pallet storage racks. It also modifies each of the other standards above in areas that are not addressed for pallet storage racks and areas of those standards that are not applicable to pallet storage rack design.

13.2.1.3 Rack Manufacturer's Institute

The Rack Manufacturer's Institute (RMI) was formed in 1958. The organization is comprised of all the major storage rack manufacturers who produce rack for sale in the United States. The primary goal of the RMI is to advance standards, quality, and safety for the intended use of industrial steel storage rack systems, and to promote the research of rack structures through testing.

In 1964, the RMI approved a rudimentary RMI "Minimum Engineering Standards for Industrial Steel Storage Racks". Shortly thereafter they began working with Cornell University, and an extensive revision was approved by the RMI membership in 1972. This specification was accepted as an ANSI standard (ANSI MH 16.1 – 1974) in 1974.

Subsequent research and testing has been ongoing since and there have been several editions of the RMI Spec (1979, 1990, 1997, 2002, 2008 and 2012 as of this writing). Many of these have ANIS acceptance including the current latest ANSI MH 16.1 – 2012. RMI continues to work both internally and in conjunction with outhouse consultants, testing laboratories and universities to improve future editions of the RMI Spec. (The RMI spec and the ANSI specification are generally referred to interchangeably, and there are no differences between the two printings.)

The RMI Spec takes into account considerations unique to material handling environments that can affect the storage rack integrity, such as handling equipment abuse and rack loading and unloading practices. Consideration of these additional requirements in incorporated into the column, frame bracing, beam and beam-to-column connection design. These additional requirements from the RMI Spec of the rack components may result in a lower capacity than may be computed with only the requirements of the AISC or AISI specifications. However, the RMI Spec is the state-of-the-art design requirements for the storage environment. The storage racks will perform better when designed to the RMI Spec requirements. The IBC specifically references the RMI Specification for the design of storage rack.

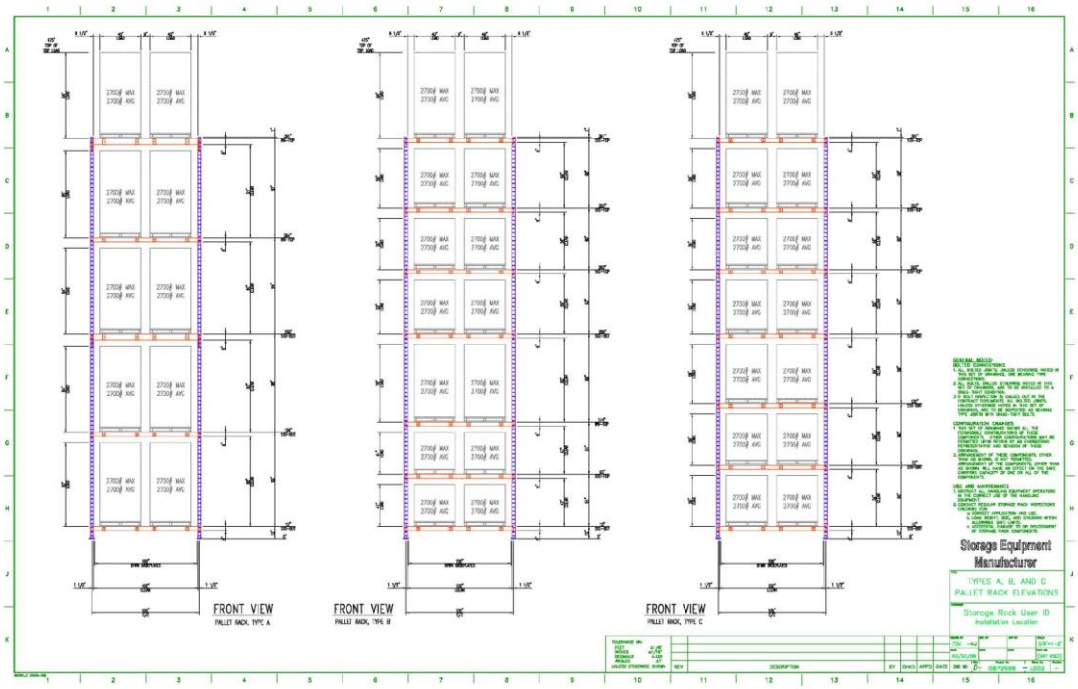
Some of the important highlights of the RMI/ANSI MH 16.1-2012 (the RMI Spec) are:

- System Documentation

An important part of the storage rack equipment is its adjustability. The rack may be used in a wide variety of configurations using many different parts to satisfy specific needs of the storage system. Each configuration, each different set of parts has a specific capacity. Changing the parts and/or the configuration will change the amount of product that the rack will hold. An individual system may have many different configurations that are required. It is important that the rack system user tell the rack system designer the configuration requirements and the product weights that will be stored in the system. The system designer will then select the correct components for the requirements.

Along with the rack components the system supplier will provide a “Load Application and Rack Configuration” (LARC) drawing. On this drawing will be details of each configuration with the associated permissible capacity. An example of the LARC drawing is shown below.

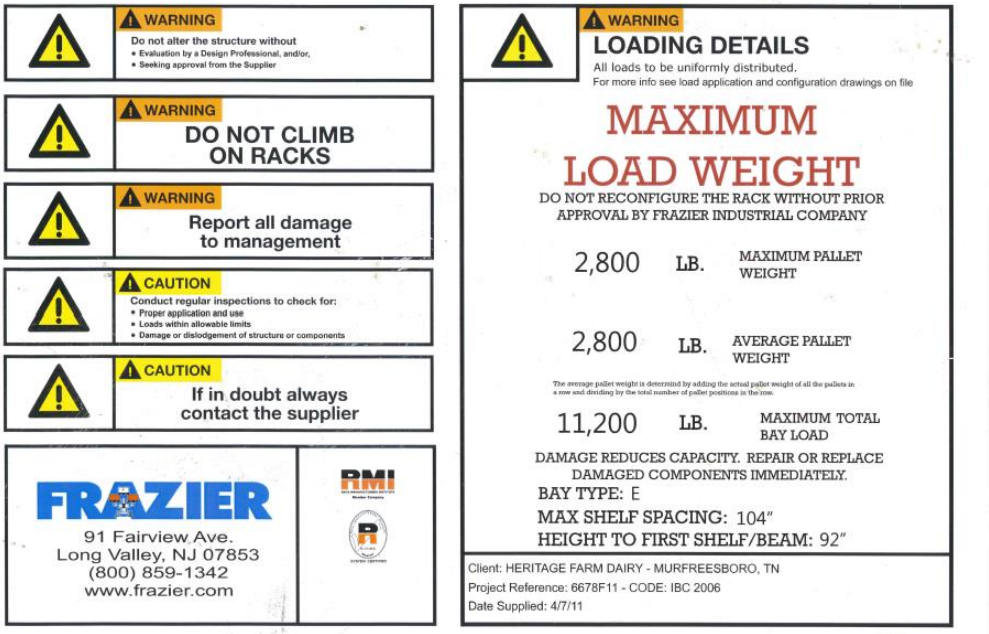
Figure 13.1 Load Application and Rack Configuration Drawing



The rack may be safely built with any combination of these configurations. The LARC drawings should be kept on-site in case it is required to reconfigure parts of the rack system. (Note, if a configuration is not shown on the original LARC drawing, a request should be made to the system designer for an additional configuration review. A capacity will be determined and a revision issued to the LARC drawings.)

In addition to the drawing, a plaque is required to be located and maintained, by the rack system user, in one or more conspicuous locations, that will inform the equipment operators of general safety information and the loading limitations. This is intended to be very general as the specifics are detailed on the LARC drawing. An example of the plaque is shown in Plaque below.

Figure 13.2 Rack System Information Plaque



Storage racks are a high-performance structure. The product loads that are expected to be safely carried by a pallet storage rack, proportionately, are much greater than a building structure. The RMI Spec details, to the storage rack system designer, how to properly combine the product loads with the other expected loading, such as the dead load, live load and seismic load.

- Product Load

The product to be stored, the unit load, the pallet weight are all the same thing. It is the most important loading that is placed on the storage rack. Generally, the maximum weight of the product is what is considered to be loaded into every slot in the system. This is generally the most conservative assumption that is used for the design of the components.

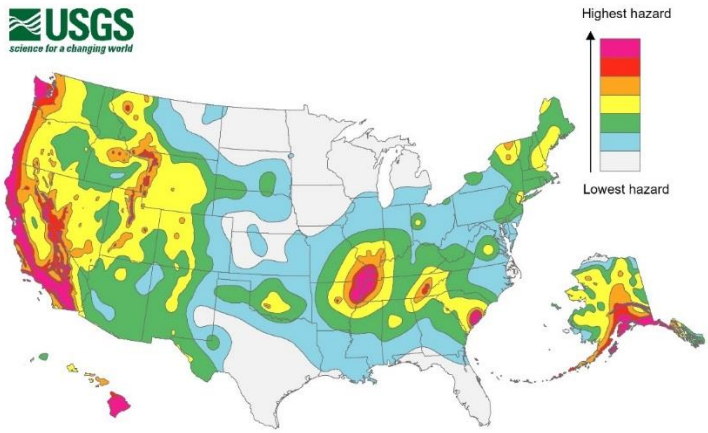
Frequently, though, it is not a realistic representation of the loading seen during the lifetime of the system. In most rack systems very few of the loads stored are at the maximum weight and frequently there are one or more slots that do not have product. For the design for the forces from a seismic event the RMI Spec allows a Product Load Reduction factor (P_{RF}) to take into account these realities of warehouse operation. Only on the basis of information supplied by the rack user may a P_{RF} be computed and used only for the down-aisle seismic force. P_{RF} is computed by dividing the average weight of the product in a bay by the maximum weight of product in any bay. The average product weight is the maximum total weight of product expected in a row, as reported by the system user, considering less than full weight product loads and empty product storage positions, in any rack row divided by the number of beam levels in that row.

This P_{RF} is then used to modify the horizontal seismic force that the row of rack must withstand. Take advantage of this design benefit by reviewing the actual expected products to be stored on the storage rack system rows.

- Storage rack seismic design.

In many parts of the country the storage rack must, by the requirements of the IBC, be designed to withstand the ground motion from earthquakes. The USGS has mapped their assessment of the risk from seismic activity. This risk assessment can be found on the USGS website - http://earthquake.usgs.gov/designmaps/us/application.php the mapped data is modified for local site conditions called the Site Classification. The Site Classification is determined by a soils engineer and may be anything from an A to an E classification. (If there has been no site study done the design must be based on a default Site Classification of D.) The higher the classification the more rack steel is required to withstand the ground motion forces. These factors are then combined and a "Seismic Design Category" is determined. **Error! Reference source not found.** shows a map of the Seismic Design Categories if the default Site Classification D is used. The Seismic Design Categories are what are used to determine the need for and the level of seismic design required (sorry Virginia, there is no more Seismic Zones – It's all about the Site Classification).

Figure 13.3 Seismic Design Category – Site Class D



It is important to understand, as a storage rack owner, that the individual site classification may make the difference in whether a system design is controlled by seismic activity. It is interesting to note that the lower the mapped assessment, the greater the effect of the site classification. In some places an incorrect site classification or the use of the default Site Classification D where a B or C may be appropriate could mean a 240% higher seismic force for the design of the storage racks.

Take advantage of the geology at each individual system site by getting a copy of the soils report done for the warehouse building and reviewing it with the rack designer.

- Shelf-beam deflection limits.

As the product loads are placed on the shelves, the shelves will deflect downward. When looking down the narrow aisle the loaded shelf deflection is apparent. The RMI Spec limits this loaded deflection to the shelf span between uprights divided by 180 (L/180). For example, a 96" long beam may deflect as much as 0.53" (96"/180). Deflection at this limit not only appears sound but will also limit the amount the pallets will tip together at the top. This will allow the placement of the product loads closer together and still maintain the ability to store and retrieve the loads.

- Performance of shelf-connection locking device.

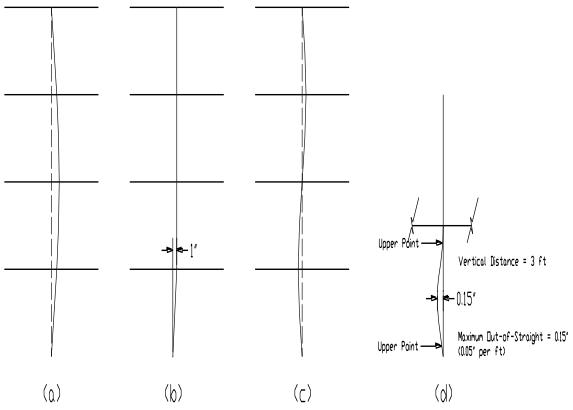
It is not uncommon that a handling equipment operator, in the process of retrieving a load, to lift the product and contact the bottom of the beam above. If that beam is unloaded a clip type connector may become dislodged from the column causing the beam to drop to the floor, or even worse, appearing to be connected until another load is attempted to be put into that storage location. The RMI Specification requires that positive restraint of upward loading be provided, such as bolts (which have equal impact resistance both up and down) or locking devices that must withstand a 1000# upward impact.

- System plumb and straight requirements.

No structure, not a building, not a bridge, not even a storage rack can be installed perfectly straight up and down (plumb). Any deviations from perfectly plumb require extra column and connection strength and stiffness. The design of all structures account for the extra strength required to accommodate these slight imperfections. The design of storage racks is limited to an out-of-plumb to not more than ½" in 10' (h/240).

The new RMI Spec requirements further clarify the "out-of-straight" requirements. These requirements are to prevent excessive bows, kinks or dog-legs of the rack column. The column may be plumb when measured at the top and bottom but have an unacceptable bow as shown in. A 20 ft tall column shown in **Error! Reference source not found.**b, where the entire out-of-plumb is between the floor and the first shelf would not be within the specification requirements. This type of condition is frequently due to column damage. The RMI Spec out-of-straight requirements requires all of these conditions to be within the 1/240 limit, not just the overall plumb.

Figure 13.4 Plumb Measurements



- Details of base-plates and shimming

Base-plates are welded onto the bottom of each column to distribute the column load to the top of the floor (although that is not usually the critical design case) and to allow anchoring to the floor. The columns are anchored to resist sliding when bumped by handling equipment and to hold the column down in the event of extreme seismic activity.

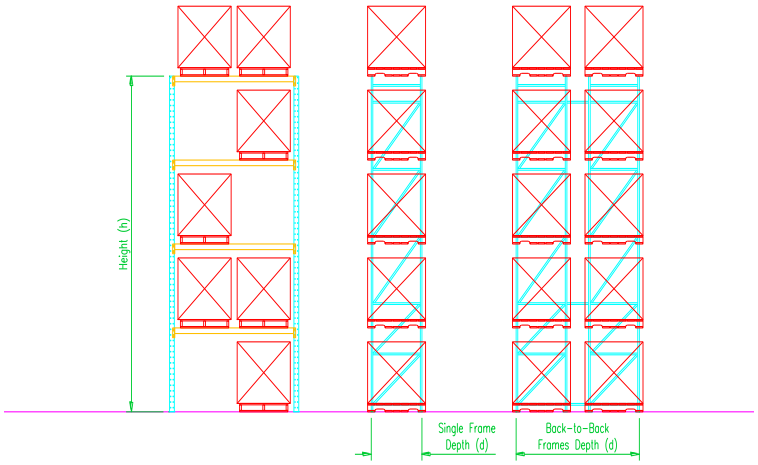
Under the base-plate there might be one or more shims to plumb the fames in the cross-aisle direction and, in the case of a push-back type rack, to elevate the bottom of the columns to a common level datum. There are limits to the shim stack prescribed by the IBC and the RMI Spec. First, the shims used need to be the same size as the base-plate. The shim must be made of material that matches or exceed the bearing strength of the floor slab. The height of the shim stack shall not exceed six times the diameter of the larges anchor in that base. If the shim stack is between two times and six times the largest anchor diameter the shims shall be interlocked or welded to transfer all the horizontal shear forces. If the stack is less than or equal to twice the largest anchor interlocking or welding the stack is not required.

- Design requirements for cross-aisle tying and anchoring.

13.2.1.4 Height-to Depth

The height-to-depth ration is a critical design parameter of the storage rack design. The height is measured to the top of the top shelf. The depth is the depth of the upright frame or the depth of all the frames connected in the cross-aisle direction. This depth is measured from the faces of the outermost interconnected columns. See **Error! Reference source not found.** below.

Figure 13.5 Frame Height and Depth



If the height-to-depth ratio (h/d) is less than 6 to 1, anchoring is required to carry forces such as seismic. If the h/d ratio is greater than 6 to 1 but less than 8 to 1 an additional stabilizing force of 350# at the top of any empty frame is required. This may result in greater anchoring requirements. If the h/d ratio is greater than 8 to 1 the frames must be tied overhead or tied to a building capable of stabilizing the frames, unless the design is specifically reviewed by an engineer.

Height to Depth Ratio

Single Frame Depth	Height-to-Depth Ratio (H/D)	Maximum Height to Top Shelf
42”	6-1	21’
	8-1	28’
Back-to-Back Frame Depth	Height-to-Depth Ratio (H/D)	Maximum Height to Top Shelf
102”	6-1	51’
	8-1	68’

The table shows some height limits for standard frame depths. You will note that for conventional pallet storage rack the height limit of the back-to-back frames is greater than the lifting heights of the equipment. Generally these limits are a consideration of single rack rows.

All rack columns are required to be anchored to the floor. This is to prevent the uprights from sliding when bumped by any operations in the aisles or in the event of an earthquake. The anchoring must be capable of resisting the forces such as the stability

forces, the seismic forces, or the wind forces (if applicable). The design of post-installed anchors in concrete floors is regulated by the American Concrete Institute (ACI) and is dependent on testing done by the anchor manufacturers and the concrete floor design.

13.2.1.5 Cross-Aisle Tie Requirements

Storage rack systems with an h/d greater than 6 to 1 will move, in the cross-aisle direction, when the load is placed or removed. To restrain this movement cross-aisle ties are recommended. The cross-aisle tie will be installed above the top of the top load (including any lift-off clearance space required). It will be attached to the aisle column of the upright on either side of the aisle.

13.2.1.6 System Redundancy

In seismic activity it is highly desirable to spread the seismic lateral forces out through as many of the rack components as possible. This will allow the effects of the seismic energy to dissipate safely into the rack components. The IBC, ASCE 7 and the RMI recognize this and require that there be redundancy in the overall system design. If there is not some redundancy the codes require an increase in the seismic forces to beef up the components.

- Inclusion of Pick-Module design.

Pick-modules are customized multi-level pallet rack that have pallets loaded from one side and support a pick aisle floor on the other. Most pick-modules are used in an industrial warehouse environment and accessed by authorized and trained order picking personnel. These types of rack systems are not generally open to the public. In order to provide a safe operation of these type of systems, the RMI has specified a series of modifications to the public access elevated platforms that are in the IBC. Guardrails are required around elevated openings except where those rail would interfere with the loading and unloading of the product. Part of the order picking personnel training must include where they are allowed to walk without extra fall protection. In the case of a picking aisle a safety flooring is required to be used under the flow lanes at least 4 ft. away from the picking platform edge.

13.2.1.7 Platform Loads

Platform loading needs to be specified by the storage rack used. Platforms supported by storage racks such as walk-pick module levels or elevated platforms are required by the RMI Spec to have a safe floor loading of 60 psf over the entire area of foot traffic. In addition, where applicable only, the loading from conveyor legs, pallet staging, superimposed shelving, mobile handling equipment and/or any additional loads on the platform.

The maximum deflection of the supporting beams from the live load must be less than their span divided by 240 (L/240). The total deflection shall be less than L/180.

13.2.1.8 Walkway Clearance

The clear width of a walkway of a pick module shall be 30 in. or more. Stairways need to have a minimum tread width of 30". Landings, if required must be at least the width of the stairway and not less than 30" in the direction of travel. The must be at least 7' of clear headroom, measured vertically from the leading edge of the stair tread.

13.2.1.9 Guardrail and Stair Handrail Requirements

Guardrails are to prevent someone from inadvertently falling off an elevated walking surface. Stair Handrails are for someone to grasp and help stabilize themselves as they go up or down a stairway.

Guardrails must be used to close openings through which an order picker may fall. The maximum permitted gap in guardrails is 6"

The top rail of a guardrail is to be 42 in. above the walking surface. The top rail and intermediate rails are spaced so that a sphere 21 in. in diameter cannot pass through any opening. Usually this means that there will be one intermediate rail. The bottom of a guardrail is required to have a 4 in. high kick plate.

The top rail of the guardrail needs to support a 200 lb. force placed at any single point along the guardrail and acting in any direction. All other portions of the guardrail needs to support 20 plf in any direction.

Stairways must have handrail on both sides of the stairway. The handrail should not interfere with the walkways nor the handing equipment traffic. The handrail should not extend beyond the top or the bottom stair tread. The handrail should be between 30" and 34" above the leading edge of the stair tread. The handrail should be away from any walls or other obstructions so that there is at least 3" of clearance. The amount that the handrail sticks out over the stairs does not reduce the stairway width. On stairways the handrail mounted 30" to 34" above the stair tread may be used as the top rail of the guardrail as long as the other requirements of the guardrails are met, such as the intermediate rails and the loading requirements.

13.2.1.10 Sprinklers and Fire Suppression

An integral part of warehouse design is the lighting, egress and fire protection systems. The fire system design and its integration with the storage rack and handling equipment can have a major impact on the type and design of the rack.

The code of reference in the United States for sprinklers and fire suppression for warehouse and rack systems is the National Fire Protection Association (NFPA) 13. However, since many localities use older versions of this document, the local authorities should be contacted. Building owners should also be aware that insurance carri- ers often place restrictions on acceptable risks that are more restrictive than the NFPA codes and local authorities. The rea- son for this is that the NFPA codes and local authorities ensure public safety, while insurers want to ensure accept- able monetary risks.

Integration of sprinkler design with the rack design may affect the flue space and beam-to-beam heights. Coordination among insurance carriers, local code officials, and sprinkler installers is essential.

In the NFPA code, fire suppression requirements in ware- houses is a function of height, density and product stored. For insurers, it is also a function of the value and the amount of product stored. The NFPA distinguishes the risk using classifications, which rate risk according to how the product is stored and packaged. Products are generally classified as Class I through Class IV category. (I is non-combustible and IV is highly combustible).

Many warehouses are Class III. This covers food storage on wooden pallets. The following general rules of thumb can be used to determine fire protection requirements for this classification.

13.2.1.11 System Height

1. Class III commodities or less, with top of the product less than 25' - standard ceiling sprinklers are acceptable and in-rack sprinklers can be avoided.
2. Class III commodities or less, with top of product over 25' - In-rack sprinklers are required.
3. Under 40' of product storage, in-rack sprinklers can be avoided by using ESFR (Early Suppression, Fast Response) sprinklers overhead. ESFR however, requires high pressure and more available water (gallons per minute)
4. Above 40', in-rack sprinklers are almost always required. These sprinklers are generally provided in the flue space (rear of the product) of every other bay (typically on every other product level).

13.2.1.12 Flue Spaces

A minimum flue space (load to load) of 6" clear is needed. Sprinkler lines run horizontally in the flue space, one per bay, every 15 vertically and horizontally along the face of the rack every 20 vertically, one per bay. Additional clearance is nec- essary in elevation when face sprinklers are required. (Valid for class IV and lower)

It is increasingly popular to place holes in the rack columns so that the sprinkler lines can be run from the flue to the rack aisle face.

13.2.1.13 Sprinkler Head Clearance

For standard ceiling sprinklers, the product must be at least 18" from the sprinkler head to allow for proper water diffusion. For ESFR heads, 36" is required. Obstructions such as structural members, light fixtures and duct-work can impact the design in ESFR sprinkler systems. In-rack sprinklers usually need additional beam-to-beam clearance. When face sprinklers are required, the horizontal distance from the heads to the pallet face should not exceed 18".

Higher risk product storage such as aerosols and alcohol (Class IV and higher) have tighter restrictions. Both flue and face sprinklers may be needed. In addition, fire baffles may also be required. Fire baffles are horizontal fire blocks, typically made of sheet steel, which delay the fire from rising to the layer of product above. This gives the sprinklers a chance to put the fire out before it rises to the next level. These steel sheets are placed directly over the shelf beams.

Face sprinklers typically require increased beam-to-beam spacing. Care must be taken to ensure that the pipes and heads are protected as well as possible. Exposed pipes and heads can be hit with product or with fork-lift trucks resulting in water leaks and product loss.

13.2.1.14 Freezers

Freezers have their own special requirements. Since water in this environment will freeze within the pipes, these systems must be "dry". Pipes are either filled with compressed air or glycol (anti-freeze). In dry systems, all heads must be turned up so no moisture freezes to block the lines at these points. All lines have to be pitched to allow for the water to drain out in the event of a discharge.

13.2.1.15 Floor Slabs

Pallet racks are normally supported on concrete slabs on grade. These slabs are poured directly on a prepared gravel foundation. The design of the slab is separate from the design of the rack system and must be checked. The necessary forces and base plate sizes are required for this evaluation to be completed by the designer of the building. Rack supported on a structural floor (i.e. above grade) represents a special situation which should be made known early in the design process.

Floor slabs are the foundation of the storage rack system. They must be designed to carry the storage rack and handling equipment loads into the sub-grade. The rack system designer will provide the loading from the frame columns into the floor. It is important to have the floor slab and the sub-grade properly design for the loading on the floor slab.

There are a couple of critical points in the slab review to keep in mind. First, it is generally the sub-grade performance that will result in good slabs. If there is good material used in the sub-grade and it is properly placed and compacted the floor loading will not require as thick a slab. Secondly, it is not desirable for concrete to dry, rather, the concrete chemically combines with the water to develop its full strength. Therefore, during the curing process of the slab, it will need to be kept moist to provide the chemical process as much water as it needs. Unless highly specialized mixtures of concrete is used it will shrink as it cures. (There will be less shrinkage if the concrete is allowed to fully cure.) This shrinkage will form cracks in the surface of the floor that may not occur only in the control cuts in the floor (These cuts are made to weaken the slab such that the cracking occurs in those locations.) The appearance of small, tight, cracks are not as a result of the load on the floor and do not indicate a slab failure.

Upright frames should be installed on a concrete slab on grade with a minimum thickness of 6", and not on any other surfaces, such as asphalt or structural slabs. Base plates should not be located on top of drains or any other opening in a floor.

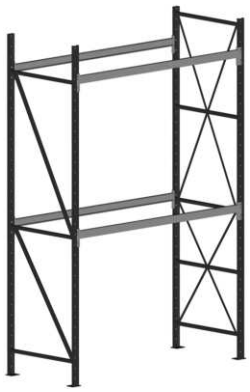
Frazier sizes its base plates according to criteria established by AISC for the design of column foundations. The design of the concrete slab and/or the underlying foundation must be referred to a professional engineer. If anchors require embedments greater than 21/4", a thicker slab may be required.

There are currently differences of opinion regarding the methods used to check the capacity of concrete slabs on grade. The most conservative is the Portland Cement Association (PCA) method. Other techniques are found in the literature and supported by full-scale slab tests. One such alternative is described in an article in the Journal of Structural Engineering, entitled "Load-Carrying Capacity for Concrete Slabs on Grade."

13.2.2 Components of a Frazier Rack System

Standard components of every pallet rack system include the upright frame and shelf beam.

Figure 13.6



13.2.2.1 Upright Frames

An upright frame is composed of two columns (usually a structural C-channel) which carry the axial or vertical load of the pallets. The frame horizontals (structural angles) and diagonal members form the bracing of the frames.

Frazier offers two types of frame bracing; the traditional Sentinel series "X" panel bracing and the "Z" braced panel.

Column punching is on 4" centers.

Base plate size depends on the size of the upright channel (post) and whether or not the column is boxed (see diagram). All base plates are 3/8" thick with two, 13/16" holes to accommodate either 1/4" or 5/8" anchor bolts. Two holes are provided in case an obstruction is encountered when drilling the first hold location.

One anchor bolt is provided for each base plate. Shim packs can be ordered separately to facilitate leveling.

X-Braced Frames

X-bracing offers an extremely durable design that has become very popular high seismic areas. The horizontal spacing in the high impact area is 24" and increases to 36" above.

Closer spacing provides additional support to the column in order to better resist impact forces. The diagonal bracing featured in our X-braced system is made from flat bar.

Diagonals work in tension rather than compression, and any looseness is pulled taut when a force is placed on the system.

Figure 13.7

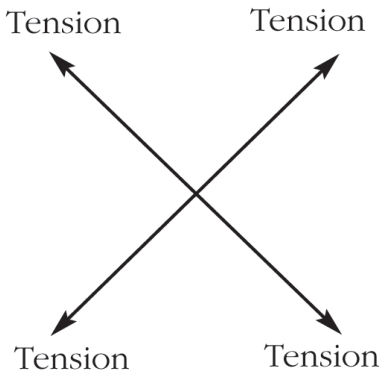


Figure 13.8 Standard Column Base Plate

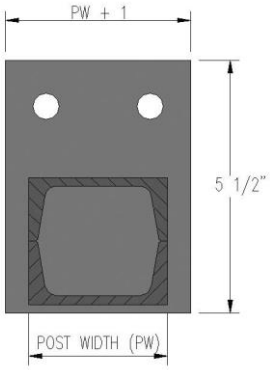


Figure 13.9 Boxed Clumn Base Plate

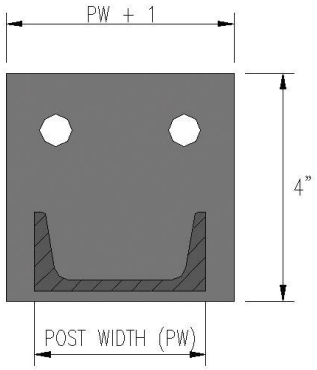
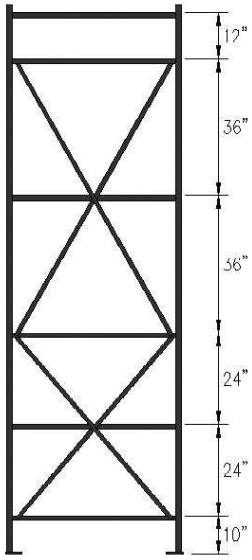


Figure 13.10 X-Based Frames



Z-Braced Frames

The Z-bracing pattern is a durable, cost effective design that has become the Frazier standard. The spacing of the horizontals is typically 40" vertically, although custom frames are available based on customer specification. Horizontals are made from structural angles. The diagonal bracing in the Z-braced design features structural angles as opposed to the flat bar bracing standard in the X-braced design.

Although the Z-braced pattern requires the diagonals to be used in compression, Frazier is able to provide additional capacity and durability by using structural angles. The Z-braced design features the Frazier time-tested, high strength and extra durable, hot-rolled structural components.

Figure 13.11 Based Frames

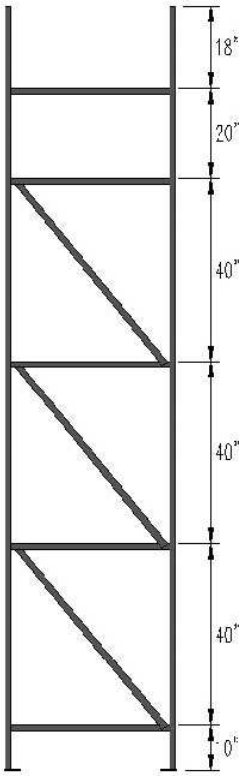
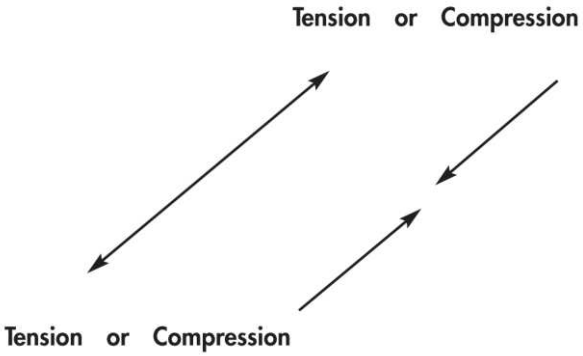


Figure 13.12 Z-Based Frames



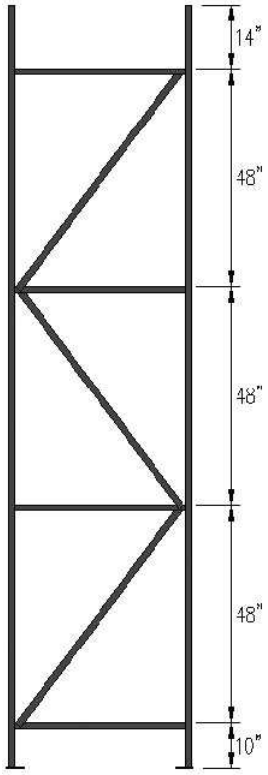
K-Braced Frames

The most popular bracing configuration in the industry is K-bracing. It was initially developed for the roll-formed industry and, as result, is used by every major rack manufacturer today.

The K-braced system varies from the Z-braced system in that the horizontal spacing is 48" top to bottom. Since the spacing of the frame horizontals determines the load carrying capacity of the column, the longer the distance between horizontals, the less capacity the column can carry.

In addition, a K-braced frame has fewer joints than a Z-braced frame with comparable horizontal spacing to resist the axial (downward) load of the frame. As in the Z-braced frame design, the diagonals are designed for compression.

Figure 13.13 K-Braced Frames



Note: Frazier can custom design bracing patters for large projects

13.2.2.2 Shelf Beams

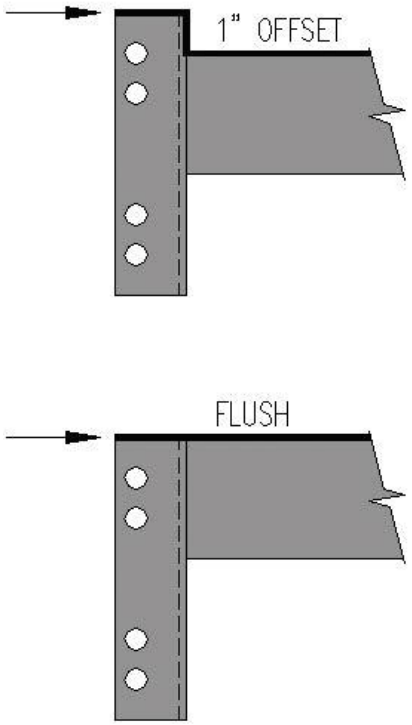
Shelf beams are made of hot-rolled structural steel channel at 3", 4" or 5" depths. Each beam is punched with pairs of 7/16" diameter holes located 32" apart and centered under each 40" wide pallet position for the installation of pallet supports or safety bars. Additional information is provided in section 13.2.7.

3" deep beams are mounted on the connector with a 1" offset and permit 1" adjustability by inverting the beam. The lowest possible elevation is 5" from the bottom of the base plate to the top of the beam. Upon special order, Frazier will fabricate 3" deep shelf beams mounted flush with the top of the connector.

4" deep beams are mounted flush with the top of the connector and permit vertical adjustability on 2" centers. There are certain elevations on which the 4" beam cannot be mounted, starting with 7", and in 4" increments above: (11", 15", 19", 23", etc.)

5" deep beams are mounted on the connector flush and permit 1" vertical adjustability with lowest possible elevation at 6" from the bottom of the base plate to the top of the beam.

Figure 13.14



Note: When beams are installed on boxed columns, the bolt length must be increased to 4" for the 4" column, 3 1/2" for the 3" column and 4 1/2" for the 5" column.

Figure 13.15



13.2.3 Guidelines for Designing Your Pallet Rack System

The following three factors must be determined prior to designing a pallet rack system.

- Unit to be stored (the product load)

- Method of handling equipment (lift trucks)
- Area available for storage (the building)

13.2.3.1 Unit

The unit refers to the product stored. It is usually comprised of a load or product sitting on a pallet, or a container storing parts. A common error made by systems designers is to assume that the customer is using only one type of pallet. Get as much information as possible regarding the unit load prior to laying out the system.

The Pallets

The first step in laying out the floor plan is to choose which type(s) of pallets will be used to store the loads. This is critical as the pallet often dictates frame depth, and the type of truck equipment and aisle needed.

Several types of pallets are in common use:

1. **Wooden GMA 48"x40"** — The wooden GMA style is the most widely used type of pallet in North America. We indicate "type" of pallet as there are many manufacturers in the market, each with slightly different numbers of boards, board widths, and thicknesses. Typically, GMA pallets are two-way and stored with the 40" face to the aisle (48" deep). On the 48" side, there may be fork notches in the stringers. These allow the pallets to be handled from the side when a full fork pocket is not provided. In some applications, such as to allow for easy piece picking, the pallets are stored on the 48" face, 40" deep. There are four-way, 48"x40" pallets (such as the 9-block GMA pallet) which have fork pockets on both the 40" and 48" faces.

Figure 13.16 4-Way Pallet: Openings are located front and rear (40" side) with 2 cutouts on the 48" sides



Figure 13.17 2-Way Pallet: Openings are located on the front and rear for fork truck use



2. **Wooden 48"x48"** — This size is less common than 48"x40" pallet and is typically four-way (fork pockets on both faces).
3. **Wooden Euro 40"x32"** — These are common in Europe and are often seen in import applications. They are similar to the GMA pallets as they are most often two-way pallets stored with the 32" face to the aisle.
4. **Small Wood** — This is a smaller version of the 48"x48" two-way pallet above; 36"x36" and 40"x32".
5. **Plastic Pallets** - Plastic pallets are becoming more popular due to cost, durability, stackability and usefulness in applications where wood is not sanitary. They come in a variety of sizes that mirror the wooden pallets described above. There are however, two typical types of plastic pallets from the point of view of their interface with pallet rack beams; those with "feet", such as the nine footed postal pallet, and those with a "waffle" bottom. Rack for storing plastic pallets with feet must be designed with care to ensure that the pallet sits on the beam correctly. This is normally done by providing wire mesh decks. Waffle pallets do not have this problem since the bottom of the pallet is continuous.

Note: Use of plastic pallets may push the classification of the building to Class IV, requiring a more restrictive fire protection design.

Pallet supports may be required with use of plastic pallets.

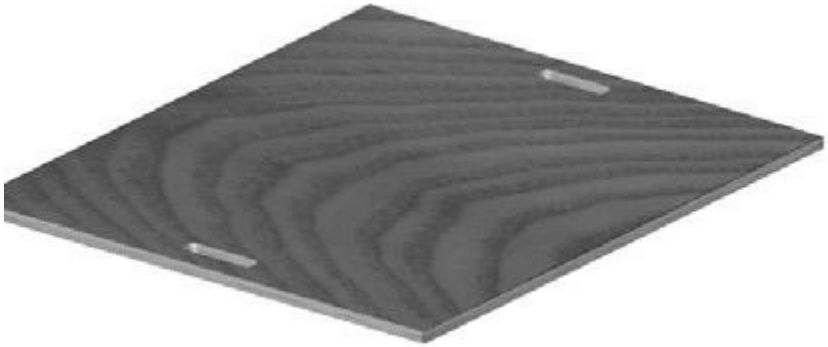
6. **Skid Pallet** — The skid pallet does not have bottom boards or openings in the side. Skids can only be handled from one direction.

Figure 13.18 Skid Pallet



7. **Slip Sheet —** A slip sheet stays with the system throughout the plant. Typically, it is a 1.5" thick sheet of plywood. Risers must be provided for fork truck entry.

Figure 13.19 Slip Sheet



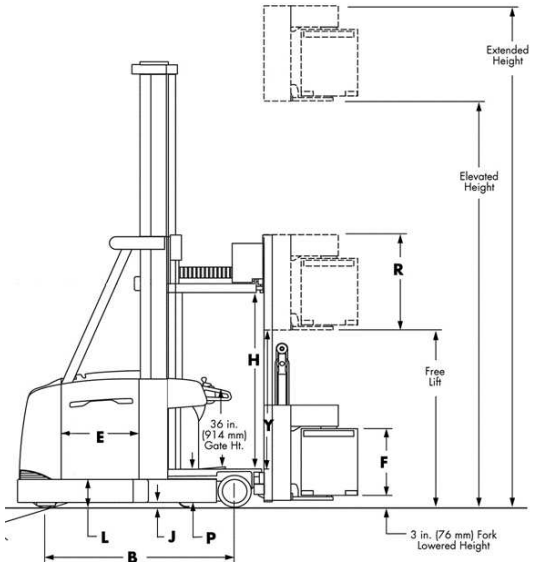
13.2.3.2 Method of Handling

Why is the method of handling so important to the design of the system? It's essential because the very large number of vehicles in the marketplace have a variety of unique design criteria such as aisle width, outrigger specifications, elevated mast heights and capacities. Each must be considered before designing the pallet rack system.

Critical Factors:

- Elevated mast height
- Elevated fork height with back rest
- Lift capacity and downrating
- Base leg openings, both inside and outside
- Required clear aisle dimension
- Collapsed mast height (especially for tunnels) Outrigger dimensions (width, length and height)
- Vehicle Types: Reach, Straddle, Straddle-Reach, Swing mast or Turret (VNA)

Figure 13.20



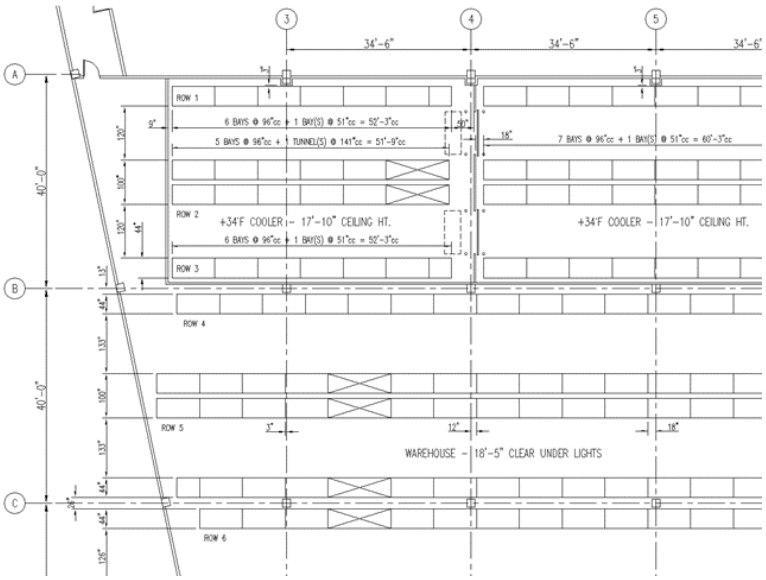
13.2.3.3 Area

The location where the rack system is placed provides the most challenging task to the rack designer. On paper, the design of the rack is easy since there are no obstructions in the way. However, in the real world there are building columns and other obstructions. Therefore, it is essential that a thorough site audit be conducted.

Site Considerations:

- Building column sizes and spacings in both directions
- Heaters hanging from the ceiling Utility lines, usually gas or electric Lights, both height and spacings Sprinkler locations and fire hoses Downspout, leaders and cleanouts
- Utility lines, usually gas or electric
- Lights, both height and spacings
- Sprinkler locations and fire hoses
- Downspout, leaders and cleanouts
- Seams in the floor, floor drains

Figure 13.21



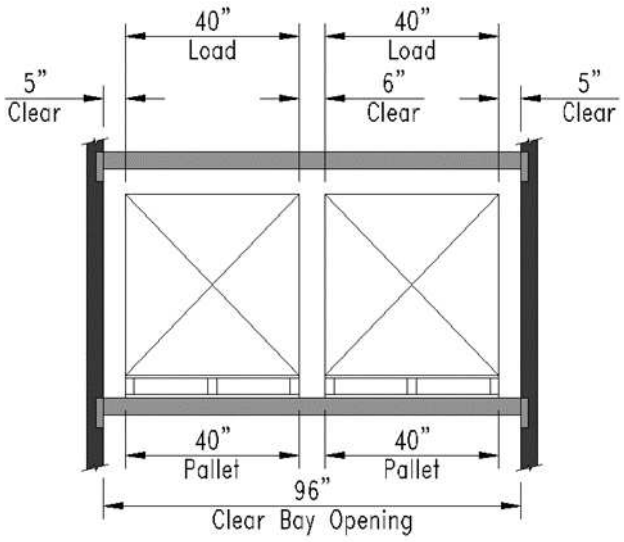
13.2.4 Getting Started

The following steps should be followed to design your pallet rack system.

13.2.4.1 Determining Clear Bay Opening

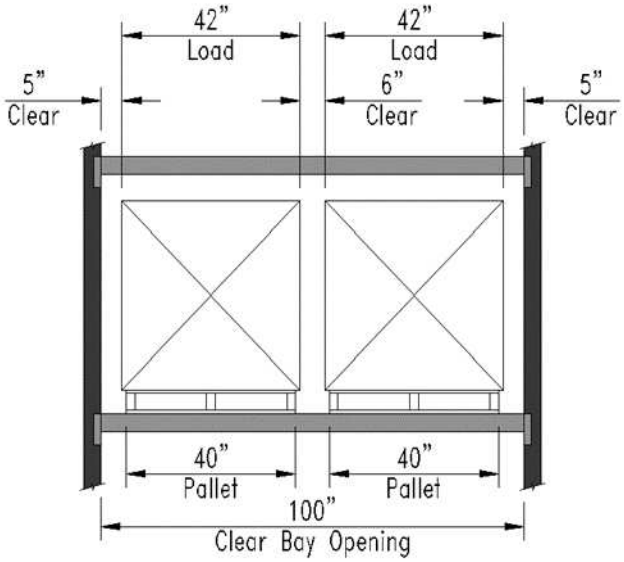
To establish the clear bay opening, the clearance between the loads and the frames must be defined. The clear bay opening is the nominal beam length used in Chapter 5. The industry standard is shown below, resulting in a 96" clear bay.

Figure 13.22 Clear Bay Opening - Loads 40" Wide



If the load width is wider than the pallet, use load width to determine the required clear bay opening.

Figure 13.23 Clear Bay Opening - Loads 42" Wide

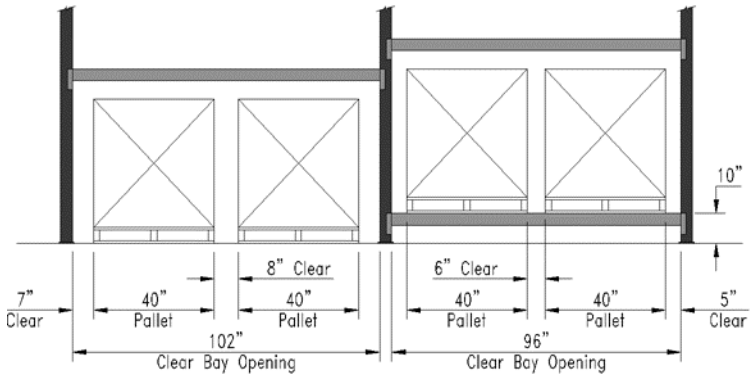


When using straddle or deep reach trucks, allow extra space between the pallets and frames for the outriggers (base leg). Make sure to verify the exact base leg opening from the fork lift manufacturer as these dimensions will vary. (see diagram below).

The downside of the larger clear opening is reduced product density (fewer pallets for a given row length). An alternative is to elevate the first load off the floor (approximately 10") so that the outriggers can enter beneath the bottom beam. Make sure to check truck specifications since this will also increase the height of the top shelf and may affect the amount of weight that the truck can lift at the new elevation. Minimum aisle width may also increase (see Sizing the Aisle, section 13.2.4.3).

Pallets other than wooden 48"x40" GMA may interface with beams differently. For example, bottom board location, width, orientation, and fork notches must be checked. Plastic pallets come with a variety of bottom configurations.

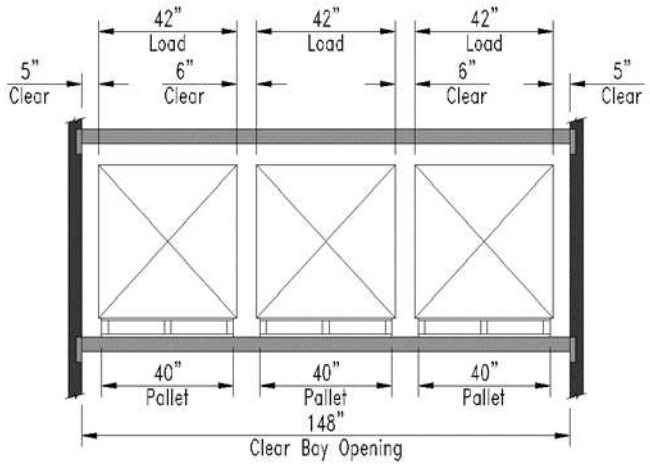
Figure 13.24 96" Opening Compared to 102" Opening



Note: Consult fork lift truck manufacturer for actual base leg openings and heights.

There are certain situations in which it is more economical to store loads three pallets across instead of two. Common examples are when the unit loads are lighter than 1500 lbs., or less than 40" wide. Tunnel bays are another common situation. Tunnels have to be three or four pallets wide to allow for the truck turning radius or to allow trucks to pass each other.

Figure 13.25 Clear Bay Opening – 3-Wide, Loads up to 42"



13.2.4.2 Determining Frame Depth

The appropriate frame depth is typically set by the pallet and/or the product depth. The following depths are commonly used.

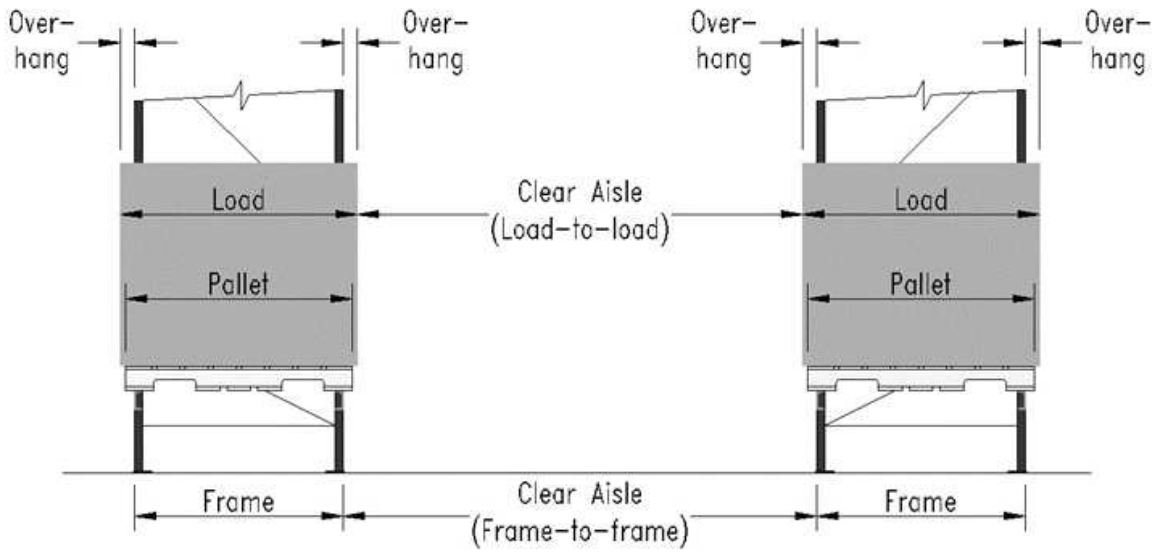
42" Frames - This is by far the most commonly used frame depth in North America. It is typically used for 48" deep pallets, resulting in 3" overhang, front and back.

44" Frames - This is a less commonly used variation of the 42" frame. It is often used when there is substantial product overhang in the cross-aisle direction. They are also used in deep reach systems where pallets are stored flush with the beam on the aisle face.

48" Frames - These are used for man-up order picking applications. Applications are for either loose and bulky products and single sided picking or for double sided carton picking. In both cases, the shelves are typically decked.

36" Frames - This depth is selected when 48"x40" pallets are turned with the 48" face to the aisle and for 40"x32" Europallets, turned with the 32" face to the aisle. It may also be chosen when single sided hand picking on shelves with wire mesh deck is used.

Figure 13.26



Remember to show both steel-to-steel and product-to-product dimensions when laying out your floor plan.

13.2.4.3 Sizing the Aisle

Optimal aisle width depends upon the truck, load dimensions and building column spacings. Industry standards for aisle widths are listed below. Please note that these are clear aisle dimensions with typical load overhang of 2"-3".

Man-up Order Pickers -

Guided Trucks - use platform width + 10"

Non-Guided Trucks - use 18" clearance on each side + bed width

Turret Trucks - Allow for load length + 18"

Counter-Balance Sit-Down - 132"-144", depending upon capacity

Reach Trucks - 96"- 132", depending upon truck and battery size

Deep-Reach Trucks - 108"-132", depending upon truck and battery size

Order Picking - Any aisle with two-way order picking using walkie jacks - minimum aisle is suggested as 120" or (2 x load width + 36")

Recommended clearance between the rack and building columns or walls should be no less than 3" (steel-to-steel) and no less than 1" per 10 of height, allowing for typical construction tolerances. Other obstructions, such as interior roof drains, curbs, vari- able depth columns (Butler, etc.) should be checked.

Clearance between product and building columns or walls should be checked. Typical product overhang is 2"-3". Rack that is placed too close to an obstruction may result in product damage.

Building columns can be located in flue spaces or within a rack bay. Many non-standard beam lengths are available so that individual bays with building columns can be sized to avoid losing pallet positions.

Remember - if aisles are replenished with full pallets, aisle width may be dictated by a different truck.

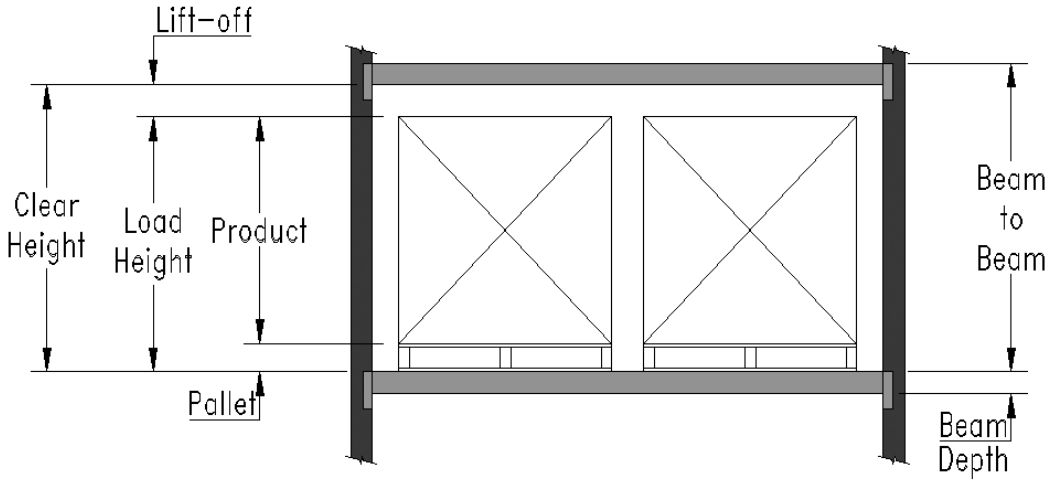
13.2.4.4 Sizing the Flue Space

Minimum flue space is typically 6" clear (product-to-product, pallet-to-pallet, or steel-to-steel). Wider flue spaces may be required due to fire suppression issues, load and pallet over- hang, building columns, or floor layout.

13.2.4.5 Load Interface Details

The first step to determining beam elevations is to establish the load interface details. This is comprised of three vertical dimensions: load height, lift off, and beam height.

Figure 13.27



1. Load Height - The load height is simply the product height plus the height of the pallet.
2. Lift Off - Lift off is the distance from the top of the load to the underside of the next beam. The amount of lift off required depends on the type of vehicle and whether or not the operator elevates with the load. The following are typical lift off dimensions:
    - Reach Truck - 6" to 8"
    - Deep Reach Truck - 8" to 10" (minimum clear opening must be 48")
    - Straddle Truck - 8" to 10"
    - Swing or Turret Vehicle (man-up) - 6" to 8"
    - Swing or Turret Vehicle (man-down) - 6" to 8"

Required lift off may vary with beam elevation. Near the floor, the lower number is typically used. For systems with beams above 20', consult truck manufacturer.

Note that the use of wire mesh decks reduces the clear height by about 1/2".

At sprinkler locations, an extra 6" of lift off may be required. When face (aisle) sprinklers are needed, deeper aisle beams can be used to protect the sprinkler heads.

3. Beam Height - Beam height is determined by beam type. For the time being, assume a 3" beam for a single bay, 4" beam for a double bay, and 5" beam for a tunnel or 3-wide bay.

Repeat this process for each load height from the floor to the top of the system. Cross check each beam height with the truck to ensure it has the required capacity. Remember, truck capacity may down-rate as height increases.

13.2.5 Beam Selection

13.2.4.1 Beam Selection Criteria

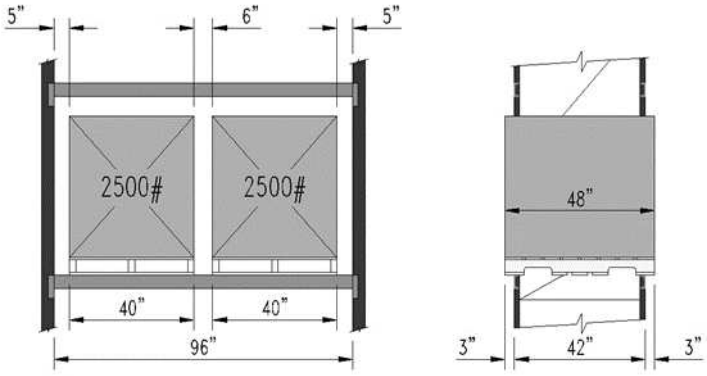
After laying out the floor plan and estimating elevations, the most economical beam should be selected. Note that beam selection may affect the elevations. (For example, if a 4" beam is required instead of a 3" beam). Beam size selection requires the following five parameters be defined.

1. Pallet Type and Material - Load capacities are based on the assumption that all products are stored on wooden pallets.
2. Beam Length - Beam lengths typically range from 46" to 144".
3. Number of Pallets Wide - Load tables cover one, two or three pallets wide.
4. Number of Beam Braces - Load tables include zero, one, two or three braces. For beams 108" and longer, a minimum of one brace is required.
5. Deflection - All beams in load tables are designed in accordance with RMI. The deflection limit for this code is given as L/180.

Compare the maximum allowable beam load in the tables with the actual load on each shelf beam. Normally the shelf loads are centered between the beams (equal overhang front and rear). Thus, load is divided equally between the front and rear beams. For other cases, the load on each beam must be calculated. Sample beam load tables are provided below.

When loads are stored on wire mesh decks, or on pallets made of materials other than wood, please consult factory, a beam brace may be required.

Figure 13.28 Beam Design



In this example, two 2500 lbs., wooden GMA 48"x 40" pallets are stored on a 96" shelf. The pallet loads are equally distributed between the front and rear beams. The load on each beam is 2500 lbs. The shelf weight is 5000 lbs.

From the sample load table provided below, the following can be selected:

C4 x 4.5 no braces, deflection = L/180

Beam Size: CB3 (C3 x 4.1)

Beam Clear Span, inches			Allowable Shelf Loads (lbs.)							
			No braces		1 brace		2 braces		3 braces	
			L/180	L/160	L/180	L/160	L/180	L/160	L/180	L/160
	1 pallet wide	<=60	7980	7980	7980	7980	7980	7980	7980	7980
	2 pallets wide	92	4860	5440	4860	5440	4860	5440	4860	5440
		96	4460	5000	4460	5000	4460	5000	4460	5000
		99	4200	4720	4200	4720	4200	4720	4200	4720
		102	4140	4140	4140	4140	4140	4140	4140	4140
		108	3520	3960	3520	3960	3520	3960	3520	3960

SAMPLE

Beam Size: CS4 (C4 x 4.5)

Beam Clear Span, inches			Allowable Shelf Loads (lbs.)							
			No braces		1 brace		2 braces		3 braces	
			L/180	L/160	L/180	L/160	L/180	L/160	L/180	L/160
	1 pallet wide	<=60	11460	11460	11460	11460	11460	11460	11460	11460
	2 pallets wide	92	7660	7660	8180	8180	8180	8180	8180	8180
		96	7040	7040	7840	7840	7840	7840	7840	7840
		99	6640	6640	7620	7620	7620	7620	7620	7620
		102	6260	6260	7400	7400	7400	7400	7400	7400
		108	5580	5580	6700	7000	6700	7000	6700	7000

SAMPLE

Notes:

1. *Loads are assumed to be stored on GMA-type wooden pallets. See text for other assumptions and limitations.*
2. *All strength requirements are in accordance with RMI.*
3. *Minimum guaranteed column yield = 50 ksi*
4. *Shading indicates values are limited by deflection, NOT strength.*
5. *Beams with clear span greater than 108" require at least 1 beam brace.*

13.2.6 Frame Selection

After determining the load interface details and selecting the beam, the next step is to select the frame. Begin by sketching each elevation, stacking the load interface details of each shelf level. Check the top beam elevation with the elevated fork height of the vehicle. Remember that the forks must be able to lift the pallet about 8" above the top shelf in order to place and retrieve pallets.

All frame loads given in the load tables meet the requirements of RMI and IBC. In Canada, these tables meet the new CSA A344.1/A344.2 rules. For Mexico, these tables follow guidelines for the seismic design of pallet rack. Sample frame load tables are provided below.

Sample Frame Load Table

Frame Column Size: 4S (C4x4.5)

Shelf spacing (inches)	Maximum Load (lbs)																
132											19,000	19,000	19,000	19,000	19,000	19,000	19,000
128											19,800	19,800	19,800	19,800	19,800	19,800	19,800
124										20,600	20,600	20,600	20,600	20,600	20,600	20,600	20,600
120									21,300	21,300	21,300	21,300	21,300	21,300	21,300	21,300	21,300
116									22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
112								23,800	23,800	23,800	23,800	23,800	23,800	23,800	23,800	23,800	23,800
108							25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
104							26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200
100						27,600	27,600	27,600	27,600	27,600	27,600	27,600	27,600	27,600	27,600	27,600	27,600
96					29,000	29,000	29,000	29,000	29,000	29,000	29,000	29,000	29,000	29,000	29,000	29,000	29,000
92					31,000	31,000	31,000	31,000	31,000	31,000	31,000	31,000	31,000	31,000	31,000	31,000	31,000
88					33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000	33,000
84			35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
80			35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
76			35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
72		35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
68		35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
64		35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
60		35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
56		35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
52		35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
48	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
	8	12	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Frame height (feet)																

Sample Frame Load Table

Frame Column Size: 3S (C3x3.5)

Shelf spacing (inches)	Maximum Load (lbs)												Maximum Load (lbs)				
132											11,500	11,500	11,500	11,500	11,500	11,500	11,500
128											12,000	12,000	12,000	12,000	12,000	12,000	12,000
124										12,800	12,800	12,800	12,800	12,800	12,800	12,800	12,800
120									13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500
116									14,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000
112								14,500	14,500	14,500	14,500	14,500	14,500	14,500	14,500	14,500	14,500
108							15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
104							16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
100						17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000	17,000
96					18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
92					19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000	19,200	19,200	19,200	19,200	19,200
88					20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,600	20,600	20,600	20,600	20,600
84			21,000	21,000	21,000	21,000	21,000	21,000	21,000	21,000	21,000	21,000	22,000	22,000	22,000	22,000	22,000
80			22,200	22,200	22,200	22,200	22,200	22,200	22,200	22,200	22,200	22,200	23,200	23,200	23,200	23,200	23,200
76			23,600	23,600	23,600	23,600	23,600	23,600	23,600	23,600	23,600	23,600	24,600	24,600	24,600	24,600	24,600
72		25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	26,000	26,000	26,000	26,000	26,000
68		25,600	25,600	25,600	25,600	25,600	25,600	25,600	25,600	25,600	25,600	25,600	27,200	27,200	27,200	27,200	27,200
64		26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200	26,200	28,600	28,600	28,600	28,600	28,600
60		27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	30,000	30,000	30,000	30,000	30,000
56		27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	31,500	31,500	31,500	31,500	31,500
52		27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	33,000	33,000	33,000	33,000	33,000
48	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	30,000	30,000	35,000	35,000	35,000
	8	12	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Frame height (feet)												Frame height (feet)				

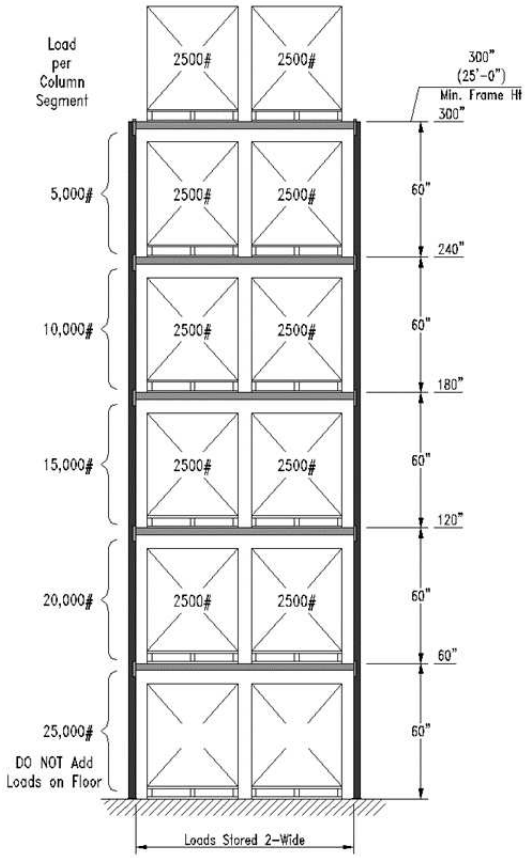
Notes:

1. For shelf spacing that falls between tabulated values, select next highest spacing value.

2. Light shaded cells indicate frames whose slenderness ratio can be greater than 8 to 1. Additional anchorage and/or concrete uplift may need to be checked.

3. Dark shaded cells with no values indicate frames, which are too short for a minimum of two shelves at that spacing.

Figure 13.29



Frame capacity requirements must be rechecked before changing beam elevations or removing beams. Moving beams should only be done with the entire bay unloaded.

13.2.6.1 Frame Restrictions

There are some restrictions on the use of the frame load tables.

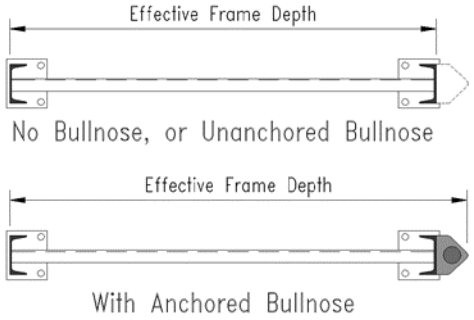
1. All load tables meet RMI and IBC earthquake requirements for lateral forces. Refer to **seismic maps sections 13.2.1.3**. For all shaded areas, please consult the factory as downrating may be necessary.
2. A minimum of two shelves is required.
3. The ratio of the height to the top beam divided by the effective frame depth (see below) should be limited to 8 to 1 for single rows and 16 to 1 for back-to-back or cross-aisle tied rows. When these values are exceeded, additional anchorage or cross aisle ties may be required. Consult fac- tory
4. The maximum shelf load should be limited to **12,000 lbs.** For loads above this, special beam-to-column connectors may be required.
5. Special design requirements apply to tunnels**.** Tunnels are bays storing three or more pallets wide with pedestrian and/or truck traffic underneath. Normally, tunnels are similar to the adjacent bays but with one or more shelf beam missing.
6. All frames must be anchored with a minimum one 1/2" diameter anchor per column. The anchors must have a minimum embedment of 2 1/4".
7. Frame base plates have been sized to meet AISC bearing requirements for base plates on large foundations.

Frazier does not accept responsibility for the concrete slab design (flexural strength, line shear, punching shear).

13.2.6.2 Effective Frame Depth

The effective frame depth is shown in the following figure. Note that the bull nose is included in this measurement only if it is anchored to the floor.

Figure 13.30



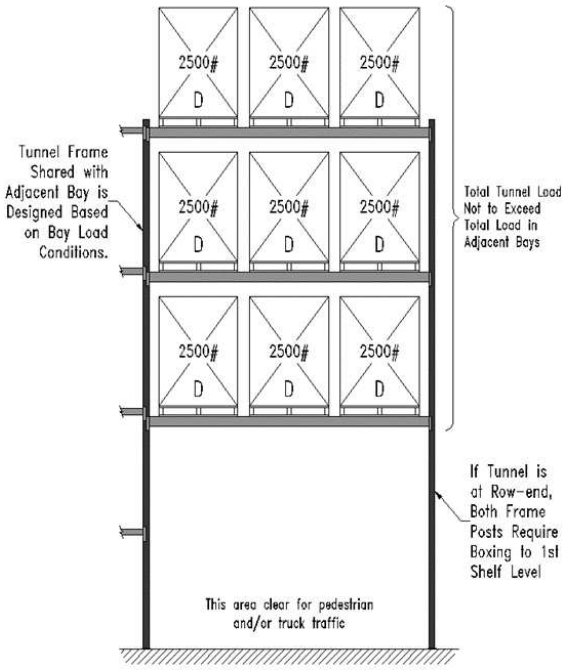
13.2.6.3 Tunnel Frames

Tunnels are bays storing three or more pallets wide with pedestrian and/or truck traffic underneath. Tunnel frames can be designed according to the following conditions:

1. Limit tunnels to a maximum of one tunnel per ten standard bays per row.
2. The total load in the tunnel bay should not exceed the total load in the adjacent bays.

If the tunnel is interior to the row, use the same frame as in the adjacent bay. If the tunnel is at the row end, the row end frame should be boxed to the first tunnel shelf elevation. The same column size (C3, C4) as the interior tunnel frame should be used.

Figure 13.31



13.2.6.4 Frame Installation

All frames must be installed to meet RMI requirements. Frazier recommends shimming and plumbing to within 1/8th of an inch per 10' (stricter than the RMI tolerances). Hardware (nuts and bolts) should never be reused.

13.2.6.5 Frame Damage and Protection

Frame damage can be classified into two groups: major and minor. Minor damage includes column bends, twists or bent bracing. This can be field repaired using hand tools, if anchors are not sheared and welds remain unbroken. All other frame damage should be classified as major.

Rack aisle side protection is always recommended. With the size and weight of modern trucks, no rack or building column can resist a major impact. Structural rack is designed to take minor impact and retain a large part of its original load carrying capacity when subjected to major impact.

Frazier suggests cross-aisle tying every frame to have the same effect in a single row. (See Frame Restrictions, section 13.2.6.1).

Applications requiring minor impact consideration are those where the truck is not wire-guided or rail-guided. Impact protection options are discussed in the Accessories section, section 13.2.7.

Any rack bay with major beam or frame damage should be unloaded and repaired. Any row of rack found to be leaning more than 1/2" in the bottom 10' should be unloaded, inspected and replumbed.

13.2.6.6 Boxed Columns & Additional Bracing

Boxing the front columns provides excellent fork truck impact resistance. Two options are suggested; front column boxed to 60", and front column boxed to 72". All boxing is provided with a factory installed, slanted sanitary cap.

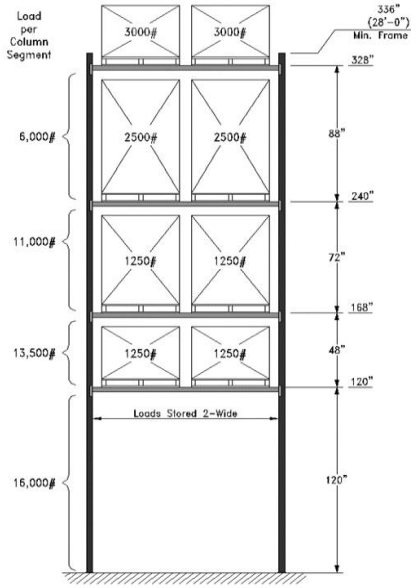
Driver training and rack maintenance are essential for ensuring a safe environment in any warehouse.

13.2.6.7 Rack Repair

When major frame damage occurs, frames can be repaired with a manufacturer supplied repair kit. These kits repair either the front column and bracing, or replace the entire lower portion of the damaged frame. Frazier Repair Kits are available for the following components:

1. Front Column & Bracing - Used if the rear column is not damaged.
2. Front & Rear Column & Bracing - Used if the rear column is damaged.

Figure 13.32 Example - Frame Design



Repair Kits - Use Caution: Do not attempt to use frame repair kits supplied by any other source than the original manufacturer. Use or repair of damaged components VOIDS

LOAD CARRYING CAPACITIES provided by Frazier Industrial, with the expressed exception of Frazier Repair Kits or Frazier replacement parts.

Refer to sample frame load table – Section 13.2.6

Top beam is at 27' 4", thus minimum frame height is 28'

1. Check frame segment from floor to 1st shelf:
   Total load is 6000 + 5000 + 2500 + 2500 = 16,000 lbs.
   Beam spacing = 120".
   From frame load tables - the minimum frame size is **C4x4.5**
2. Check frame segment from 120" to 168": Total load is 6000 + 5000 + 2500 = 13,500 lbs. Beam spacing = 168 - 120 = 48"
   From frame load tables - the minimum frame size is **C3x3.5**
3. Check column segment from 168" to 240": Total load is 6000 + 5000 = 11,000 lbs.
   Beam spacing = 240 - 168 = 72"
   From frame load tables - the minimum frame size is **C3x3.5**
4. Check frame segment from 240" to 328": Total load is 6000 lbs.
   Beam spacing = 328 - 240 = 88"
   From frame load tables - the minimum frame size is **C3x3.5**

The largest frame size required above is C4x4.5. Therefore, any C4x4.5 or C4x5.4 frame (at least 28' tall) may be selected for this application.

13.2.7 Accessories

The following accessories can be incorporated into the design to increase abuse resistance from material handling equipment, or to enhance the safety of the storage rack system. In some cases, accessories will be required depending upon the design and/or application.

13.2.7.1 Pallet Supports

Pallet supports are required when pallet overhang is less than 2". They are designed to support the full weight of the pallet. The size of the support is a function of frame depth and pal- let weight. Two pallet supports per pallet are suggested. For load weights up to 1500 lbs., 2"x2"x1/8" no-welds may be used (see beam braces). For loads between 1500 and 3000 lbs., 3"x2"x3/16" structural angle with welded angle clips should be used.

13.2.7.2 Continuous Pallet Supports

Continuous pallet supports are used in deep reach applications. They allow pallets to be placed anywhere from front to rear without the possibility of the pallets missing a beam support or having a fork notch catch on a beam. Pallet position is important relative to the beam when single supports are used, due to the gap between the front and rear frames.

Continuous pallet supports are notched to fit over the interior beams of double-deep shelves. Welded clips at the notches allow bolting to the interior beams, thus bracing them.

13.2.7.3 Back-Stops

There are two types of back-stops available.

Offset back-stops - Offset back-stops consist of standard shelf beams turned backwards and mounted to the frames using a bolted pipe spacer. Any number of offset back-stops can be mounted at any height (as long as it doesn't coincide with load beam elevations). The pipe spacers are available in two lengths for achieving a 2" or 3" back-stop offset. Offset back-stops are flexible and will bend if abused. They are typically located at heights where impact with product (not the pallet) is anticipated.

Figure 13.33

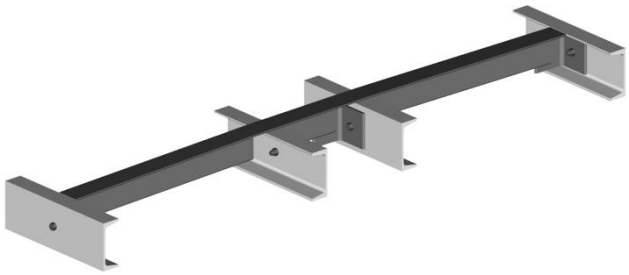
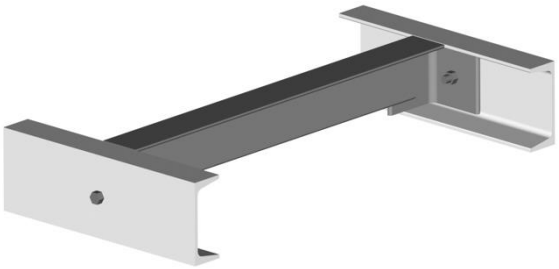


Figure 13.34



Z-stops - Z-stops are formed plates mounted directly to the rear shelf beam. Z-stops allow for 3" of pallet overhang at the rear of the shelf. They are at least 3" high to allow for normal lift off, while not damaging the product (typical pallet height is 5 1/2").

Figure 13.35 Z-Stop



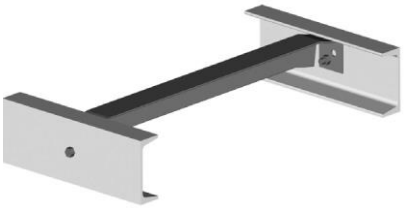
13.2.7.4 Safety Bars/Beam Braces

Safety bars prevent accidental pallet fall-through between beams. Beam braces are designed to brace the beam against rotation, but are not intended to support the weight of the pallets.

Safety Bars - The size of the safety bar is a function of frame depth and pallet weight. Two safety bars per pallet are suggested. 2"x2"x1/8" no-welds (see beam braces) may be used for pallet weights up to 3000 lbs.

Beam Braces - Frazier offers a no-weld beam brace made from 2"x2"x1/8" structural angle that fits both C3 and C4 beams. They are strong enough to resist bending during nor- mal usage when product overhang is 2" or more (such as in the case of 42" or 44" deep frames with 48" deep GMA wooden pallets).

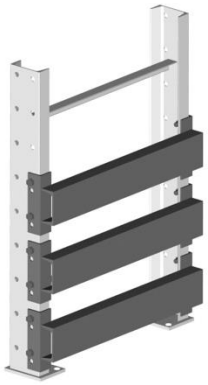
Figure 13.36



13.2.7.5 Row End Protectors

Row end protectors provide protection against fork lift damage where it is needed most - at the end of the aisle. They are made of 4" structural channel and are installed parallel to the end row frame. They are bolted to the columns with 1/2" diameter, grade-5 bolts.

Figure 13.37 Row End Protector



If using boxed columns, remember to order longer bolts for any components that bolt to the boxed section.

13.2.7.6 Bolt-In Rub Rails

Rub rails are horizontal members that bolt into frames below the lowest horizontal brace. Rub rails protect the frame from damage by the fork truck or pallet. The frame is

protected in two ways; the rub rail helps distribute any impact forces to the rear column of the frame, and it prevents the column from rotating when hit.

Bolt-in rub rails should be made from steel sections with the same width as the frame post. They are installed in the frame using bolt-in angle clips, making them easy to replace if damaged.

Figure 13.37 Bolt-In Rub Balls



13.2.7.7 Bolt-On Bull Noses & Post Protectors

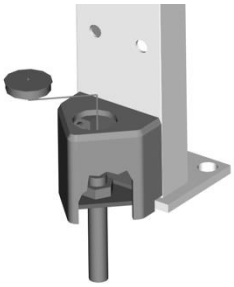
Post protectors and bull noses protect the front column from damage by deflecting impact from pallets or fork trucks.

Bull Noses are 4" high aisle column protectors that mount to the frame directly at the floor. They protrude approximately 3" into the aisle. The bull nose is equipped with its own independent base plate. A 3/4" anchor can be installed inside the bull nose providing an additional 15,000 lbs. of impact, sheer resistance. If damaged, the bull nose and its anchor bolt may be removed and replaced.

Two types of sanitary plugs are available, plastic and steel. Plastic plugs are standard. Steel plugs are more durable and recommended for temperatures below 28 degrees F.

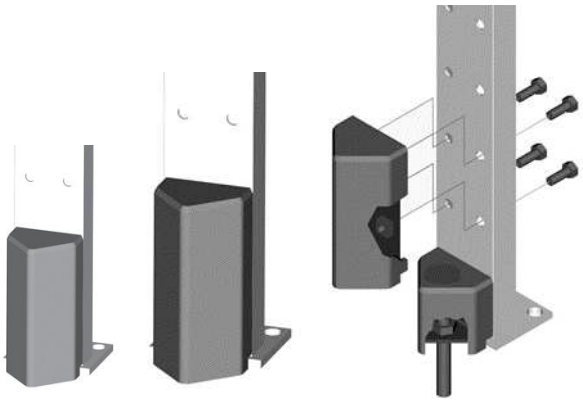
Post Protectors are deflectors that mount to the front of the frame, typically directly above the bull nose. These come in several lengths and should be sized for the type of truck used. Frazier suggests that the post protector be high enough to cover the posts at least up to the second horizontal brace. Post protectors can also be installed without the bull nose.

Figure 13.38 Post Protectors



Extended Post Protectors are deflectors that mount to the front of the frame, typically directly above the bull nose. These come in several lengths and should be sized for the type of truck used. Frazier suggests that thepost protector be high enough to cover the posts at least up to the second horizontal brace Post protectors can also be installed without the bull nose

Figure 13.39 Extended Post Protectors



Make sure to mount the first shelf higher than the post protector.

13.2.7.8 Back-to-Back Ties

Back to back ties are 1 1/4" x 1 1/4" x 1/8" angles with plate clips on each end for bolting to the frame in the flue space. They provide additional stability and abuse resistance.

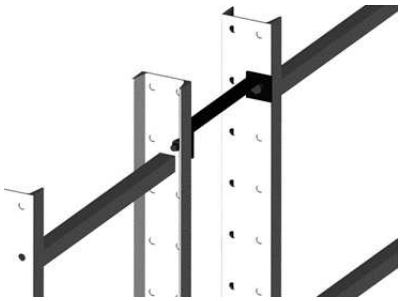
A minimum of two back to back ties or one back to back tie per 10' of height (whichever is greater) is required. Each tie should be placed as close as possible to a horizontal brace in the frame. The top and bottom ties should be installed as close as possible to the top and bottom horizontal braces of the frame. The others should be roughly equally distributed. The bottom tie helps distribute truck impact among four base plates instead of just two.

Minimum flue width is typically 6", product to product. Please consult local fire code and insurance company. In the case of a 42" deep frame with 48" deep pallets, a back

to back the length of 12" is needed. Longer back to back ties are available in cases where additional clearance is required due to fire restrictions or when building columns are buried in the flue space.

If back to back ties are to be used for suspending sprinkler piping, the maximum load must not exceed 300 lbs.

Figure 13.40 Back-to-Back Ties



13.2.7.9 Floor Angle

4"x6"x1/2" thick angle (6" vertical leg) is directly mounted to the floor, providing protection to the rack, building walls, or to act as truck guides. Angles are provided with holes to mount 3/4" anchors on 12" centers.

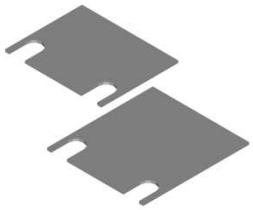
13.2.7.10 Cross Aisle Ties

Cross aisle ties may be needed when single row slenderness (height to top shelf/effective frame depth) exceeds 8 to 1. They may also be needed when additional load paths are required. Cross aisle ties should be placed above the top-most obstruction of the fork lift truck and at least 8" above the top of the highest load. This avoids damaging the truck, product or cross aisle tie.

13.2.7.11 Shims

Three types of shims are available - black unpainted steel, galvanized steel, and plastic. Plastic shims should be avoided in freezer applications where the temperature is below 28 degrees F (-2 Celsius). Typically, an average of one shim is needed per frame on new floors, and additional shims may be required on older floors. Shimming is not required under the bull nose. Make sure to order ample shims to avoid installation delays

Figure 13.41 Shims



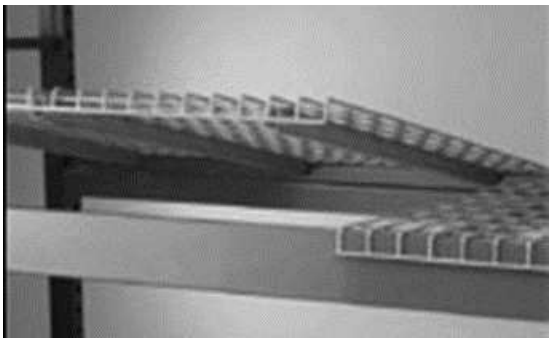
Floors may have local slopes provided for drainage which will require additional shimming. If the floor is sloped in the down-aisle direction over the entire length of a row, a Frazier authorized sales representative should be contacted since this requires special design consideration.

13.2.7.12 Wire Mesh Decks

Wire mesh decks can be placed on the shelf beams to provide the flexibility to store cartons, drums, and multiple pallet sizes. Decks used with structural beams are typically designed with a "waterfall" front and rear (see below). There are several combinations of sizes and features to consider:

1. **Beam Size**: Decks to be used with structural channel beams are made for specific beam sizes. In some cases, the same deck can fit more than one beam size (as with C3 and C4 beams).
2. **Frame/Shelf Depth**: Decks are designed to fit specific shelf depths. Selective pallet rack shelves are generally 42" deep or 44" deep.
3. **Capacity**: Deck load carrying capacity varies based on wire size and spacing, and depends on the quantity and type of stiffener used (see below). Note: When "sanitary" stiffeners are used, deck capacity is reduced by one third compared to the "standard" stiffeners.
4. **Waterfall Depth**: Decks may have a "waterfall" design, where the mesh is bent to fit over the front and/or rear beams. Waterfall depth varies, but is typically 1 1/2", which can obstruct labels applied to the beam face.
5. **Wire Size and Spacing**: Decks are available in many combinations of wire gage and mesh spacing. Common sizes are 4ga and 6ga. Common mesh spacing is 4 1/2" x 2 1/2" (depth x width).
6. **Stiffeners**: Decks for pallet rack typically have reinforcement channels or stiffeners. Stiffeners are typically thin-gage U-shaped channels flattened at the ends where the deck sits on the beam. The number of stiffeners depends on the width of the deck and desired capacity. They come in two types: standard and sanitary. Standard stiffeners are oriented with the U-shape opening facing up. The sanitary type has the U turned downward so that debris does not collect.
7. **Finish**: Decks can be obtained in a variety of finishes to suit a variety of needs. A gray coat is common.

Figure 13.42 Wire Mesh Deck



Calculate the optimal deck width using the formula below, which is based on the nominal beam length and the number of pallets wide per shelf:

Deck Width = (Beam Length - 2" per Pallet), divided by No. of Pallets wide.

For example, for a 144" long, 3-wide tunnel beam, the optimal deck width is:

[144 - (2*3)]/3 = 46"

Note: Top wires should run front to back for smooth removal of cartons.

13.2.7.13 Hardware

Use the following guidelines regarding hardware for bolted rack connections:

1. For beam-to-column connections and for attaching components such as row end protectors, rub rails, back-to-back ties, cross-aisle ties, and full-length back-stops to frame columns, use grade 5 (A449) nuts and bolts.
2. For components that bolt to an upright post, a count of unboxed (single) and boxed (doubled) post locations must be made to arrive at the correct quantities of short and long bolts. Fully threaded bolts are preferred to avoid having nuts "bottom out" before becoming fully tight.
3. Grade 5 (A449) nuts and bolts should also be used for beam braces, pallet supports, and other components that attach to beams.

When bolts are properly installed, lock nuts and washers are not needed.

Typically, 1/2" diameter x 3 3/4" long wedge-type anchor

Bolts are used for anchoring rack frames to concrete floors. The recommended minimum embedment depth is 2 1/4". For bull noses & floor angle, 3/4" diameter anchors are preferred

Note: Be sure to take shim thickness as well as baseplate thickness into account when calculating anchor bolt lengths.

Note: Minimum anchor embedment in all cases is 2 ¼”

13.3 General Rack Maintenance Guidelines – the ANSI Specification

A portion of the ANSI Specification MH16.1 deals with rack maintenance. Note that this specification was revised in 2012, so if you are familiar with the 2008 version you will note some changes.

Section 1.4.1(2) states:

> "Regularly inspect for damage. If damage is found, immediately isolate the affected area. Have a storage rack design professional evaluate the damage, and unload, replace or repair if directed by the professional, any damaged columns, beams, or other structural components to restore the system to at least its original design capacity."

Section 1.4.11 deals with out-of-straight and out-of-plumb limits:

> "The maximum top-to-bottom out-of-plumb ratio for a loaded rack column is 1/240 (for example ½ inches per 10 feet (12.5 mm per 3 m) . . . The maximum out-of-straight ratio for a loaded rack column is 1/240 (0.05 inches per foot or ½ inches per 10 feet (12.5 mm per 3 m) of height)."

The question is commonly asked whether the out-of-straight rule applies to "kinks" in racking. The answer is yes. A kink in a rack upright that is outside of 0.05 inches' deviation per foot of upright would be outside of the limit for rack damage, and therefore in need of repair or replacement. Additional guidelines include:

- Shelf beams are allowed slightly greater tolerance for deflection, at 1/180 instead of 1/240 for rack uprights.
- Pallets should not be double-stacked (which can sometimes be possible for the top position) unless the rack is specifically designed for this.
- A plaque should be displayed indicating a) the maximum load per level (uniformly distributed), b) the maximum load per unit load (usually per pallet), and c) the maximum total load per bay.
- Beams should have connection locking devices (or bolts) designed to resist an upward force of 1,000 pounds or more (Section 5.4.2).
- Shims may be used under base plates, provided that a) the material meets or exceeds the design bearing strength or the allowable bearing strength of the floor, b) their size is equal to or greater than the size of the base plate, c) a shim stack thickness shall not be greater than six times the diameter of the largest anchor, and d) shim stacks with thicknesses of over two times the diameter of the largest anchor (but less than six times) shall be interlocked of welded together (Section 7.1.4).
- All rack uprights should be anchored to the floor. Anchor bolts should be inspected periodically by an independent qualified inspector (Section 7.3.2 and Commentary Section 1.4.7).

13.4 Other General Rack Maintenance Guidelines

There are other guidelines that are generally followed by the rack engineering community, with some variation depending on the specialist. The Rack Manufacturers' Institute (RMI) is expected to publish a document with specific recommendations, but it is not yet available.

For example, rack inspections. How frequently should they be conducted? A common approach is that they are conducted in accordance to damage rates in the particular warehouse environment. For example:

- Immediate inspections should take place if a rack has received damage, or if there has been seismic activity in the area.
- Monthly inspections for racks with a high degree of damage potential.
- Quarterly inspections for racks with a medium damage potential.
- Semi-annual inspections for racks with a low damage potential.
- Annual inspections for all other racks.

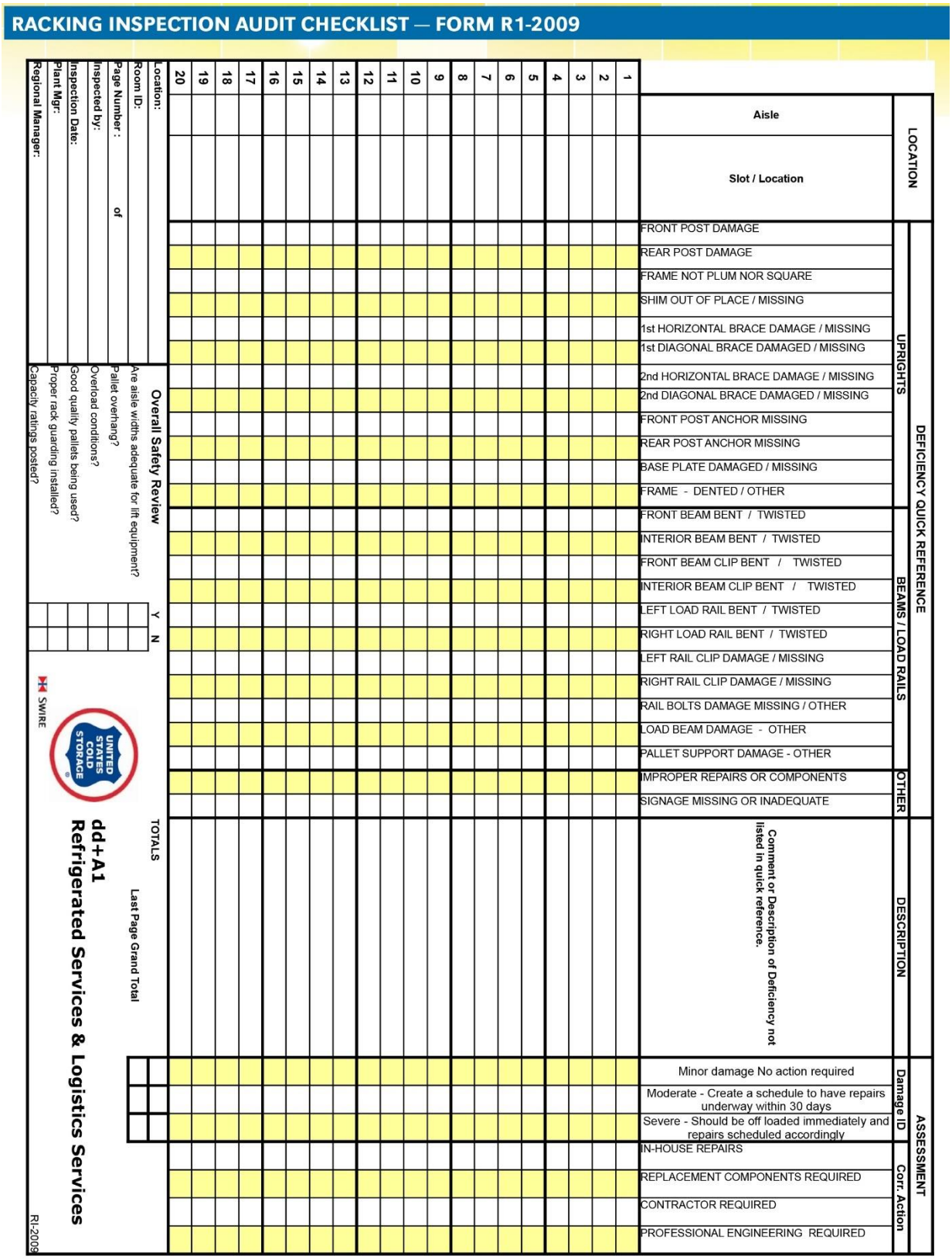
Also, there is additional scope of rack inspection and maintenance not covered in the ANSI MH16.1 specification, which is recommended:

- Are protective devices installed in locations that are vulnerable to damage (e.g. from lift trucks)?
    - Rack upright protectors in vulnerable, or in some cases, all uprights are recommended
    - End-of-aisle guards for ends of aisles, ideally with stiffeners that prevent "bending" of guards into racks.
- Are all uprights in a rack system consistent with the original design? It is common to find that original uprights have been replaced over the years by uprights that do not match, or are installed backwards. This needs to be corrected.
- Are crossbars or wire decking used to help prevent goods from falling between beams?
- For racks that are placed against walls, do pallets get pushed against the wall causing damage/indentations? Pallet stoppers for the rail or floor levels can be used to stop this.
- For racks whose backs are exposed, is there danger of products (as a result of a push or otherwise) in danger of falling? Netting or back-stop beams can be used to prevent this.
- Are pallets in good condition (for example, without broken planks)?
- Are pallets placed squarely on the racks?
- Is there adequate room between loads and the racking? The following clearances are recommended:
    - Four inches between loads and rack uprights
    - Five inches between adjacent loads on a beam

    - Six inches between the top of the load and the next beam (more clearance may be needed for double-deep racking)
- Is there rust or corrosion on the racking? If so, it should be inspected further for possible repair or replacement.
- Is the rack bracing damaged? Some rack repair companies have special replacement braces, obviating the need to repair or replace the entire upright.
- Are lift trucks used to hold racks in place during repairs? This is not recommended, as racks are not designed for this kind of operation. In particular, rack beams are not designed to sustain significant upward force.

Please note that there are additional considerations for seismic zones that are beyond the scope of this article. Also, this article does not address the possibility of defects in the original rack or building design (for example, unsuitable floor slab design, defects in the original rack design, etc.) that can lead to rack maintenance and safety issues.

The enclosed "Racking Inspection/Audit Checklist" used by US Cold Storage is a good example of a rack inspection form for a cold storage company that performs its own rack inspections. Outside firms who specialize in rack inspections have similar forms.


RACKING INSPECTION AUDIT CHECKLIST — FORM R1-2009
LOCATION
Aisle
Slot / Location
DEFICIENCY QUICK REFERENCE
UPRIGHTS
FRONT POST DAMAGE
REAR POST DAMAGE
FRAME NOT PLUM NOR SQUARE
SHIM OUT OF PLACE / MISSING
1st HORIZONTAL BRACE DAMAGE / MISSING
1st DIAGONAL BRACE DAMAGED / MISSING
2nd HORIZONTAL BRACE DAMAGE / MISSING
2nd DIAGONAL BRACE DAMAGED / MISSING
FRONT POST ANCHOR MISSING
REAR POST ANCHOR MISSING
BASE PLATE DAMAGED / MISSING
FRAME - DENTED / OTHER
BEAMS / LOAD RAILS
FRONT BEAM BENT / TWISTED
INTERIOR BEAM BENT / TWISTED
FRONT BEAM CLIP BENT / TWISTED
INTERIOR BEAM CLIP BENT / TWISTED
LEFT LOAD RAIL BENT / TWISTED
RIGHT LOAD RAIL BENT / TWISTED
LEFT RAIL CLIP DAMAGE / MISSING
RIGHT RAIL CLIP DAMAGE / MISSING
RAIL BOLTS DAMAGE MISSING / OTHER
LOAD BEAM DAMAGE - OTHER
PALLET SUPPORT DAMAGE - OTHER
OTHER
IMPROPER REPAIRS OR COMPONENTS
SIGNAGE MISSING OR INADEQUATE
DESCRIPTION
Comment or Description of Deficiency not listed in quick reference.
ASSESSMENT
Damage ID
Minor damage No action required
Moderate - Create a schedule to have repairs underway within 30 days
Severe - Should be off loaded immediately and repairs scheduled accordingly
Corr. Action
IN-HOUSE REPAIRS
REPLACEMENT COMPONENTS REQUIRED
CONTRACTOR REQUIRED
PROFESSIONAL ENGINEERING REQUIRED
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TOTALS
Last Page Grand Total
Location:
Room ID:
Page Number : of
Inspected by:
Inspection Date:
Plant Mgr:
Regional Manager:
Overall Safety Review
Y N
Are aisle widths adequate for lift equipment?
Pallet overhang?
Overload conditions?
Good quality pallets being used?
Proper rack guarding installed?
Capacity ratings posted?
UNITED STATES COLD STORAGE
SWIRE
dd+A1
Refrigerated Services & Logistics Services
RI-2009

13.5 Guidelines Specific to Cold Storage Environments

Conditions in cold storage environments, and particularly in freezer environments, impose additional recommendations for rack maintenance.

For example, in cold storage environments labor is usually more expensive than in dry environments, stemming both from higher per-hour labor rates and also because many maintenance activities require more time to the extent that they require fine motor skills, specialized equipment, frequent pauses due to more congested work areas, more frequent work breaks out of the cold, etc. This alters the economics of rack maintenance, tilting cold storage managers toward procedures that minimize labor. For example:

- Cold storage managers will tend to invest more in protective guarding than would be typical in dry environments. Ideally, the protective guarding should be bolted on the upright and should be properly anchored to the ground, rather than weakly anchored away from the upright where an impact can cause the guarding to damage the rack. This will lower the need for future repairs and/or replacements that are more time-consuming than installing protective guarding.
- Cold storage managers will tend to favor repair rather than replacement of damaged rack, since labor is typically lower (on average one hour versus 2-4 hours per upright).

A second consideration is that because of the cost of maintaining a cold storage environment, there is typically less spare racking capacity than in a dry environment. Therefore, there is less tolerance for "ribboned off" bays due to rack damage. This is an additional factor that favors ample protective guarding.

Finally, there are additional difficulties performing weld repairs in freezer environments. Metals need to be pre-heated prior to the weld, which increases time and labor costs. Alternatively, the damaged component could be moved to a dry environment for a weld repair, but this also adds time, labor, and possible transport costs. Bolted repair solutions that require no welding are therefore often preferable.

13.6 Rack Inspection

13.6.1 Definition of Terms

- **Competent Trained Person:**

  A person who has been properly trained and appointed to carry out a task.

- **Code 1 Damage:**

  A damage that requires immediate unloading of a rack bay or bays.

- **Code 2 Damage:**

  Damage that has been noted but is not posing a structural risk.

- **Pallet Rack Upright Frames:**

Consist of two columns that transfer the vertical forces towards the ground. The columns generally consist of various types of thin-walled, open steel sections that are constructed from cold formed elements or hot formed structural shapes. They differ from one another, in part because of their shape, width or gauge, as well as the characteristics of the steel used, the forming process, and the position and quantity of the anchors securing the beam brackets.

- **Design of Pallet Rack Upright Frames:**

  A few of the factors that will determine if a frame will stay rigid are,

  - The height of the first horizontal brace (or the distance between the ground and the first horizontal brace)
  - The spacing between the horizontal braces
  - The physical characteristics of the bracing (angel iron, C-shaped section, tubular section, etc.)
  - The type of fastener between the column and the bracing members (tack welding, complete joint penetration weld, bolts, etc.)
  - It is important to extend the diagonal braces deep into the column to improve the stability of the frame. (Structural brace design does not allow the diagonal brace to be terminated inside the formed column channel, but they should be welded to the horizontal brace within 2" of the face of the column). Several types of frames are available, the most common being the type Z configuration where bracing members are installed to form the letter "Z".

- **Horizontal/Diagonal Braces:**
  Connect the two columns of an upright frame. These components, including their quantity and location, determine in part the load capacity of the frame, and its ability to resist impact.

- **Base Plates:**

  Secured at the base of the columns base plates distribute the load to the floor to prevent localized deformations, and are also used to anchor the pallet rack to the floor slab. They are generally rectangular in shape, and measure about 8 to 10 cm (3 to 4 in. x 5 in.). Two holes behind the column accommodate the anchor bolts. Since these holes are very close to one another, there is a risk of chipping the concrete floor when screwing in the bolts. On some base plate models, the holes are at the front and rear of the column, so that the bolts can be anchored without damaging the concrete and maintain the plumb tolerance of the columns. If there are more than 2 shims required under the column, a 2nd anchor or a tack weld should be used to prevent the shims from spinning out of alignment with the baseplate.

- **Steel Leveling Pads or Shims:**
  Are equal in size to the base plate and can be installed underneath it to correct an uneven floor, and maintain the plumb tolerance of the columns. If there are more than 2 shims required under the column, a 2nd anchor or a tack weld should be used to prevent the shims from spinning out of alignment with the baseplate.
- **Beams:**

  The beam is a horizontal member with beam column specific connectors at either end to secure the different frame columns. Stored loads will rest on the beams. Since the connectors secure the beams to the columns, they play a major role is ensuring racking stability. The length of a beam can be between 4 ft. to 14 ft.

  In determining the load capacity of the beam the following factors must be considered:

  - Shape
  - Width
  - Length
  - Gauge
  - Characteristics of the steel used
  - Forming process

  Two common types of beams are,

  - Box Beam – Consisting of two C-shaped section that fit into each other, and are usually welded to form a unit resembling a closed box.
  - Built-In Step Beam – Resembles a box beam where one section is perpendicular on one side to form an edge on which an accessory for protection against falling objects can rest.
- **Anchoring:**
  There are different types of anchoring bolts, the expansion-sleeve bolts and the chemical anchorages. A chemical anchorage is an anchoring device secured into a hole normally filled with epoxy glue. Chemical anchors are used in specific situations such as when the concrete is not strong enough to hold a standard anchoring device. As well, since they have a higher resistance to tearing, they are also used when this type of stress is particularly significant, such as in certain types of cantilever assemblies.

  - Expansion-sleeve bolts are highly capable of resisting shear forces and tearing.

- **Row Spacers:**

  The row spacer allows the connection of uprights placed back to back on two different rows. This vastly improves the stability of the entire unit by maintaining an even spacing between the frames.

- **Safety Bars:**

  Safety bars shall be installed on the load support beams to prevent loads from falling, and secured to the beams. They are usually installed in pairs, perpendicular to the beams, into which they can be fitted, depending on the system. They are not designed to support the entire weight of the load.

  Drop in or hook over safety bars for roll formed can only be secured with Tek screws.

- **Pallet Support Bars:**

  Contrary to safety bars, pallet support bars are designed to support the entire load in cases where the size, resistance, or type of pallet being used prevents it from being deposited directly onto the beams. The support bars leave enough space to allow the fork of the lift truck to pass under a load that is not resting on a pallet.

- **Safety Pins:**

  Safety pins are installed at the end of each beam to prevent the accidental dislodgment of beam connectors and uprights. They shall be designed to prevent their intentional or unintentional removal. These may include shear pins, screw pins, etc.

- **Row End Protection:**

  Row end protectors are most often guard rails used to ensure the protection of the racking at the end of each row, or along tunnel bays. Since they are generally independent of the racking, they must be anchored to the ground. It is recommended to paint them bright orange or yellow.

- **Component Identification:**

  According to Section 6, Product Identification, In CSA Standard A344.2, Standard for the Design and Construction of Steel Storage Racks:

  Note: Beams and Frames shall bear a permanent identification mark that is traceable to their manufacture

  - They shall also bear an identification code, and specify the properties of the components. These properties shall be determined by the manufacturer, or an engineer, before the component is installed. The manufacturer shall maintain records to ensure that they can determine the component properties from a permanent identification mark or code. The tests performed to establish the component's capabilities shall also be included in the records.

- **Pallet Rack Load Plaque:**

  It is recommended to install plaques to specify the rated load of a pallet rack. The plaques shall be corrosion resistant, placed in such a manner as to be easily read by the operator, and contain the following information at the very least:

  - Manufacture's name,
  - Maximum Beam Capacity
  - Maximum Bay Capacity
  - The maximum Beam Capacity is the load that can be placed on two beams.
  - The Maximum Bay Capacity is the load that can be placed in each bay, excluding the loads that are deposited on the ground.
  - If the rated load is the same for all the beams in one bay, one plaque placed on the first beam of that bay is sufficient.
  - If the rated load is the same for all the beams in one row, one plaque installed at the end of that row is sufficient.
  - It is also recommended to add the following marking of the plaques:

  Note: The rated load or the configuration of the pallet rack shall not be modified in any way without prior approval from the manufacture, or an engineer

13.6.2 Racking Inspection Plan

13.6.2.1 Introduction

This plan has been prepared as a "best practices" guide to provide a routine procedure on how to inspect and maintain roll form and structural racking in refrigerated warehouses. The following documents and resources were used to prepare this plan;

- CSA A344.1-05 User Guide for Steel Storage Racks
  - CSA A344.2-05 Standard for the Design and Construction of Steel Storage Racks
  - RMI Guideline for the Assessment and Repair or Replacement of Damaged Rack (version 1.00)
  - RMI Consideration for the Planning and use of Industrial Steel Storage Racks
  - Frazier Industrial Co Storage Rack Safety Audit Tech Talk 4.02. Written by Dann Clapp.
  - Gilles Ducharme, Structural Engineer, President of Structurack
  - Jonathan Hirst P. Eng, Vice President and General Manager, North American Storage Equipment's

- Rack inspection personnel should be selected by the Engineering/Maintenance Management team. Each Facility Manager will appoint a member from the Operations Team to be trained on the "Racking Inspection Procedure." Racking Inspections should be done on a monthly basis for Operations and quarterly inspections are to be done by the Engineering/Maintenance Team. The Engineering/Maintenance team should also complete an annual comprehensive inspection.

13.6.2.2 Plan Scope

This plan was written to help maintain safe storage systems. It is meant to protect the health and safety of workers in warehouse facilities, to prevent a possible rack collapse and to maintain storage systems in an efficient manner.

13.6.2.3 Critical Limits

All Critical limits were determined by the following;

- CSA A344.1-05 User Guide for Steel Storage Racks
- CSA A344.2-05 Standard for the Design and Construction of Steel Storage Racks
- RMI Guideline for the Assessment and Repair or Replacement of Damaged Rack (version 1.00)
- RMI Consideration for the Planning and use of Industrial Steel Storage Racks
- Frazier Industrial Co Storage Rack Safety Audit Tech Talk 4.02. Written by Dann Clapp.
- The measurements provided for twisted feet in this plan were calculated by Gilles Ducharme, President and Structural Engineer of Structurack.
- The measurements provided for roll form rack with a welded C channel insert or double boxed posts not for capacity reasons were provided by Jonathan Hirst, Vice President and General Manager of North American Steel Storage Solutions.

13.6.2.4 Training

Training should be provided, including classroom sessions followed by an inspection on-site training. Training should be conducted by Maintenance/Engineering experts. The trainee should sign off on their training agreeing to follow the safe practices put forward by this plan.

13.6.2.5 Plan Application

- Monthly Racking Inspections should be conducted by the Operations team. Quarterly and Yearly inspections should be completed by Engineering/Maintenance team. All damages should be recognized at the time of the incident.

- The person responsible for the damage or sighting the damage should fill out a rack damage report. Reports are located elsewhere in this document. The report should be passed on to both the Maintenance & Operations department and signed off and filed by Managers.
- The damage rack report should be investigated immediately by the Maintenance team. If the maintenance team determines the damaged component is creating a drop-in load capacity the location should be unloaded and deactivated from the system.
- Damaged racks should be tagged out for repair or replacement. The floor location does not need to be unloaded.
- When deemed necessary, professional consultation should be considered.

Please see pictured examples for the Tag Out Station

13.6.2.6 Monthly Operations Limited/Light Duty Inspection

- Monthly inspections should be conducted by the Operations team. Area's to be inspected should be determined by what aisles are available at the time of the inspection. If all aisles are available then all racks should be inspected.
- The monthly inspection should require no product to be moved. It should be considered a light duty inspection.
- Only components that are available at the time of the inspection should be inspected. Areas that were not available should be carried forward to the next inspection

13.6.2.7 Quarterly (Limited/Light duty inspection) by Engineering/Maintenance

Quarterly inspections should be conducted once every 3 months. Area's to be inspected should be determined by what aisles are available at the time of the inspection. If all aisles are available then all racks should be inspected. The quarterly inspection should require no product to be moved. It will be considered a light duty inspection. Areas that were not available should be carried forward to the next inspection.

13.6.2.8 Annual – 4th Quarter Inspection by Engineering/Maintenance

Note: Prior to the annual racking inspection, the following criteria should be met:

- All floor locations should be completely emptied by operations. To do this, operations should unload the bottom locations to a maximum of four aisles at a time.
- The person responsible for the rack inspection should conduct their inspections on the above-mentioned aisles at the time of unloading.

- When the racking inspection of the uprights is completed Operations should begin to load the bottom locations that were emptied. Once the components are inspected Operations should have the next four aisles (floor locations only) emptied so the person responsible can continue his/her inspection in an efficient manner.
- The person responsible for the annual racking inspection should be granted one to three weeks to complete their annual racking inspection.

13.6.2.9 Conclusion

All annual inspection reports should be compiled and reviewed by Maintenance Managers and Facility managers. Code 1 severity issues should be addressed in local Health and Safety meetings and at high level with Directors of Engineering and Operations. All Code 1 damages should be immediately unloaded. Health and Safety will be provided a copy of the current inspection reports. A formal discussion should be scheduled with the method of repair and to allocate the proper monies to each facility to have the rack repaired/replaced. By agreeing to this plan, management will have 14 days to provide a written action plan for the damaged racks noted in the annual inspection.

Figure 13.43 Racking Tag Out Station



Figure 13.44 Signage, chain, tape, forms & procedures



Figure 13.45 Racking tagged out with tape & signs



13.6.3 Racking Inspection Policy (Draft for Customized Use)

The following policy has been put in place to protect the workers at (Insert Company Name). The following policy will be followed by all employees. Employees who do not follow this policy will be subject to discipline.

(Insert Company Name) shall ensure that there is a systematic pallet rack inspection program in place and that a competent person performs the inspection. The person conducting the racking inspection will be provided with a current plan and elevation drawing. The inspection will identify any variance from the provided layout and elevation drawings, as well as structural damage and/or missing or out of position components.

Examples Include:

- Out of plumb, damaged, or corroded posts
- Damaged or missing horizontals and/or diagonal braces
- Sheared or missing anchors
- Damaged or permanently deflected (yielded) beams or improper beam bracket engagement
- Missing or improper safety pins (roll form)
- Missing or improper safety bolts (structural rack)
- Missing row or wall spacers
- Misplaced, missing, or damaged safety bars

The inspection should also include the observation of poor operating practices such as,

- Improper overhang of goods over pallets or pallets over beams
- Use of damaged pallets
- Storage of improperly sized pallets
- Overload conditions
- Unsafe material handling equipment operation

(Insert Company Name) shall keep a record of each inspection, and where the workplace has a Health and Safety committee, a copy of the report will be provided to the committee. The frequency of the inspection should be as follows;

- **Operations Team:** Monthly Racking Inspection
- **Maintenance & Engineering Team**: 3 limited/light duty inspections and 1 annual comprehensive inspection
- When a component is determined to be damaged it should be clearly identified by **Operations Personnel** as such by yellow and black marking tape found in the Racking Tag-out Station.
- The affected racking bay should be immediately unloaded if necessary and measures will be taken to prevent them from being reloaded. (a damaged frame requires the bays on either side to be unloaded excluding floor levels).
- Maintenance should then later assess the damage and mark it with an additional marking tape of the appropriate color to indicate Code 1 or 2.

A priority system will be used by **Maintenance** when inspecting a pallet rack. Each damage item noted during the inspection should be characterized as one of the following:

- Green (Code 2) = Within critical limits. Note damage/missing component. If the rack is missing a component it must be replaced immediately.
- Red (Code 1) = Passed the safe or critical limits. Any damage that has met the "Red Limits" must be unloaded immediately. (floor location excluded) Repair/replacement method must be discussed with the Head of Maintenance and the Director of Engineering.

Figure 13. 46 Black & Yellow Marking Tape



Figure 13. 47 Code 1 (Red) on Damaged Post



Figure 13. 48 Code 2 (Green) Damage to Diagonal Tie



Note: Any damaged racking component characterized as green might still represent an unacceptable risk if it is being used:

- To store hazardous or toxic material
- In public areas
- In high seismic zones

Reconfiguration or Request for beam level changes

- *(Insert Company Name)* will verify that the proposed removal or repositioning of beams would not create an overload condition.
- Approval for proposed changes should first be obtained from the vendor, manufacture, or professional engineer except when reconfiguration is in accordance with a supplier's predetermined specification.
- In addition, an authorized person within *(Insert Company Name)* Engineering/Maintenance team will document such approval and inspect the changes once complete.
- **Roll Form Racking**

  Missing or damaged safety pins will be replaced immediately because they are intended to resist the accidental dislodgement of beams.

- **Structural Steel Racking**

  Missing, lose or damaged safety bolts will be tightened/replaced immediately because they are intended to resist accidental dislodgement of beams.

13.6.4 Racking Inspection Procedures

13.6.4.1 Light Monthly Racking Inspection by Operations Team

- Conduct racking inspection once every month. Racking inspections are only to be conducted by a competent trained person.
- Determine which locations have sustained impact and have damaged/missing components.
- Log all damages found on the logging sheet provided with this procedure.
- When a component is determined to be damaged it will be clearly identified as such by marking or tagging. Yellow/black tape is provided in the Racking Tag-out Station on the Dock. Cut a 2 - 3ft foot strip and wrap it around the damaged components to leave a 1 foot visible flag in length. Date and initial the tape once installed.
- Once the racking inspection has been completed, a copy of the report should be sent to the supervisor. Also provide a copy of the report to the Facility Manager and the Maintenance Manager of the facility.
- Maintenance will assess and rate the damage with a colored marking flag to indicate Code 1 or Code 2 within 2 days of receiving the report.
- The Maintenance staff will advise the Operations staff if the damage is rated as code 1 or code 2.
- All Code 1 damages will be unloaded immediately (Floor locations excluded).
- All Code 1 damaged locations will be deactivated from logirack.
- All areas that were not accessible at the time of the inspection will be noted and carried on to the next inspection.

13.6.4.2 Operations Monthly Inspections

- Check uprights for frontal and side dent damage. Refer to critical limit section.
- Inspect horizontal and diagonal brace ties for damages, broken welds and missing pieces.
- Inspect cross beams for frontal and vertical damages. Refer to critical limit section.
- Inspect cross beams for permanent deflection. Refer to critical limit section.
- Check all base plates for squareness (twisted feet, loose shims, broken welds and proper anchorage to concrete. Refer to critical limit section.
- Check and inspect all row end protection for integrity and proper anchorage.
- Note safety bar alignment and integrity. Absence of bars where they are normally installed.
- Inspect bracket engagement area for missing and proper safety pins (roll form).

- Inspect bracket engagement area for missing, lose or damaged safety bolts (structural).
- Check that load capacity signs are posted at each row end.
- Inspect for missing row spacers.
- Observe the area for any damaged or poorly loaded pallets. Pallet misalignment on beams, improperly stacked pallets for the racking. etc.
- Check for possible overloaded weight capacities.
- Once the racking inspection has been completed, a copy of the report should be sent to the supervisor. Also provide a copy of the report to the Facility Manager and the Maintenance Manager of the facility.

13.6.4.3 Quarterly Racking Inspection Procedure Engineering/Maintenance

- Conduct a racking inspection once every three months. Racking inspections are only to be conducted by a competent trained person.
- Determine which locations have sustained impact and surpassed their critical limits or have damaged/missing components.
- Log and measure the damaged components. Log all damages found on the logging sheet provided with this procedure.
- If major components are missing or have Code 1 damage the rack must be unloaded and the components must be replaced/repaired before the rack can be reloaded.
- Maintenance will assess and rate the damage with a colored marking flag to indicate Code 1 or Code 2. Red=#1. Green=#2. All code 1 damages should be unloaded by the operations team.
- Colored tape is provided in the Racking Tag-out Station on the Dock. Cut a 2 -3ft strip and wrap it around the damaged components to leave a 1-foot visible flag in length. Date and initial the piece of tape once installed on the component.
- Allow operations 2 hours to unload priority code 1 damage. Operations should notify the person who conducted the inspection as soon as the location is unloaded.
- Once the location has been unloaded the operations supervisor should email IT that they want this location deactivated from the system. Do this as soon as the rack is unloaded. You do not have to unload or deactivate the floor level.
- A copy of the report should be retained on file with the Maintenance/Engineering Manager for that jurisdiction, Facility Manager and Facility Health and Safety Representatives.
- All areas that were not accessible at the time of the inspection should be noted and carried on to the next inspection.

13.6.4.4 Guide to Quarterly Racking Inspection Procedure (Maintenance/ Engineering)

- Check uprights for frontal and side dent damage. Refer to critical limit section.
- Inspect horizontal and diagonal brace ties for damages, broken welds and missing pieces.

- Inspect cross beams for frontal and vertical damages. Refer to critical limit section.
- Inspect cross beams for permanent deflection. Refer to critical limit section.
- Check all base plates for squareness, loose shims, broken welds and proper anchorage to concrete. See limit section details.
- Check and inspect all row end protection for integrity and proper anchorage.
- Note safety bar alignment and integrity. Absence of bars where they are normally installed etc.
- Inspect bracket engagement area for missing and proper safety pins (roll form rack).
- Inspect bracket engagement area for missing, lose or damaged safety bolts (structural rack).
- Check that load capacity signs are posted at each row end.
- Inspect racking for damage or missing row spacers.
- Observe the area for any damaged or poorly loaded pallets. Pallet misalignment on beams, improperly stacked pallets for the racking. etc.
- Check for possible overloaded weight capacities.
- A copy of the report should be retained on file with the Maintenance/Engineering Manager for that jurisdiction, Facility Manager and local Health and Safety Officer.

13.6.4.5 Annual Racking Inspection Procedure by Engineering/Maintenance

- Conduct an annual racking inspection once a year. Racking inspections are only to be conducted by trained personnel.
- Have operations supply two forklift operators to help move product out of the first/floor level. To complete an annual inspection, you will need to do this for single, double deep, four deep and drive in rack locations.
- For drive in rack have the forklift operators remove all racking levels so all components can be inspected.
- For single, double deep and four deep rack, use a skyjack or an elevating lift platform to inspect all components in all levels of the racking system.
- Determine which locations have surpassed their critical limits or have damaged/missing components. This should be done only by a trained qualified person.
- Maintenance should assess and rate the damage with a colored marking flag to indicate Code 1 or 2. Red=#1. Green=#2. All code 1 damages will be unloaded by the operations team.
- If major components are missing or have code 1 damage the rack should be unloaded and the components must be replaced/repaired before the rack can be reloaded. Colored tape is provided in the Racking Tag-out Station on the Dock. Cut a 2 -3ft strip and wrap it around the damaged components to leave a 1-foot visible flag in length. Date and initial the piece of tape once installed on the component. Log and measure components. Log all damages found on the logging sheet provided with this procedure.

- During the yearly inspection, you should fill out the document titled "Annual Inspection Checklist for Single or Double Deep Pallet Racks." This is regardless of what type of system you have. Answer all questions on the sheet that are applicable. This checklist should be submitted with the annual report.
- If major components are missing or have code 1 damage the rack should be unloaded immediately and the components must be replaced/repaired before the rack can be reloaded. Notify operations of the code 1 damage. The floor locations do not have to be unloaded.
- Allow operations 2 hours to comply to priority code 1 damage. Operations should notify the person who conducted the inspection as soon as the location is unloaded.
- The Maintenance staff should use the jack chain and signage to section off the racking bay the damaged component was found in. Please see the illustrated instruction pictures for examples.
- Once the location has been unloaded the operations supervisor should notify IT that they want this location deactivated. Do this as soon as the rack is unloaded. You do not have to unload or deactivate the floor level.
- A copy of the annual inspection should be shared with the Directors of Engineering Operations, Health and Safety and Quality Control.
- Maintenance and Operations should prepare an action plan and schedule to repair/replace the damaged locations.

13.6.4.6 Guide to Annual Racking Inspection Procedure (Engineering/Maintenance)

- For single, double deep, four deep and drive in rack use a skyjack or an elevating lift platform to inspect all components in all levels of the racking system.
- Check uprights for frontal and side dent damage. Refer to critical limit section.
- Inspect horizontal and diagonal brace ties for damages, broken welds and missing pieces.
- Inspect uprights for twisted feet. Refer to critical limit section.
- Inspect cross beams for frontal and vertical damages. Refer to critical limit section.
- Inspect cross beams for permanent deflection. Refer to critical limit section.
- Check all base plates to see if they are square, if there are loose shims, broken welds and proper anchorage to concrete. See limit section details.
- Check and inspect all row end protection for integrity and proper anchorage.
- Note safety bar alignment and integrity. Absence of bars where they are normally installed etc.
- Inspect bracket engagement area for missing and proper safety pins (roll form rack).
- Inspect bracket engagement area for missing, lose or damaged safety bolts (structural rack).
- Check that load capacity signs are posted at each row end.
- Inspect racking for damage or missing row spacers.

- Observe the area for any damaged or poorly loaded pallets. Pallet misalignment on beams, improperly stacked pallets for the racking. etc.
- Check for possible overloaded weight capacities.
- A copy of the report should be retained on file with the Maintenance/Engineering Manager for that jurisdiction, Facility Manager and local Health and Safety Officer.

13.6.5 Damaged Rack Tag Out Procedure

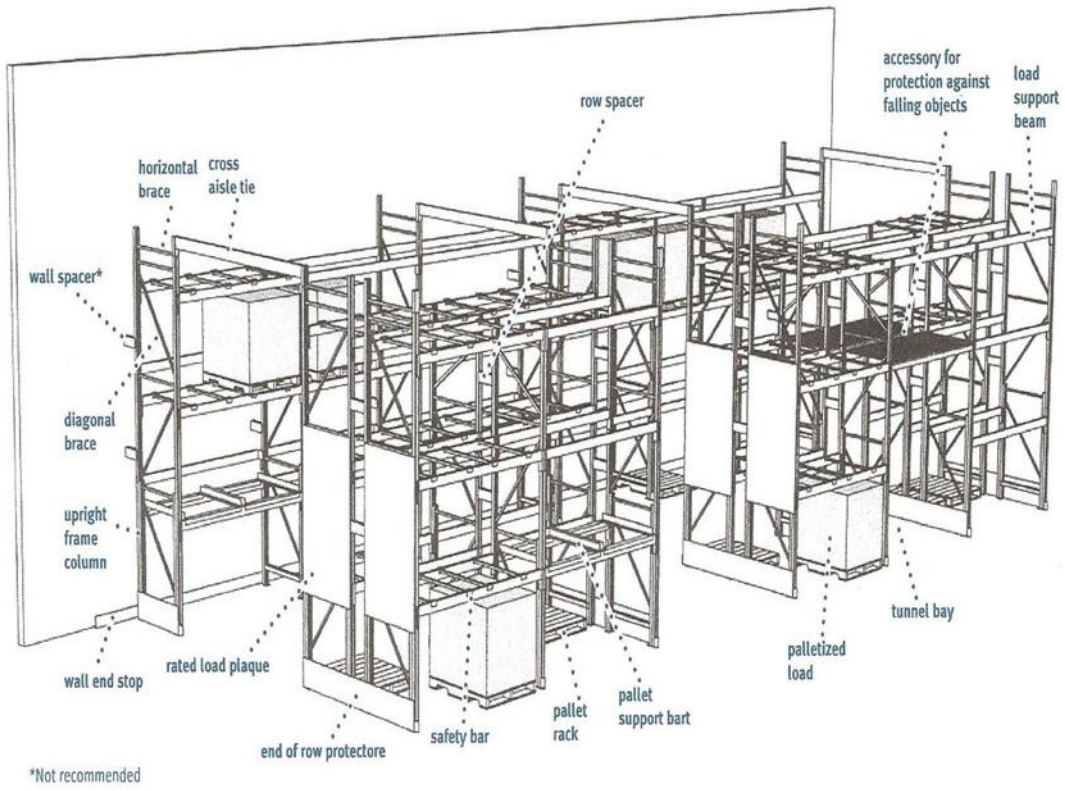
- If racking or a racking component was damaged as a result of an incident notify the Maintenance and Operations Manager.
- The Maintenance staff should assess the damage noted on the operations monthly racking inspection as well as any damage that occurs in between inspections. The Maintenance staff should use the appropriate colored tape to identify the damaged component. Colored tape is provided in the Racking Tag-out Station on the Dock. Cut a 2 - 3ft strip and wrap it around the damaged components to leave a 1-foot visible flag in length. Code 1 damage should be identified by red tape. Code 2 damage should be identified by green tape.
- Once the tape is installed around the damaged component please initial and date the tape.
- If the damage is assessed as Code 1 damage notify the Operations Manager. The Operations Supervisor should instruct their staff to unload the damaged area immediately.
- Once the location has been unloaded the operations supervisor should contact IT and request that this location deactivated from the system. Do this as soon as the rack is unloaded. They do not have to unload or deactivate the floor level.
- The Maintenance staff should use the jack chain and signage to section off the racking bay the damaged component was found in. Please see the illustrated instructions pictures for examples.
- Damages that occur between inspections should to be logged on the ongoing monthly and quarterly inspections as new damage.

13.6.6 Damaged Rack Tag Out Procedure – Operations (After hours)

- If racking has been damaged or a damaged rack was sighted **after** regular business hours **or** when the maintenance staff is not available for further assessment, please notify your supervisor or team lead member of the damaged rack immediately.
- Fill out a rack damage report. Place a copy in the Facility Managers mailbox and the Head of Maintenance mailbox.
- Mark the component that was damaged using the yellow/black tape found in the Rack Tag Out Station located on the dock.
- Unload the rack to keep all conditions safe. The floor level does not have to be unloaded.
- Once the location has been unloaded use the signage and the jack chain located in the Rack Tag Out Station located on the dock to clearly identify that the rack shall not be reloaded.

- **The maintenance team should check the damage the following day. Only the maintenance department should be allowed to determine if the rack can be re-loaded.**

Figure 13.49



13.6.7 Roll Form Critical Limits

13.6.7.1 Single Channel or Double Channel for Capacity Increase

Foot Twist		
Baseplate Width	**Green**	**Red**
6”	0” – 11/16”	> ¾”
5-1/2”	0” – 11/16”	> ¾”
5”	0”- ¼”	> 5/16”
4 ½ “	0” – ¼”	> 5/16”
4 “	0” – ¼”	> 5/16”

3 ½ “	0 – 3/16”	> ¼”

Side Post Damage Limits	
Green	**Red**
0” – 3/8”	> 3/8”

Front Post Damage Limits	
Green	**Red**
0 – ¼”	>¼”

Horizontal/Diagonal Limits	
Green	**Red**
0 – ¾”	>¾”

- Any horizontal or diagonal found that has a cracked weld should be considered a Code 1 damage.
- The limits provided were taken from the Prevention Guide Safety of Pallet Racks, Construction, Purchase, Installation and Use. This guide was created by the CSST and the IAPA. The limit for twisted feet was provided by Structurack structural Engineers.

13.6.7.2 Reinforced Channel Welded Inside the Column or Double Boxed Post

- Note: Frames double posted for capacity reasons are excluded from the below limits. For these uprights, you should use the critical limits provided for roll form uprights single channel. Please consult your manufacture.

Foot Twist		
Baseplate Width	**Green**	**Red**
6”	0” – 11/16”	> 3/4”
5-1/2”	0” – 11/16”	> 3/4”
5”	0”- ¼”	> 5/16”
4 ½ “	0” – ¼”	> 5/16”
4 “	0” – ¼”	> 5/16”
3 ½ “	0 – 3/16”	> ¼”

Side Post Damage Limits	
Green	**Red**
0" – 3/4"	> 3/4"

Front Post Damage Limits	
Green	**Red**
0 – 1/2"	>1/2"

Horizontal/Diagonal Limits	
Green	**Red**
0 – ¾"	>¾"

- Any horizontal or diagonal found that has a cracked weld should be considered a Code 1 damage

13.6.8 Structural Rack Critical Limits

Foot Twist		
Baseplate Width	**Green**	**Red**
6"	0" – 11/16"	< ¾"
5-1/2"	0" – 11/16"	< ¾"
5"	0"- ¼"	< 5/16"
4 ½ "	0" – ¼"	< 5/16"
4 "	0" – ¼"	< 5/16"
3 ½ "	0 – 3/16"	< ¼"

Note: If an upright column is bent to the point of not touching the floor; bent in the down aisle direction more than 3"; or in the cross-aisle direction more than ½"; for unboxed columns; or 3" for boxed columns; then the bay on either side of the damaged upright should be immediately unloaded and not used until repairs are completed.

The above information was taken from "Frazier Industrial Co Storage Rack Safety Audit Tech Talk 4.02. Written by Dann Clapp.

Side Post Damage Limits (Down Aisle)	
Green	**Red**

Less Than 3”	Greater Than 3”

Front Post Damage Limits (Cross Aisle)		
Type of Column	**Green**	**Red**
Unboxed	Less than 1/2”	Greater than ½”
Boxed	Less than 3”	Greater than 3”

Note: If any horizontal is damaged to the extent that it is not connected to the upright column or any diagonal is not connected to the horizontal, the bay on either side of the upright with the damaged bracing should be unloaded immediately. If any horizontal is bent more than 1 ½” from straight the bays should be unloaded. If an X-Brace diagonal is bowed more than 4” or a Z-brace diagonal is bent more 1 ½” the frame should be unloaded until repairs can be made.”

The above information was taken from “Frazier Industrial Co Storage Rack Safety Audit Tech Talk 4.02. Written by Dann Clapp

Horizontal/Diagonal Limits		
Type of Bracing	**Green**	**Red**
Z-Brace	Less than 1 ½”	Greater than 1 ½”
X-Brace	Less than 4” bowed	Greater than 4” bowed

- Any horizontal or diagonal found that has a cracked weld should be considered a Code 1 damage
- The limits provided were taken from the Prevention Guide Safety of Pallet Racks, Construction, Purchase, Installation and Use. This guide was created by the CSST and the IAPA. The limit for twisted feet was provided by Structurack structural Engineers.

13.6.9 Inspection of Bean Deflection

- When pallet support beams are loaded in accordance with the rated load, the beam deflection does not normally exceed 1/180 of the span.
- The deflection shall disappear when the beams are unloaded, and should not be confused with the permanent deformation caused by an overload, or by damages resulting from impact. Several deformed beams in a rack indicate that the rated load has been exceeded.
- All beams that are permanently deflected should be unloaded until the beam is replaced.

Length of Beams	Calculation	Total Deflection Red Limit
8 Ft Beams = 2400 mm	2400/180 = 13.3 = 0.51”	½ inch deflection
10 Ft Beams = 3000 mm	3000/180 = 16.6 = 0.65”	5/8-inch deflection
12 Ft Beams = 3600 mm	3600/180 = 20 = 0.78”	¾ inch deflection
14 Ft Beams = 4270 mm	4270/180 = 23.70 = 0.93”	15/16-inch deflection
16 Ft Beams = 4876 mm	4876/180 = 27 = 1.1”	1 inch deflection
Note: All beam numbers have been rounded down		

13.6.10 Beams Bent Vertically and Horizontally

Beams can be bent either vertically or horizontally. If the load currently on the shelf does not exceed the shelf capacity, vertically bent shelves, upwards or downwards, does not pose a safety hazard. A structural steel shelf beam has the same capacity even if it has been bent vertically previously. Roll formed beams, on the other hand, have a tendency to buckle locally at which point they have lost a substantial portion of their load capacity and, usually, cannot be repaired.

However, if any type of beam is bent horizontally more than 2”, the load should be removed from that level until the beam can be replaced.” \

- Never remove a beam unless the whole bay has been unloaded.

The above information was taken from “Frazier Industrial Co Storage Rack Safety Audit Tech Talk 4.02. Written by Dann Clapp.

13.6.11 Beams Bent Dented Horizontally

Green Limit	Red Limit
Less than 2”	Greater Than 2”

13.6.12 Anchorage

All base plates must at least have 1 anchor in place. Please see manufacture drawings for specifics.

13.6.13 Determining Maximum Allowable Damage Limits (Roll Form and Structural)

13.6.13.1 Dented Front Posts

Critical Limit = Greater than 1/4" = Red/Code 1

Tools Needed = 36" Level, Measuring Tape

- Locate a dented front post.
- Put your level against the front post. Make sure your level starts on the flush area of the rack and travels downward towards your dent.
- Measure the distance between the gap and the level.
- Record your findings on the Racking Inspection Sheet!

Figure 13.50



Figure 13.51



13.6.13.2 Damaged Horizontals/Diagonals

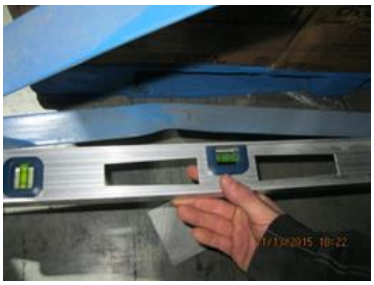
Critical Limit = Greater than ¾" = Red/Code 1

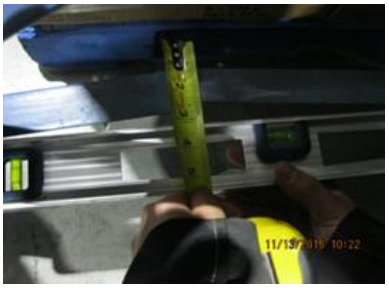
Tools Needed = 36" Level, Measuring Tape

- Locate the upright with the damaged horizontal.
- Place your 36" level across the damaged horizontal/diagonal.
- Measure the gap between the level and the damaged horizontal/diagonal.
- Record your findings on the Racking Inspection Sheet.

Figure 13.52

Figure 13.53





13.6.13.3 Dented Front Posts from Side

Critical Limit = 3/8" = Red/Code 1

Tools Needed = 36" Level, Measuring Tape

- Locate the damaged post.
- Place your level half on the flush side of the upright with middle of the level going over the dent.
- Measure the gap that is created between the level and the upright.
- Document your findings on the racking inspection sheet!

Figure 13.54



Figure 13.55



13.6.13.4 Twisted Posts (Roll Form)

Critical Limit = (Please see limit chart)

Tools Needed = 1 Straight Line String, Measuring Tape, Camera

- Locate the twisted foot
- Find the closest straight foot to the twisted location.
- Tie your straight-line string to the straight foot and wrap it around so the string comes in front of the straight post going in the direction of the twisted post.
- Unwind the string towards the twisted foot. Pull the string tight to the far end of the twisted post.
- Measure the distance between the string and the front post.
- Record your findings on the racking inspection sheet

Figure 13.56



Figure 13.57



Figure 13.58



13.6.14 Annual Inspection Checklist for Single/Double Deep Pallets

Name of the Establishment:			
Name of the Rack Manufacture:			
Name of the Rack Installer:			
Inspected By:			
Inspection Date:			
ITEM TO BE INSPECTED	YES	NO	NOTES & CORRECTIVE ACTIONS
Drawings & Specifications:			
The drawings and specifications are available			
The Drawings and specifications are current			
The drawings and specifications are approved by the manufacturer, or an engineer, including any modifications			
Preventative Maintenance & Inspection Program:			
A maintenance and inspection program is implemented			
The workers carry out the quarterly inspections of the racking and report any visible anomalies			
Aisle Width:			
The walkways are wide enough to allow the safe handling of the material, and are at least 600 mm (24")			
The width of the warehouse aisles is at least equal to the width of the loaded truck, plus 150mm (6") on each side, or to the width recommended by the lift truck manufacture			

The width of the main aisle (for two-way traffic) is at least equal to the width of the loaded lift truck plus 1,000mm (40")			
The width of the main aisles (for one way traffic) is at least equal to the width of the loaded lift truck, plus 1400mm (55")			
Rack Stability:			
The deflection of the beams loaded in accordance with the rated load does not exceed 1/180 of the span			
Row Spacer: The row spacers are installed and placed in accordance with the drawings and specifications established by the manufacturer, or an engineer			
Cross Aisle Ties: The cross-aisle ties are installed and placed in accordance with the drawings and specifications established by the manufacturer, or an engineer			
Base Plate Anchoring: All base plates are secured with at least one anchor bolt			
Base Plate Anchoring: The anchor bolts are tightened according to the bolt manufactures recommendations			
Base Plate Anchoring: The concrete floor slab is free of cracks near the base plates			
Shims: The leveling pads are well seated			

Shims: The leveling pads are equal in size to the base plates			
Shims: The leveling pads are well secured to the base plates (e.g., with two anchor bolts, or by welding)			
Component Condition: Columns & Frames			
The upright frames have no damage due to impact (e.g., dents, cracks, bulges, etc.)			
The frames show no sign of corrosion damage			
The frames show no sign of corrosion damage			
The horizontal and diagonal braces show no signs of corrosion damage			
Component Condition: Beams			
The beams show no sign of permanent deflection when unloaded			
The beams and the beam connectors have no damage due to impact			
The beams and the beam brackets show no sign of corrosion damage			
The beam positions are in conformance with the drawings and specifications established by the manufacturer, or an engineer			
The safety pins are secured at each end of the beams			
The safety pins are designed so as to prevent their intentional or unintentional removal			

Component Identification			
The frames and beams bear a permanent identification mark that is traceable to their manufacturer, or another means of identification			
The frames and beams are from the same manufacture			
The frames and beams are compatible with one another			
Repairs Performed on the Components			
The frames and beams are repaired according to the manufacturer's recommendations, or an engineer's			
Protection Against Impacts			
The column guards and the row end protectors are in good condition			
Protection Against Falling Objects			
Accessories for the protection against falling objects are installed over the walkways and behind the compartments where pedestrians may circulate			
At least two safety bars are installed for each pallet position.			
The safety bars are secured to the beams			
The pallet support bars are secured to the beams			
Clearance and Load Layout			
The clearance between the top of the loads and the			

automatic sprinkler system is at least 18”			
The clearance between two loads, or between one load and an upright frame, is at least 3”			
The clearance between one load and the overhead beam is at least 3”			
The clearance between two palletized unit loads placed in two back to back compartments is at least 4”			
The palletized unit loads pallet overhang over the front and back beams is between 2 and 4”			
Pallet Rack Rated Load Plaques			
The rated load plaques are visible, and are easily read by the operator			
The rated load plaques contain the following information, at the very least:			
• Manufactures Name,			
• Maximum Beam Capacity			
• Maximum Bay Capacity			
Personnel Training			
The lift truck operators have received the required training on safe driving practices			
The operators are aware of the effects of impacts on racking			
The workers have received the training necessary to report visible anomalies			

13.6.15 Damaged Rack Report

Name of the Establishment:	
Inspected By:	
Date of Inspection:	
Time of Inspection:	
Report Submitted to:	

TO BE FILLED OUT AT THE TIME OF DAMAGE OR THE TIME THE DAMAGE WAS DISCOVERED!

ZONE	AISLE	LOCATION	COMPONENTS DAMAGED	COMPONENTS TAGGED OUT	
				YES	NO

Operations Manager Name & Signature		
Maintenance Manager Name & Signature		

Maintenance Follow Up:

Name:	
Date:	
Time:	

Type of Damage (Circle One):	Code 1	Code 2
Has the damage been flagged? (Circle One)	Yes	No
Does the location need unloading? (Circle One)	Yes	No

Please return this report to the Operations Manager if the rack needs unloading. Please return a copy of this report once completed to the Maintenance Manager.

13.6.16 Operations Monthly Racking Inspection Logging Check Sheet

Name:					Date:		
Zone #	Aisle #	Location #	Component Damaged	Brief Description of Damage	Ailes Not Available for Inspection	Maintenance Verification (initial)	Maintenance Only Needs Unloading Y/N

Chapter 14: Dock Equipment

Acknowledgements

Walt Swietlik, Rite-Hite, LLC, Milwaukee, Wisconsin, USA

Jake Weyand, Rite-Hite, LLC, Cincinnati, Ohio, USA

Depending on one's point of view, the Material Transfer Zone (also known as The Loading Dock) is either the beginning or the end of the line for cold chain logistics. Any materials received from the processor or delivered to the customer will travel through it. It's no wonder then why this section exists. Quite frankly, the loading dock is at the heart of any manufacturing or distribution business. Which begs the question; Why does it so often get over-looked?

It's true that other more mechanized systems tend to command engineering and maintenance attention in cold chain operations, both in pre-construction and in production. But with the dock being such an important conduit (or bottleneck in some cases), perhaps it's time to reconsider its importance.

Starting with the basics, what is the dock designed to do? The easy answer is to facilitate the safe transfer of materials and/or material handling equipment from the trailer to the facility and vice versa. To make it relevant to the cold chain operation, we would add an energy efficient requirement. Therefore, safe, energy efficient material transfer is what it's all about. This sounds easy until we start considering all of the variables. Factors include trailer bed heights, cube utilization, pallet orientation, door sizing, the list goes on and on. So, let's get started.

14.1 Evolutions in Trucking

The biggest variable in any logistics operation, as it relates to the dock, is the trailer. Specifically, different types of trailers and how they are loaded. Whereas at one point in time trailers at a cold dock were consistent--about 45 feet long, 8 feet wide and 52 inches to the trailer floor--today there seems to be no such thing as a standard trailer. Why is that? It all has to do with freight protection, trailer loading patterns and fuel efficiency.

Trucking receives considerable attention in an effort to improve supply chain productivity. Initiatives reach well beyond negotiations with carriers to reduce rates. Companies take a variety of steps to increase payloads, reduce wasted "cube" space, increase truck operating efficiency, enhance driver comfort, and reduce truck waiting time.

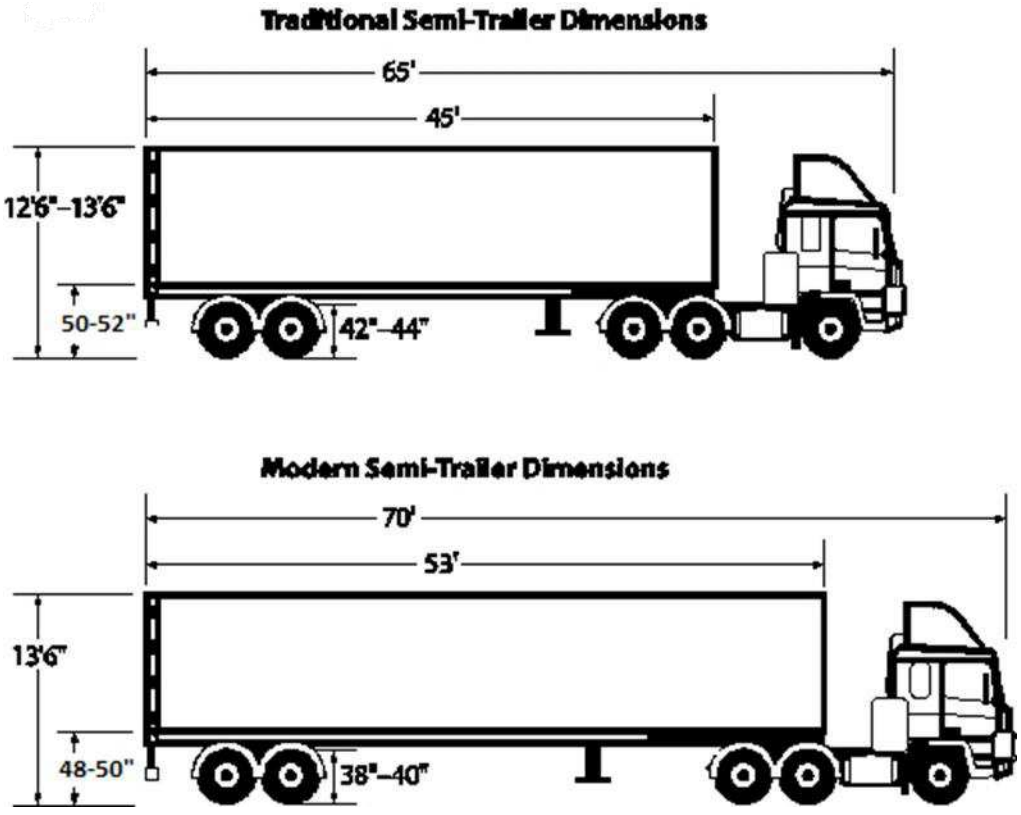
Physical changes in trucks and trailers increasingly affect receiving and shipping efficiency. Twenty years ago, the standard trailer was 45 feet long with a 50-inch bed height. The box size was typically 96 inches' overall width and 96 to 102 inches high. Today, trailers in that size range still exist, but the trend is clearly toward larger units and toward load configurations that make better use of the increased space.

14.1.1 Trailer Dimensions

Trailer dimensions are constrained by the width of highway lanes and by the clearances beneath bridges and overpasses. However, designers have found ways to fit the greatest possible cube space into the available envelope.

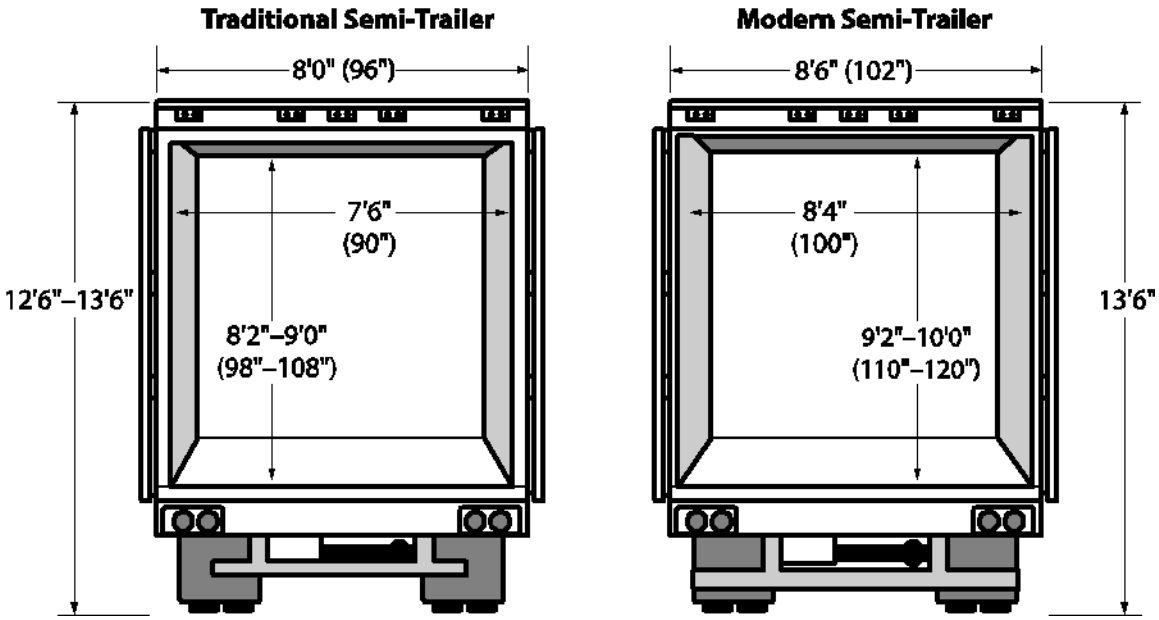
Today, the majority of trailers are 53 feet long (Figure 1). Some can be as long as 57 feet. Double and triple trailers are also prevalent. In Canada, doubles can consist of two 48- to 53-foot trailers; triples can consist of three 45-foot units.

Figure 14.1



The preferred trailer width (outside dimension) is 102 inches (Figure 2). To maximize interior space, trailer walls have been made thinner. Some dry trailers now have as much as 101 inches of clear width inside, 99" for refrigerated trailers due to the insulated side walls.

Figure 14.2



The tallest trailers are an overall 13 feet 6 inches high with an interior box height of 9 feet 4 inches. Some trailer manufacturers squeeze more cube out of trailers by using low-profile tires. The box itself then can be 6 to 8 inches higher while overall truck height remains the same. Interior clear space in such configurations can be as high as 10 feet (120 inches).

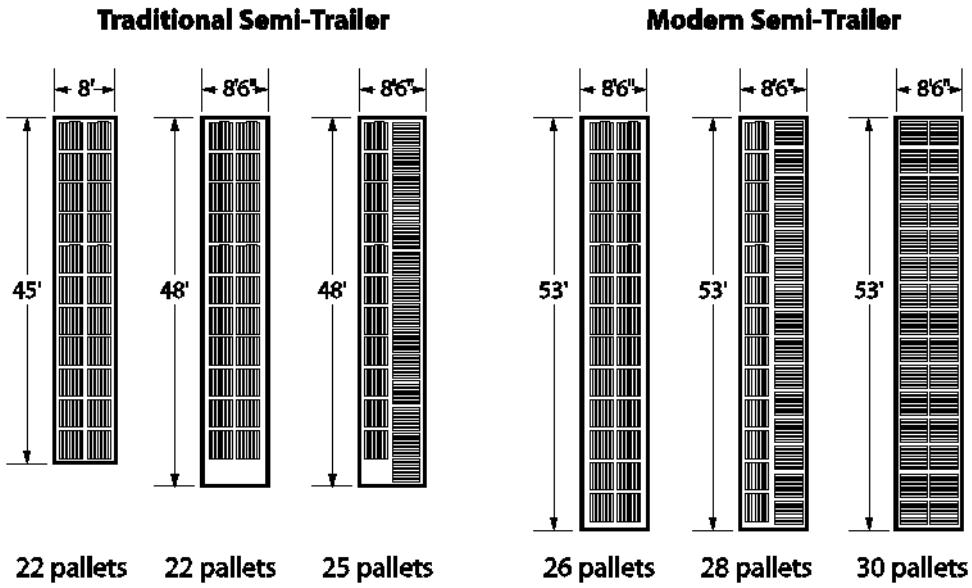
14.1.2 The Suspension Factor

Further complicating matters, increasing numbers of trailers now ride on air suspensions, designed to minimize cargo damage and increase trailer life. When these trailers are parked at the dock, their bed heights can fluctuate by several inches as loads are added or removed and as lift trucks move in and out. Today, air-ride suspensions are found on about two-thirds of new trailers and on nearly half of all trailers on the highways.

14.1.3 Load Configurations – The Pallet Factor

As trailer dimensions have increased, shippers have reconfigured loads to take advantage the increased payload space. In particular, 102-inch-wide trailers with larger interior clear width enable pallets to be pinwheeled (turned 90 degrees) so that forklifts place standard 40- by 48-inch pallets with the 48-inch side leading (Figure 3). If one row of pallets is pinwheeled, a 53-foot trailer can carry three more pallets than in standard configuration. If both rows are pinwheeled (double-pinwheeling), the payload increases by six pallets. If pallets are stacked two high, double-pinwheeling increases the total payload by 12 pallets. The shipping economies are obvious.

Figure 14.3



Irrespective of trailer width, some shippers have opted for full-width loads so as to fill trailers with fewer lift truck cycles, thus saving time. Full-width loads may travel on wood or plastic pallets.

Changes in trucks, trailers and the loads they carry can add substantial shipping efficiencies. Unfortunately, they also can create bottlenecks on loading docks that have not kept pace with today's requirements, erasing efficiencies that have been gained elsewhere in the supply chain.

Typical Truck Heights

Type of Truck	Bed Height (inches)	Overall Height
Standard (Dry) semi	44" to 54"	12' to 13' 6"
Reefer	48" to 56"	12'6" to 13'6"
Container	56" to 62"	12'2" to 13'6"
Straight truck	36" to 48"	10'6" to 12'
City delivery	44" to 48"	11' to 12'6"
Step van	20" to 30"	8'6" to 10'

Key Truck Dimensions

Attribute	Traditional Semi	Modern High-Cube
Bed Height	50"	46"
Overall width	96"	102"
Interior clear width	90"	101"
Overall box height	96"	114"
Interior clear height	92"	112"

14.2 Mismatches on the Dock

14.2.1 Outdated Dock Designs

Many existing loading docks are undersized and ill-equipped to handle today's larger loads and wide range of trailer sizes. In fact, even many new dock designs rely on outdated rules of thumb for critical design decisions such as dock height, dock leveler dimensions, door opening dimensions, and weather sealing configuration. Taken together, the extra inches added to trucks and their loads in the name of shipping efficiency can push inefficiency on the loading dock to the point of critical mass.

Figure 14.4

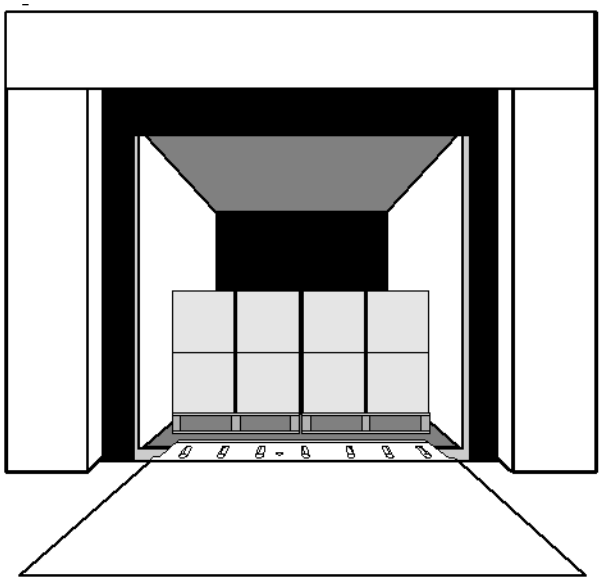
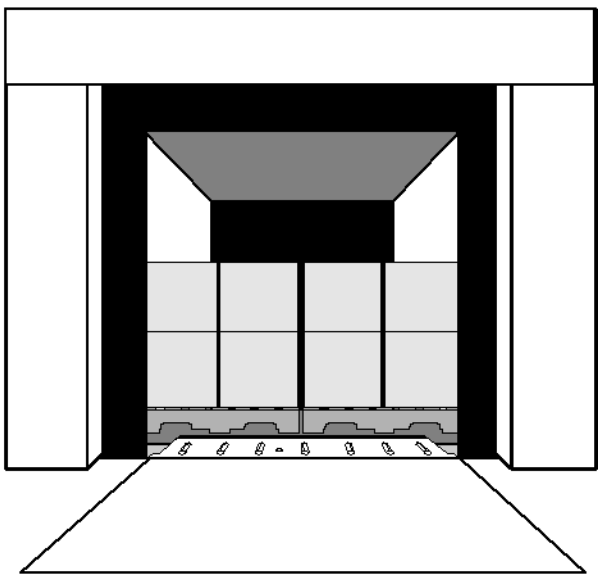


Figure 14.5



The long-time rule of thumb for designing refrigerated docks dictated a 50- to 52-inch dock height, a door opening 8 feet wide by 9 feet high, and a dock leveler 6 feet long

by 6 feet wide. In many cases, that dock would be protected by a foam pad seal, often encroaching slightly on the door opening.

Such a dock is entirely adequate for serving the traditional 96-inch-wide trailer carrying a single layer of pallets and with bed height at or about 48 inches (Figure 4). A few inches of clear space remains at both sides and in the center of the rows of pallet. Lift trucks can easily remove pallets with little or no obstruction.

14.2.2 Challenges of Larger Trailers

However, a larger-capacity trailer at the same dock creates significant problems (Figure 5). Consider a 102-inch-wide trailer in position at the dock, full to the rear sill with double-pinwheeled, 48-inch-wide pallets. The pallet loads fill the width of the trailer, leaving virtually no maneuvering space. A lift truck can remove the first loads (end loads) only by pulling them straight off. But that is difficult, because the foam pad dock seal obstructs the load on each side. Even with no dock seal present, the building wall may interfere on one side or the other, unless the truck has backed in perfectly on-center. If the forklifts cannot remove the end loads, employees must unload those pallets by hand.

Now assume that the 102-inch-wide truck rides on low-profile tires, so that its bed rests 4 to 6 inches below the 48-inch dock height (Figure 6). Lift trucks now are constrained by the walls of the 6-foot-wide leveler pit – straight-in access to the end pallets is not possible, even if the truck is perfectly aligned at the door and no dock seal encroaches on the opening. The building wall obstructs the pallet loads at the outer corners. (Figure 7). In order to extract the end loads, the forklift must lift them in perilously tight quarters.

Figure 14.6

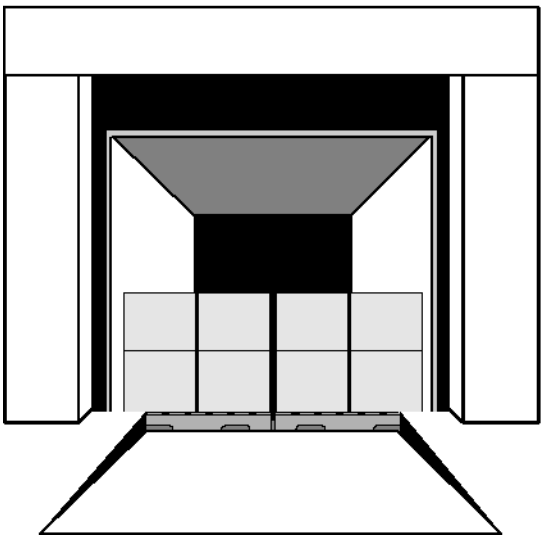
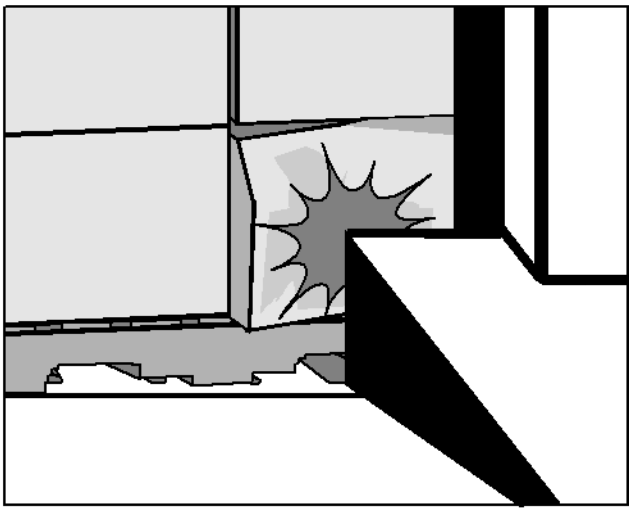


Figure 14.7



To complicate matters further, assume the same 102-inch-wide trailer carries double-pinwheeled, double-stacked pallets (Figure 8). Now the upper loads cannot pass through the door opening; hand unloading is virtually unavoidable. In this instance, even a 9-foot-high door may not provide adequate clearance at the top.

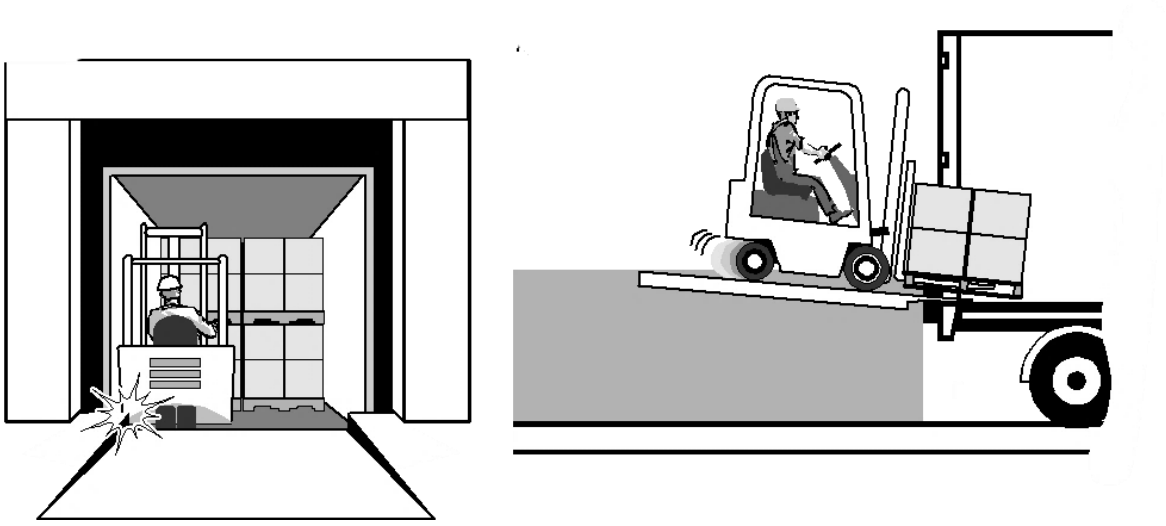
Figure 14.8



These are not the only possible pitfalls to servicing modern's trailers with conventional dock designs. For example:

- After removing the end loads from a 102-inch-wide trailer, forklift drivers still can face a substantial hazard. In backing out with a load, the forklift may violently strike the corner of the building wall projecting into the trailer opening (Figure 9).
- Lift trucks servicing trailers with low beds (6 to 12 inches below dock) by way of 6-foot-long levelers may face excessive platform slopes (Figure 10). In such cases, drivers backing out with loads must accelerate sharply up the include, causing load instability.

Figure 14.9



14.3 Consequences of Design Mismatches

Difficulties like these inherently drain productivity and profits. And their impact is greatly magnified in a finely tuned supply chain that depends on the smooth flow of materials at all points.

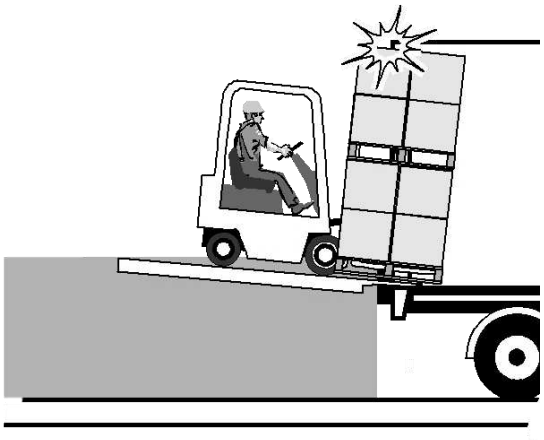
In this context, hand unloading of end-load pallets now means more than an hour of wasted labor and extra demurrage charges. On the outbound side, obstacles in the material transfer zone may mean late shipments, dissatisfied customers, and ultimately loss of business to competitors. In the broadest sense, any inefficiency on the dock that costs money or wastes time erodes a company's ability to compete. Here are how docks improperly designed for today's needs and unable to provide full access can erode efficiency and profitability:

- **Delay and Exposure** - Slowdowns are inevitable if full access to loads is not possible and materials can't be quickly, smoothly and safely loaded onto or removed from trailers. If the dock is not refrigerated, product can be subject to spoilage while the slow process of unloading takes place.
- **Product Damage** - Cartons can fall, pallets can spill and racks can topple while loads are jostled through inadequately sized door openings or driven up steep leveler ramps. The losses can go well beyond the value of the damaged goods themselves. In many cases, recipients are intolerant of damaged pallets or cartons. Instead of simply filing freight claims, they may issue charge-backs not just for the damage but for handling and disposal. Product damage is a significant issue in the food and consumer products sectors. According to a grocery industry survey performed by the Joint Industry Unsaleables Steering Committee (Lightburn 2002), 60 manufacturers and retailers responded that the cost of unsaleable food

and grocery products accounts for 1% of sales in the US. Damage is the largest component accounting for 63% of unsaleables. According to Progressive Grocers 76th annual report, the industry reported over $547 billion in sales in 2008. That equates to $3.4 billion in product damage for this one industry.

- **Increased Labor Rates** - Loads that can't be adequately accessed by a forklift due to insufficient door opening size, intruding dock seals or pit wall interference must be hand unloaded.
- **Dock Equipment Damage** - Lift trucks traversing steep slopes place excessive strain on dock levelers and may cause premature failure. Pallet boards can catch and tear dock seals while loads are squeezed through tight door openings. Jostling of pallet loads can bend or break roll-up door tracks.
- **Building Damage -** Dock leveler pit walls can be damaged by forklifts reaching for loads on platforms too narrow for the application. Lift trucks backing into pit wall corners also can cause structural damage, eventually requiring high-cost repairs. Dock bumpers can be damaged or torn off completely by air-ride trailer fluctuation.
- **Trailer Damage** - If double-stacked or other tall loads have too little "head room," the loads may strike the trailer roof (Figure 11). Jostling of loads also can stress trailer sidewalls. Puncturing the trailer skin or breaking a support strut can weaken the trailer's entire structure, leading to a catastrophic failure.
- **Excess Shipping Costs** - Delays of any kind in the material transfer zone can add up quickly in the form of demurrage charges for driver waiting time.
- **Workplace Injuries** - Hand unloading of end pallets forces employees to lift and bend, placing them at risk of back injuries – among the most debilitating and costly of all workplace injuries. Forklift drivers can sustain back and neck injuries when their vehicles strike exposed pit wall corners or absorb the shock of accelerating up a steep leveler ramp.

Figure 14.10



14.4 Productive Solutions for the Material Transfer

While material transfer zone efficiency may pose complex challenges, solutions are readily available. The keys lie in intelligent facility design and in equipment designed specifically to suit current trends in trailers and load configurations.

The most common mistake made in dock design today is to overlook the many factors that need to be considered and underestimate the importance of the decisions made in this area in achieving overall productivity goals. "Cookie cutter specs" no longer suffice when designing docks for optimum material flow and true supply chain efficiency. Critical elements of dock design that must be considered include facility layout and the location of docks, loading dock design specifics and loading dock equipment selection.

14.4.1 Facility Layout and Location of Docks

Ideally, plans for the material transfer zone should start with an eye toward the efficient flow of goods into and through a facility. For fast-moving product, cross-docking has become a norm. In a cross-dock facility, incoming product is unloaded at one end of the building, placed in a staging area, then moved directly to outbound trucks on the other end of the building.

14.4.2 Loading Dock Design Specifics

Regardless of dock configurations or material flow schemes, an efficient material transfer zone depends on a smooth interface between trucks or trailers and the loading dock. Docks must be designed and equipment sized so that all loads, from smallest to largest, can move quickly and efficiently to their destination.

- **Lower Dock Height -** As air-suspension trailers and high-cube trailers with lower bed heights become more common, it makes sense to consider refrigerated docks lower than the traditional 50-52 inches. 48 inches is becoming common for many shippers. Dock height should be chosen based on a careful assessment of all expected inbound and outbound traffic.
- **Larger Door Openings -** Dock doors must be sized to admit large loads such as double-stacked pallets and full-width automotive racks without interference. Current recommendations call for doors at least 9 feet wide by 10 feet high.

14.4.3 Loading Dock Equipment Selection

- **Longer, Wider Dock Levelers -** Forklifts must have straight-in, straight-out, full-width access to even the largest loads on high-cube trailers. Conventional dock levelers, 6 feet long and 6 feet wide, may not be equal to that task. To ensure unobstructed access to all loads, even below dock level, companies should consider levelers 7 feet (and 8 1/2 feet) wide which eliminate pit wall interferences (Figures

12 and 13). Platform lengths of 8 (and even 10) feet ensure a gentle grade for lift trucks servicing below-dock trailers.

Figure 14.11

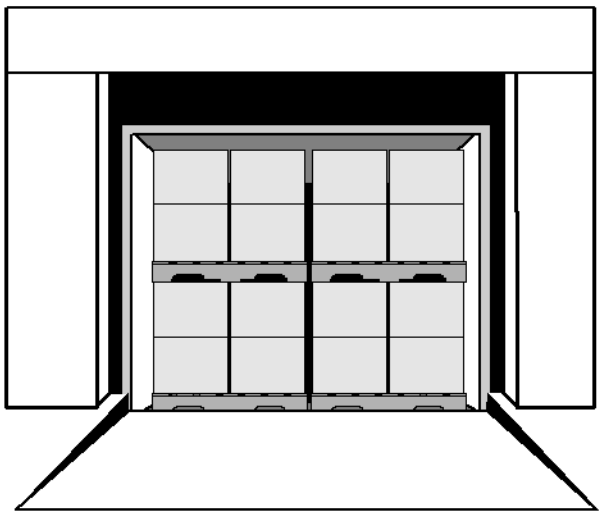
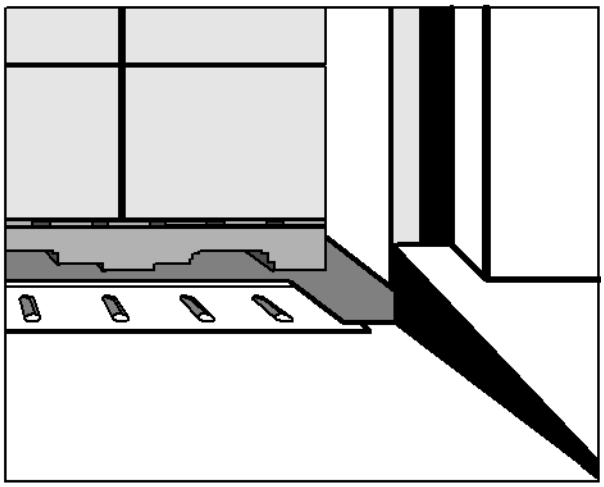


Figure 14.12



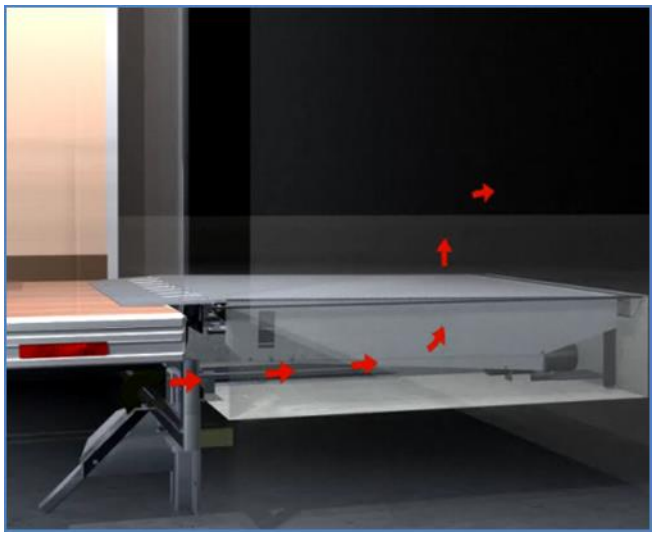
- **Hydraulic Leveler Operation -** Mechanical dock levelers can entail substantial maintenance costs. They also create ergonomic concerns, as dock attendants must stoop to activate the platform via pull chain, then walk the platform down onto the truck bed. Air-powered levelers create issues with safety leg interference that often prohibit the leveler platform from effectively reaching low trailer beds. Hydraulic dock levelers eliminate the problems associated with mechanical or air-powered levelers. They are entirely controlled from a pushbutton panel and maintenance requirements and operating costs are minimal. Only hydraulic levelers can ensure the ability to follow the movement of the trailer bed above and below dock level during all stages of loading or unloading. When chosen in proper capacities to suit the application, they can provide reliable service for 20 years or longer. Different types of hydraulic levelers are shown below.

Figure 14.13



Traditional pit levelers store level with the warehouse floor. Above model is full-width of the trailer with integrated bumpers to remove obstructions.

Figure 14.14



Consideration should be given to the heat gain presented by pit style dock levelers. When installed traversing an outer wall, they can allow for thermal bridging. Other issues include sanitation requirements in keeping the pit tidy.

Figure 14.15



Vertical levelers are becoming more prevalent, allowing for doors to close against the warehouse floor, saving energy & door repair costs.

Figure 14.16

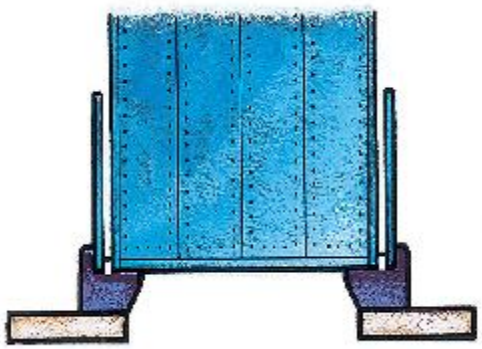


Proper pre-construction planning allows for the "drive-through" design, whereby the trailer can be docked with the doors closed, opening into the building. This reduces driver waiting time and helps to preserve the cold chain.

- **Enclosing the Door -** Foam pad dock seals provide a tight weather seal against trailers, but they may not fit all trailer sizes, and they may obstruct loads by encroaching on the trailer opening. Well-designed dock shelters provide effective weather protection yet do not obstruct loads. Shelters in impact-able designs eliminate the costly problem of traditional rigid-frame shelters being damaged or

destroyed by trucks that back in off-center. When discussing dock shelters in a refrigerated facility, careful consideration should be given to the "hinge gap" area. This white light exposure, the full height of the trailer, can be very costly. Some shelters designs have side curtains with hooks on the leading edge, specifically intended to cover the hinge gaps on trailers, maximizing energy savings.

Figure 14.17



Dock Seal (Compression Pads)



Dock Shelter (Wiper Curtains)

While the three sides of the dock door have the greatest impact on heat infiltration into a cold storage facility, an often-over-looked area is the dock leveler and the energy it leaks not only when in use, but when stored. Until recently, this was thought to be "the nature of the beast". Recent innovations now allow for this area to be sealed off, helping prevent the constant heat infiltration under the leveler and helping keep the leveler pit clean.

Figure 14.18 Under-leveler Sea



Figure 14.19 Trailer Hinge Gap



- **Dock Control Systems -** Material transfer zone efficiency requires that dock equipment deliver fast, reliable performance. Dock controls now can integrate the operation of the dock leveler, vehicle restraint, door, lights and other powered equipment from a single pushbutton panel at each dock position.

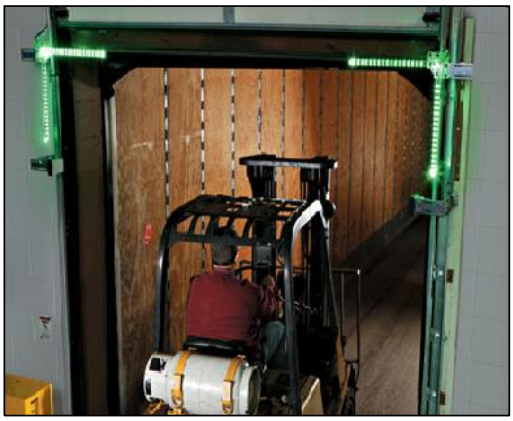
Figure 14.20



Separate controls create confusion



Single, intuitive control station



Additional safety light options create status-at-a-glance

14.5 Safety on the Loading Dock

Gaining full access to loads to maximize productivity is not the only challenge in the material transfer zone. Increased time constraints, faster material movement and variable trailer configurations all tend to increase the risk of accidents and injuries. The most serious such accidents happen when a trailer separates from the loading dock while being loaded or unloaded. Often, the result is severe, disabling or fatal injury to the lift truck driver. Several factors can cause trailer separation.

14.5.1 Hazards Affecting all Trailers

Three trailer separation hazards exist on any loading dock, no matter what kinds of trucks or trailers are being serviced:

- **Trailer Creep -** Repeated impact from lift trucks causes the trailer to gradually edge away from the dock.
- **Early Departure -** A trucker mistakenly drives away while a lift truck is entering, leaving or inside the trailer.
- **Aggressive Pullout -** A trucker "guns" the engine against the holding force of a restraint; the restraint breaks loose or loses its grip.

Trailers with air-ride suspensions pose additional risks. If the air suspension system is not properly deflated before loading or unloading, the trailer will bounce as lift trucks

enter or back out. In addition to allowing the trailer to "walk" away from the dock, this vertical motion also has negative effects on the forklift, the dock equipment and fatigue to the fork-lift driver.

14.5.2 Hazards Affecting Spotted Trailers

Trailers spotted at the dock detached from their cabs and supported by landing gear are vulnerable to other categories of accidents:

- **Landing Gear Collapse -** Lift truck traffic rocks the trailer until the landing gear gives way; the trailer pitches forward or falls to the side.
- **Trailer Upending -** The weight of a lift truck sends the trailer's nose down; the rear end moves up and away from the building.
- **Trailer Pop-up -** With tandems toward the front, the weight of an entering forklift and load causes the rear of the trailer to scoot forward and drop, in turn causing the nose to rise suddenly.
- **Trailer Collision -** A backing trailer strikes a spotted trailer, toppling it over.

14.5.3 Remedies for Trailer Separation

The only suitable remedy for trailer separation is a vehicle restraint system that holds trailers in place at the dock until loading or unloading is finished. Restraint systems are infinitely more reliable than wheel chocks, the conventional method of securing trailers. Chocks often are not used. Even when they are placed properly, a truck can easily drive over them. They can also slip, especially on wet, snowy or icy dock approaches.

Vehicle restraints physically hold trailers in place at the dock. They function in two basic ways: by gripping the trailer's rear impact guard (RIG) or by engaging the rear wheels. The latter type is recommended for docks that service trailers with liftgates or other rear-end assemblies, for docks that use truck levelers, and for other specialized applications involving trailers that do not have traditional RIGs. All viable restraints also include a communication systems of signs and flashing lights that let dock personnel and truck drivers know the status of the trailer at all times.

Among RIG-dependent restraints, rotating hook models provide the ability to control all forms of trailer separation that can lead to accidents, including when trailers are spotted, while vertical barrier models are best applied when trailers remain attached to their cabs are not at risk of tip over or landing gear failure. When selecting any vehicle restraint system, certain criteria should be met to ensure maximum safety and flexibility to serve a wide variety of modern trailer designs:

Automatic Vehicle Restraint Systems

Vehicle restraints should provide simple, pushbutton operation and have a clear, simple communication of signs and red/green lights. Restraints that grip the trailer's RIG should have a low-profile design to accommodate trailers with RIGs as low as 9 inches above the driveway surface, and should maintain consistent upward force against the RIG

as trailer bed height fluctuates, in order to ensure positive engagement through all stages of loading or unloading. Wheel restraints should be surface-mounted and able to withstand a minimum pullout force of 32,000 lbs.

Figure 14.21



Stabilizing Trailer Restraint
Limits effect of air-ride suspension



Recessed Trailer Restraint

14.5.4 Hazards at Vacant Dock Positions

Other serious accidents can happen at dock positions where no trailer is present. Through equipment malfunction or operator inattentiveness, a forklift can drive or back off the edge of the dock, plunging four feet down to the pavement. In such cases, the forklift can crash through the roll-up dock door, which is not designed to stop a vehicle weighing several thousand pounds.

14.5.5 Protection for Vacant Loading Docks

An effective device for preventing lift truck accidents at vacant docks is a hydraulic leveler with drop-off protection. As the platform settles into the stored position, the lip automatically creates a safety barrier at the dock edge that is several inches high and can withstand the impact of a forklift weighing up to 10,000 pounds and traveling 4 mph. Selection of barrier lip type levelers should be done carefully to make sure that the barrier does not interfere with the ability to handle end-loads. Alternatively, where levelers are already present and in good working order, surface mounted barriers can be installed. These barriers have a side benefit in that they protect the dock door from impact, helping to save maintenance and energy spend due to damaged doors.

Figure 14.22



Barrier Lip Dock Leveler



Curtain barrier

14.6 Conclusion

The material transfer zone, which includes the loading dock, is an often overlooked yet critical component of an efficient and high-performance cold storage supply chain. Loading dock design means much more than sizing a staging area and specifying the right number of doors. Mistakes in dock design and choice of equipment have costly consequences that can ripple throughout the supply chain. Conversely, wise choices and appropriate investment up front can create competitive advantage and pay cost-saving dividends for many years.

Businesses should consider impacts on the material transfer zone when making any significant decisions about transportation, storage, material flow schemes, and trailer, pallet or load configurations. It is also advantageous to look beyond how trailers are serviced and loads are handled today and consider how things may change in three to five years and beyond.

Companies seeking expert assistance should call upon an experienced loading dock equipment manufacturer or their representative. Such experts are exposed regularly to the real-world challenges of ensuring smooth, efficient, safe operations in the material transfer zone and are the most reliable source for information and analysis that can lead to appropriate dock design recommendations.

Chapter 15: Automated Systems

Acknowledgements

TH (Ted) Elicker, Griffco Design/Build, Inc., York, Pennsylvania, USA

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Refrigerated warehouse facilities operate in different fashions, depending upon whether they offer public or dedicated (i.e. private) refrigerated space. Public refrigerated warehouses, commonly known as PRWs and the focus of this paper, typically store food products at a stated rate for the storage and handling of a customer's product. In addition, PRWs may provide other value added activities, such as case picking, blast freezing and re-packing, for additional stated rates. Dedicated refrigerated space exists to facilitate a refrigerated warehousing role, often specific to a producer, processor or manufacturer of refrigerated and/or frozen products. A dedicated facility may or may not offer storage space publicly.

15.1 Reasons for Considering Automation

Generally speaking, Automated Storage and Retrieval Systems (ASRS) technology may be considered for the following reasons:

- **Landlocked** - A major reason to consider ASRS when looking to expand an existing warehouse facility is the simple fact that there isn't enough land for a conventional facility. Indeed, many of the early suppliers and advocates of "high-rise" ASRS construction were from Europe where there aren't too many opportunities for a sprawling 500,000 sq. ft. facility (think the Netherlands where they are still even "making land"). To highlight the area-conserving nature of an ASRS, consider the following, real- life examples:
  - A multiple-deep freezer ASRS with 14 levels rising about 125'-0" above grade. This example contains 20,932 pallet positions and covers 34,695 sq. ft., yielding a very low area utilization ratio of 1.66 sq. ft./pallet position.
  - A similar sized conventional freezer using double-deep rack (or push- back) with a bottom-of-deck height of 48'-0" that holds 23,041 pallet positions in a freezer area of 135,250 sq. ft. for an area utilization ratio of 5.87 sq. ft./pallet position.

- Clearly, at over 3.5 times the density of even a typical high-density/high-lift conventional facility the ASRS can, in certain situations be the only answer.

- **Exorbitant Land Cost** - Although not technically landlocked it may be necessary to acquire an adjacent parcel of land in order to expand. Depending on the location, the cost/square foot of the land may be a show-stopper. Imagine the impact on the decision to go ASRS vs Conventional when instead of $20,000/acre for adjoining land (about $0.50/sf) it becomes $125/sf (think Sand Island, Honolulu or some metropolitan areas stateside). In the previous, real-life example the land might have been available to support a conventional facility but its total project cost would have been penalized with over an additional $10 million in land cost.
- **Constant 24/7 Operation** - The first facilities to embrace the ASRS technology were typically manufacturers operating on a 24/7 basis, as many food plants do, especially in their peak season. Staffing a conventional warehouse for a true 24/7 operation can require more than just 3X the personnel needed for a single shift and the initial fixed cost of the ASRS starts to compare favorably with a conventional since its staffing is always lower and that effect is multiplied.
- **High Labor Costs** - The staffing differential becomes even more pronounced when the facility is located in a high cost labor market. To highlight this, consider an ASRS with a nominal throughput of 200 pallets/hour in and out. At an average forklift truck (FLT) rate of 24 pallets/hour one could budget for around 8 employees for the inbound and outbound (to deliver pallets to the truck loaders). Assuming the ASRS was fed from production by conveyor and the dock loaders fed also by conveyor spurs, the ASRS could have 18 fewer employees per shift. Allowing only a 3X multiplier the conventional would carry an additional 54 employees. At perhaps a fully burdened labor rate of $50,000/year/employee (wages, fringes, OT) the ASRS could avoid up to $2.7 million in labor cost annually.
- **Low Labor Availability** - Closely related to the issue of high labor cost is that of its basic availability. In some areas, the shift in demographics is resulting in a smaller pool of labor to draw from. Some companies fear that with the aging population and declining birth rate in the not too distant future there may be a decrease in the size of the labor pool which, in turn, will result in higher labor rates to attract people.
- **High Full Pallet Activity** - Stacker Cranes, or SRMs, like fork trucks, only handle pallet loads and are ideally suited for operations with low case pick requirements. However, the typical speeds and accelerations of SRMs (up to 600 ft./min down aisle and 200 ft./min lifting) greatly exceed those of fork trucks and can result in excess of 30 dual cycles per hour. A dual cycle is one in which the SRM picks up a pallet at the input station, goes into the rack aisle and deposits it and then retrieves another pallet from somewhere else in the aisle and brings it out to the deposit station. In such instances the SRM can handle up to 60 pallets/hour.
- **Harsh Working Environment** - It is well known that productivity is lower in freezer environments as compared to ambient conditions. SRMs on the other hand are obviously indifferent to the conditions and in fact operate quite well in freezer

environments since the moisture present is virtually nil and corrosion and degradation of electrical connections is minimal.

- **Tax Implications** - Although expensive when compared to conventional facilities, if an ASRS is constructed using the rack-supported method much of it can be classified as "equipment" and thus is eligible for rapid depreciation, typically 5 to 10 years versus the normal depreciation lifetime for buildings of around 30 years. In a detailed return-on-investment (ROI) analysis, this has an impact on the ultimate ROI in favor of the ASRS.
- **High Value Product** - The classic examples of high value product are ethical drugs in the pharmaceutical industry or storage of printed money by the Federal Reserve Bank. In either case, it's easy to see why keeping people out of such a storage area would be a good idea. This usually isn't too much of an issue for the public cold storage warehouse.
- **Needed to Support a "Monument" or Allow for its Expansion** - With storage facilities located adjacent to a well-established production operation any excess land may more often be reserved for the expansion of the production operations rather than warehousing due to the profit generating capability of production. Somewhat similar is the fact that for well-established operations, the cost of relocating the entire production operation to support continued growth is financially impractical. The production operation has become a "monument" and can't be moved.
- **Off-Site Storage with Shuttle vs. ASRS** - An alternative that is often considered is to build an off-site warehouse nearby on cheap, available land and employ dedicated shuttle trucks to move raw materials to the production facility and finished goods to the warehouse. This shuttle approach can become a very large operation with a 24/7 production plant with continuing, annual cost. In some operations, the number of shuttle operations has exceeded 14,000 annually and actually forced a re-examination of ASRS, which was ultimately built to avoid the annual cost.
- **Energy Cost -** On a square foot basis a refrigerated ASRS will consume less energy than a conventional since:
  - It will have a very low lighting load. They are typically operated in a "lights-out" fashion.
  - No people load, since they're automated.
  - Reduced infiltration load since conveyor openings for pallet passage are smaller than conventional FLT doors and usually have vestibules.
  - Smaller roof area results in lower transmission losses.
- **Owner Pride -** Although relatively rare, there are a few instances of the ASRS being the preferred type of warehouse simply because the Owner wanted to have one for reasons of corporate pride, marketing image or highlighting their "green" environmental image. It's happened.

15.2 Challenges Facing PRWs When Considering Automation

However, there are challenges a PRW faces when considering the utilization of ASRS technology. Unless governed under a multi-year storage contract, many pubic refrigerate warehouse operate month-to-month using a 30-day Warehouse Receipt with its customers. In other words, a customer pays in advance for the storage and handling of its product 30 days in advance. That same customer is free to leave and relocate its product at the end of this 30-day billing cycle if it chooses to do so. On average, less than 40% of business is done through contracts. Many dedicated facilities have 5-10 year contracts; however, typical contract terms are 3 years and less. [i]

Storage and Handling revenue accounts for approximately 80% of the revenue received with the balance received through other value added activities. The two largest expenses, typically incurred by a PRW, are labor related expenses and power. Labor related expenses can account for upwards of 50% of expenses while power typically accounts for 15% to 20% percent.

Whether retrofitting an existing warehouse or building a new warehouse, automation must satisfy these three fundamental criteria in order to be considered a viable alternative to conventional warehouse design and operation:

- Improve the storage density of a warehouse thus reducing building footprint and energy consumption.
- Improve the handling efficiency of a warehouse thus reducing labor and material handling requirements.
- Provide flexibility so that future changes in business and customer needs can be satisfied specifically in regard to storage, handling and case picking requirements.

Warehouse automation can clearly improve storage density and handling efficiency. Through the use of a rack supported structure, tall building designs, and very narrow aisle AS/RS technology, storage density (i.e. pallets per cubic feet) can typically be increased by 5% to 15% as compared to a structural framed warehouse using two-deep select rack with 40'-0" of clear storage height. Pallet density is further increased when deep lane storage is utilized over select pallet rack configuration. In addition, due to the handling speeds and efficiencies of AS/RS technology the need for warehouse operators, operating in these cold storage areas, is eliminated. This elimination of labor also reduces the number of forklifts, batteries, and chargers required to support a fleet of forklifts.

However, there are challenges a PRW faces when considering and evaluating the feasibility of integrating warehouse automation into its operation. These challenges include:

- The justification for the incremental capital investment in automation without multi-year storage contracts with its customers.
- Understanding the inherent costs and expenses (both capital and operating) when comparing automated alternatives with conventional warehouses.

- Maintaining system flexibility in the storage, handling and case pick ensuring that the automated system can change with changes in customers and customer storage and handling requirements.

The incremental cost to implement warehouse automation can range from $5 million to $15 million depending on the size and complexity of a project. It is a challenge to justify the incremental cost associate with warehouse automation when your customer base is all based upon 30-day billing. It becomes less so if your customer base is based upon multi-year storage contracts.

Secondly, it is important that a public refrigerated warehouse understands both the capital costs associated with building an automated warehouse, understanding the improvement in labor efficiencies as they pertain to headcount and throughput, and understand the changes in operating expenses such as power, and maintenance. For a company that does not have experience operating an AS/RS facility, the development of these costs and expenses can be a challenge. Involvement from the design/build contractor and automation integrator becomes very important.

Lastly, warehouse automation is not perceived to be flexible. When designing selecting equipment, the customer order and SKU data tends be based on recent and/or historical profiles. With this information, the automation integrator designs a system capable for handling the peak through put of the current customer requirements. What happens in 3, 5, or 10 years from now when the warehouse may have different customers with different storage and handling requirements? What if the case pick percentages go from 15% to 60% in five years because the warehouse landed a large retail distribution account? These concerns are real and shared among many public refrigerated warehouses. Whatever automated system that is chosen the operational parameters and confines need to be carefully identified and evaluated.

15.3 Rack Supported vs. Non-Rack Supported Structures

The traditional method of constructing a refrigerated warehouse uses a standard structural or pre-engineered steel frame to form the building, onto which are attached the wall panels, roof deck and roof insulation & membrane to form the building's thermal envelope. Inside, standard pallet rack is erected on the independent floor slab and does not interface with the building steel (at least it shouldn't). An alternate method of constructing a refrigerated warehouse is to use the rack itself as the building frame and add the necessary steel features to the rack (wall girts, roof purlins) to carry the wall panels and roof.

Although rack-supported structures are more commonly used in high-rise ASRS structures they have also been employed in typical low bay warehouses of more standard heights like bottom-of-deck heights of up to 48'-0". Both types will be discussed in this section.

Conventional Warehouse Rack-Supported Structures

To highlight the differences between standard framing vs. rack-supported in a conventional freezer, a hypothetical warehouse of the following dimensions will be considered:

- 250'-0" long x 200'-0" wide x 45'-0" B.O.D (Bottom of Deck);
- 50,000 sq. ft. gross area; and
- Single-deep rack, 6-levels high.

The conventional freezer will feature the following design/construction characteristics:

- Spread footings;
- Continuous perimeter foundation wall except at the freezer/dock interface; and
- A nominal 8" thick floor slab.

The rack-supported freezer will feature the following design/construction characteristics:

- A mat slab foundation;
- A haunched perimeter portion of the slab except at the freezer/dock interface; and
- A nominal 10" thick floor slab due to having to absorb the additional wind and roof dead and live loads.

A construction cost analysis of these identical yet two differently built facilities using basic unit costs indicates that the rack-supported building will cost between 10 and 13% more due to the additional concrete required in the mat slab foundation and the differential in the rack cost. The rack in the rack-supported building will cost more in order to provide the necessary wind and seismic bracing in addition to the added girts and purlins.

However, as the height of the building increases above 48'-0" BOD the cost of the free- standing structural steel frame does not increase linearly (quite the opposite; it increases faster due to buckling, bracing and wind moment factors) and the free- standing rack cost also increases due to the additional dead load compounding its own seismic requirements. At some point, determined by market conditions, geographic location (is it in a high wind area? a high seismic area?) and sometimes by the steel, concrete and rack subcontractor's peculiar preferences, the free-standing rack system crosses the cost inflection point and costs more than the rack-supported system. Depending on these factors, this will generally occur between the 55' and 65' range of BOD heights.

High-Rise ASRS Rack-Supported Structures

Based on the above cursory analysis it's easy to understand why most ASRS refrigerated facilities are rack-supported; in general, they are usually above 65' high. At that height, the following factors favor the rack-supported approach:

- As the wind loads increase and due to the height, the over-turning and uplift forces are easier to dissipate into a rack structure. These forces are usually distributed into the first set of rack frames along the perimeter walls.

- Similarly, the seismic forces, which are present in the rack structure regardless of the framing system, cease to cause any increase in the rack structure system just because the relatively lightweight walls and roof are now part of it. In all but the most extreme seismic areas, wind loads will generally govern the design.
- Taller rack structures are more easily and economically erected without the hindrance of an enclosing roof structure. Most low-rise, non-building supporting rack is erected in either individual frames or only small sections using FLTs or small JLG-type lifts. ASRS high-rise rack is usually erected in larger, ground-built sections utilizing large cranes and spreader beam assemblies requiring crane heights greater than the building.
- For high buildings, the frame requires a much more complete erection in order to attain the bracing and rigidity necessary to allow wall panel installation to begin. With a rack-supported structure, it is inherently more stable after only a short time and panel erection can commence earlier, thus saving schedule time.
- In high seismic areas having two (2) different framing/structural systems close together can cause issues. Extra care must be taken to ensure that the rack system and the building framing system, which have vastly different natural frequencies and response periods don't conflict with one another. Additional rigidity might need to be added for independent structures.

Concrete Slab Considerations

Rack-supported buildings obviously require that the supporting mat slab foundation be installed first. Consequently, this must be done out in the open and is therefore subject to the vagaries of weather, which, when pouring a large slab can present problems. Most ASRS mat slabs are poured in long, narrow continuous strips from front-to-back using traveling screeds not unlike those found in road construction. The construction joints are then aligned so that they fall in a rack flue. This method typically does not produce an extremely level, smooth-troweled finish since for an ASRS, which has SRMs (Storage/Retrieval Machines, or stacker cranes) running on rails, it is not necessary. Typical acceptable slab flatness tolerances are +/- 1/2 ". The rack frames are shimmed to a level plane using metal "shim packs".

For a conventional warehouse to use the rack-supported approach pouring the much larger slab out in the open can present more problems. Most large warehouse slabs are poured not in long strips but in a checkerboard fashion and unlike an ASRS, they do require a much smoother finish and flatness tolerance due to the requirements of the forktrucks running on it. Pouring and finishing such large slabs in the open is difficult due to high summertime temperatures and precipitation.

Inflexibility

It is extremely difficult, if not impossible in some cases, to re-rack a rack-supported structure to change the rack openings or the style of rack (single-deep to double- or multiple-deep). The load beams serve as longitudinal, down-aisle bracing and the rack uprights attain some of their resistance to buckling from their location. Altering their elevations should only be done after a thorough structural engineering analysis. Changing

the style of rack would be an even greater challenge, so basically, whatever the rack configuration is when it's built is what it will remain, regardless of the changes in the business.

Damage Susceptibility

Except in the most catastrophic of cases, an SRM will never run off the floor rail or otherwise hit the rack supporting the building. Clearly this is not the case in a rack-supported conventional warehouse. Rack damage by forklifts is all too common, but now it must be dealt with immediately and probably under the direction of a structural engineer. Further compounding such possible damage is that of refrigeration air units that would also be supported by the rack-supported building. Forktruck impact could now induce damage to a unit or even case an ammonia leak.

Tax Implications

A rack-supported building, be it either an ASRS or a conventional warehouse operation can generally be classified as "Equipment" for depreciation purposes, with typically a 7 to 10-year depreciation life as opposed to those of a "Building" which is 30 years. In most cases, this "equipment" classification also includes the walls, roof and most of the systems within. Thus, during the economic life of the building, it can generate larger deductions.

Conclusion

Rack-supported buildings are generally found in ASRS applications when the building/system height is over some height (60' +/-) as determined by a cost analysis. Due to cost and other problems, rack-supported conventional warehouse operations are very rare.

15.4 ASRS Building Consideration Items

Constructability Considerations

- Slab flatness and finish are usually not big factors, however the flatness tolerance for the concrete subcontractor should be tighter than the tolerance given to the rack supplier.
- Rack erection should be closely controlled to ensure that not too many bays are erected without proper tightening up.
- Consider using a strongback/spreader beam to erect larger rack sections with the sprinkler pipe already installed.
- Instead of pouring the slab in "checkerboard" fashion, pour it in long strips from end-to-end using a travelling screed.
- The AHUs need to be set in place during rack erection.
- Check the proximity to airports as an FAA permit may be required or even restrict the height of the building.
- Possible long lead times with many materials coming from overseas.

- Possible issues with customs for materials coming over from out of the country.
- The vertical joints should be face caulked at the panel seams to help prevent leakage at the panel splice joint.

Design Considerations

- Although a mat slab foundation is typically used, in poor soil conditions where piles might be needed, one should investigate if a surcharge could be used to avoid piles/caissons.
- If the rack is to be anchored using drilled expansion anchors, the slab should be designed to be clear of rebar for the top 5 inches or use fiber-reinforced concrete.
- Girt spacing on the corners will need to be closer than in the main wall sections.
- Roof corners will probably need paver blocks for wind uplift resistance.
- If roof access is provided, safety tie-off points will need to be provided.
- Lighting should only be low-level "theater" type lighting in the aisles with wall packs at the run out ends for crane maintenance only.
- To prevent excessive leakage through access doors for conveyors, provide vestibule-type airlocks.
- Crane rails should be thermite welded and continuously supported on a neoprene pad.
- Crane power buss should be mounted low for ease of maintenance. Continuous conductors should be used.
- Crane aisles need to be fenced-off at the front and rear with interlocked access gates. European crane manufacturers usually require this as part of their own insurance policies and FEM standards.
- IMP splice details need to be well thought out and defined.
- Higher wind pressures and potential movement for the IMP panels and the connection to the rack structure need to be considered.
- High density underfloor insulation in lieu of a standard 25 psi typically called out.
- Snow drift load at the adjacent lower buildings, especially on existing buildings, need to be addressed.
- Building code height limitations.

Scope Considerations

- Instead of a penthouse on an already tall structure use centrifugal-type AHUs mounted on a mezzanine in either the front or rear crane run out areas.
- Consider a reduced oxygen system instead of sprinklers.
- Lightning protection is very important.
- Consider the use of architectural graphics or other such features to break up the mass of the building if near residential or architecturally sensitive areas.
- Roof access is much more difficult – crane platform, ship's ladder, ladder w/ cage
- The location and water application requirements of the sprinklers are dependent on the specific products and configuration of the racks. Careful placement is necessary to prevent water/ice and/or physical damage. Careful commissioning

that runs all the automation equipment through its "paces" to insure against conflicts with sprinklers and heat detection are recommended as well.

- Lighting – some or none.

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241 18th Street South, Suite 620, Arlington, VA, 22202