Guide to Effective Warehouse Design, Maintenance, and Modernization

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The **Global Cold Chain Alliance (GCCA)** exists to help its members build and strengthen the temperature-controlled supply chain worldwide. We do this by bringing third-party warehouse and transportation business leaders together in events and networking activities, providing advisory and educational services, and being a voice of cold chain to government regulators and other influencers around the world.

The **Global Cold Chain Foundation's (GCCF)** mission is to strengthen the global cold chain through education, research, and international development. Cold Chain Institute trains industry practitioners in the best practices of temperature-controlled product storage, handling, and transportation. Research manuals developed by the foundation serve as the definitive guide for the proper handling, storage, and freezing of perishable products as well as energy and facility management.

International development projects engage industry professionals in the development of cold chain infrastructure in emerging markets.

And a key partner to GCCA is the **Controlled Environment Building Association (CEBA)**. CEBA's mission is to represent expert builders who specialise in designing and constructing controlled environment buildings, including cold storage warehouses, food processing facilities, clean rooms, pharmaceutical facilities, food service, and retail distribution centres. With a strong value proposition and growth momentum, industry participation in CEBA programs has doubled since pre-pandemic levels.

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Member companies

91
Countries

1000+
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Executive Summary

This Design Manual establishes a unified set of standards and technical guidelines to support the planning, construction, operation, and maintenance of facilities, aligning with best practices in safety, efficiency, and performance. The manual is intended for engineers, facility managers, designers, and technical consultants who require clear, actionable direction across the full range of facility systems.

To improve accessibility and operational efficiency, this latest edition is being published in a modular format—organized into 15 focused chapters. Each chapter addresses a core system or component of facility design and management, enabling users to quickly reference specific content and apply standards directly to their area of responsibility.

1. Design – Foundational planning principles and performance objectives
2. Maintenance – Preventive strategies and operational reliability standards
3. Structural – Load-bearing frameworks and compliance specifications
4. Walls – Materials, insulation, and environmental controls
5. Floors – Surface treatments, drainage, and durability
6. Roofs – Construction systems, weatherproofing, and safety features
7. Refrigeration – Temperature control systems and efficiency metrics
8. Doors – Selection criteria, access control, and insulation
9. Lighting – Illumination standards, energy use, and fixture design
10. Material Handling – Flow optimization and equipment interfaces
11. Batteries – Storage, charging protocols, and hazard mitigation
12. Fire Prevention – Risk reduction measures and system integration
13. Racking – Load standards, anchoring, and spatial planning
14. Dock Equipment – Levelers, seals, and operational safety
15. Automated Systems – Integration of robotics, controls, and data systems

This format enables continuous updates and targeted usage while reinforcing technical consistency across disciplines. The manual is designed to serve as both a foundational reference and an evolving toolset for ongoing facility innovation and compliance.

What follows is Chapter 15
Automated Systems – Integration of robotics, controls, and data systems

Chapter 15: Automated Systems

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) 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 "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 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 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, , 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. The normal depreciation lifetime for buildings is 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 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 that hascontinuing, annual cost. In some operations, the number of shuttle operations has exceeded 14,000 annually and 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.

15.2 Challenges Facing PRWs When Considering Automation

There are challenges a PRW faces when considering the utilization of ASRS technology. Unless governed under a multi-year storage contract, many public refrigerate warehouses 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 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% .

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 in these cold storage areas is eliminated. This elimination of labor also reduces the number of forklifts, batteries, and chargers required.

There are challenges a PRW faces when considering and evaluating the feasibility of integrating warehouse automation into its operation. These challenges include:

- 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 adjust 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 associated with warehouse automation when your customers are all based upon 30-day billing. It becomes less if your customers are based upon multi-year storage contracts.

Secondly, it is important that a public refrigerated warehouse understand the capital costs associated with building an automated warehouse, the improvement in labor efficiencies as they pertain to headcount and throughput, and 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 a system and selecting equipment, the customer order and SKU data trends dictate the solution. . 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 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 a 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 supported 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 in order 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. Essentially, 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. Fork truck impact could now induce damage to a unit or even cause 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 international
- 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

15.5 ASRS Design Builds

Many of the perceptions of incorporating an ASRS is that it is an all-or-nothing build. In addition to this, the concept of adding it to an existing facility is almost unimaginable, There are three main reasons behind these perceptions:

- Cost to shut an entire facility down to build and commission the system
- The system only works at full build
- Once a system is built it can't be easily added onto

In reality, these are all misconceptions. A system integrator can design and implement a successful ASRS solution that is not only modular, but can have minimal impact to the existing operation. This approach can be an optimal solution for operations requiring high flexibility due to changes in customer requirements, onboarding new business channels or product changes.

To start the project, solution engineers in collaboration with the Owner's team, identify the size and scope of the project. From that point, they work to determine the best way to begin the build. In most cases, the path of least resistance is an area not currently occupied with MHE or existing racking. The Owner then works to shift product/equipment out of the designated area (this sometimes means temporary storage in trailers or an off-site facility).

After the initial build of the ASRS is completed and commissioned, the product sitting in the next phase is moved into the ASRS system, thus clearing the space for the next phase of the build. This can mean, depending on size and scope, the full system isn't operational immediately, but that is the benefit of modular design. It doesn't have to be. This also allows the Owner to get the system fully functional and tested from the software perspective so that the complete system go live is a smooth one.