CHAPTER 14

REFRIGERATED-FACILITY DESIGN

REFRIGERATED facilities are any buildings or sections of a building that achieve controlled storage conditions using refrigeration. Two basic storage facilities are (1) coolers that protect commodities at temperatures usually above 32°F and (2) low-temperature rooms (freezers) operating under 32°F to prevent spoilage or to maintain or extend product life.

The conditions within a closed refrigerated chamber must be maintained to preserve the stored product. This refers particularly to seasonal, shelf life, and long-term storage. Specific items for consideration include

- Uniform temperatures
- Length of airflow pathway and impingement on stored product
- Effect of relative humidity
- Effect of air movement on employees
- Controlled ventilation, if necessary
- Product entering temperature
- Expected duration of storage
- Required product outlet temperature
- Traffic in and out of storage area

In the United States, the U.S. Public Health Service Food and Drug Administration developed the Food Code (FDA 1997), which provides model requirements for safeguarding public health and ensuring that food is unadulterated. The code is a guide for establishing standards for all phases of handling refrigerated foods. It treats receiving, handling, storing, and transporting refrigerated foods and calls for sanitary as well as temperature requirements. These standards must be recognized in the design and operation of refrigerated storage facilities.

Regulations of the Occupational Safety and Health Administration (OSHA), Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), and other standards must also be incorporated in warehouse facility and procedures.

Refrigerated facilities may be operated for or by a private company for storage or warehousing of their own products, as a public facility where storage services are offered to many concerns, or both. Important locations for refrigerated facilities, public or private, are (1) point of processing, (2) intermediate points for general or long-term storage, and (3) final distributor or distribution point.

The five categories for the classification of refrigerated storage for preservation of food quality are

- Controlled atmosphere for long-term fruit and vegetable storage
- Coolers at temperatures of 32°F and above
- High-temperature freezers at 27 to 28°F
- Low-temperature storage rooms for general frozen products, usually maintained at –5 to –20°F
- Low-temperature storages at –5 to –20°F, with a surplus of refrigeration for freezing products received at above 0°F

The preparation of this chapter is assigned to TC 10.5, Refrigerated Distribution and Storage Facilities.

Note that, because of ongoing research, the trend is toward lower temperatures for frozen foods. Refer to Chapters 23 and 24 of the 2005 *ASHRAE Handbook—Fundamentals* and Chapter 11 of this volume for further information.

INITIAL BUILDING CONSIDERATIONS

Location

Private refrigerated space is usually adjacent to or in the same building with the owner's other operations.

Public space should be located to serve a producing area, a transit storage point, a large consuming area, or various combinations of these to develop a good average occupancy. It should also have the following:

- Convenient location for producers, shippers, and distributors, considering the present tendency toward decentralization and avoidance of congested areas
- Good railroad switching facilities and service with minimum switching charges from all trunk lines to plant tracks if a railhead is necessary to operate the business profitably
- Easy access from main highway truck routes as well as local trucking, but avoiding location on congested streets
- Ample land for trucks, truck movement, and plant utility space plus future expansion
- Location with a reasonable land cost
- Adequate power and water supply
- Provisions for surface, waste, and sanitary water disposal
- Consideration of zoning limitations and fire protection
- Location away from residential areas, where noise of outside operating equipment (i.e., fans and engine-driven equipment on refrigerated vehicles) would be objectionable
- External appearance that is not objectionable to the community
- Minimal tax and insurance burden
- Plant security
- Favorable undersoil bearing conditions and good surface drainage

Plants are often located away from congested areas or even outside city limits where the cost of increased trucking distance is offset by better plant layout possibilities, a better road network, better or lower-priced labor supply, or other economies of operation.

Configuration and Size Determination

Building configuration and size of a cold-storage facility are determined by the following factors:

- Is receipt and shipment of goods to be primarily by rail or by truck? Shipping practices affect the platform areas and internal traffic pattern.
- What relative percentages of merchandise are for cooler and for freezer storage? Products requiring specially controlled conditions, such as fresh fruits and vegetables, may justify or demand several individual rooms. Seafood, butter, and nuts also require special treatment. Where overall occupancy may be reduced

because of seasonal conditions, consider providing multiple-use spaces.
- What percentage is anticipated for long-term storage? Products that are stored long term can usually be stacked more densely.
- Will the product be primarily in small or large lots? The drive-through rack system or a combination of pallet racks and a mezzanine have proved effective in achieving efficient operation and effective use of space. Mobile or moving rack systems are also valid options.
- How will the product be palletized? Dense products such as meat, tinned fruit, drums of concentrate, and cases of canned goods can be stacked very efficiently. Palletized containers and special pallet baskets or boxes effectively hold meat, fish, and other loose products. The slip sheet system, which requires no pallets, eliminates the waste space of the pallet and can be used effectively for some products. Pallet stacking racks make it feasible to use the full height of the storage and palletize any closed or boxed merchandise.
- Will rental space be provided for tenants? Rental space usually requires special personnel and office facilities. An isolated area for tenant operations is also desirable. These areas are usually leased on a unit area basis, and plans are worked into the main building layout.

The owner of a prospective refrigerated facility may want to obtain advice from specialists in product storage, handling, and movement systems.

Stacking Arrangement

Typically, the height of refrigerated spaces is at least 28 to 35 ft or more clear space between the floor and structural steel to allow forklift operation. Pallet rack systems use the greater height. The practical height for stacking pallets without racks is 15 to 18 ft. Clear space above the pallet stacks is used for air units, air distribution, lighting, and sprinkler lines. Generally, 6 to 10 ft minimum clear height is required from top of product to bottom of support structure to ensure there is no interference with drain pan and drain lines of air units. Greater clear heights are usually required if automated or mechanized equipment is used. Overhead space is inexpensive, and because the refrigeration requirement for extra height is not significant in the overall plant cost, a minimum of 20 ft clear height is desirable. Greater heights are valuable if automated or mechanized material handling equipment is contemplated. The effect of high stacking arrangements on insurance rates should be investigated.

Floor area in a facility where diverse merchandise is to be stored can be calculated on the basis of 8 to 10 lb per gross cubic foot, to allow about 40% for aisles and space above the pallet stacks. In special-purpose or production facilities, products can be stacked with less aisle and open space, with an allowance factor of about 20%.

Building Design

Most refrigerated facilities are single-story structures. Small columns on wide centers allow palletized storage with minimal lost space. This type of building usually provides additional highway truck unloading space. The following characteristics of single-story design must be considered: (1) horizontal traffic distances, which to some extent offset the vertical travel required in a multistory building; (2) difficulty of using the stacking height with many commodities or with small-lot storage and movement of goods; (3) necessity for treatment of the floor below freezers to give economical protection against possible ground heaving; and (4) high land cost for building capacity. A one-story facility with moderate or low stacking heights has a high cost per unit area because of the high ratio of construction costs and added land cost to product storage capacity. However, first cost and operating cost are usually lower than for a multistory facility.

One-Story Configuration

Figure 1 shows the layout of a one-story −10°F freezer that complies with current practices. The following essential items and functions are considered:

- Refrigeration machinery room
- Refrigerated shipping docks with seal-cushion closures on the doors
- Automatic doors
- Batten doors or strip curtains
- Low-temperature storage held at −10°F or lower
- Pallet-rack systems to facilitate handling of small lots and to comply with first-in, first-out inventory, which is required for some products
- Blast freezer or separate sharp freezer room for isolation of products being frozen
- Cooler or convertible space
- Space for brokerage offices
- Space for empty pallet storage and repair
- Space for shop and battery charging
- Automatic sprinklers in accordance with National Fire Protection Association (NFPA) regulations
- Trucker/employee break area
- Valve stations for underfloor heating
- Evaporative condenser(s) location

Other areas that must be in a complete operable facility are

- Electrical area
- Shipping office
- Administration office
- Personnel welfare facilities

A modified one-story design is sometimes used to reduce horizontal traffic distances and land costs. An alternative is to locate nonproductive services (including offices and the machinery room) on a second-floor level, usually over the truck platform work area, to allow full use of the ground floor for production work and storage. However, potential vibration of the second floor from equipment below must be considered.

One-story design or modification thereof gives the maximum capacity per unit of investment with a minimum overall operating

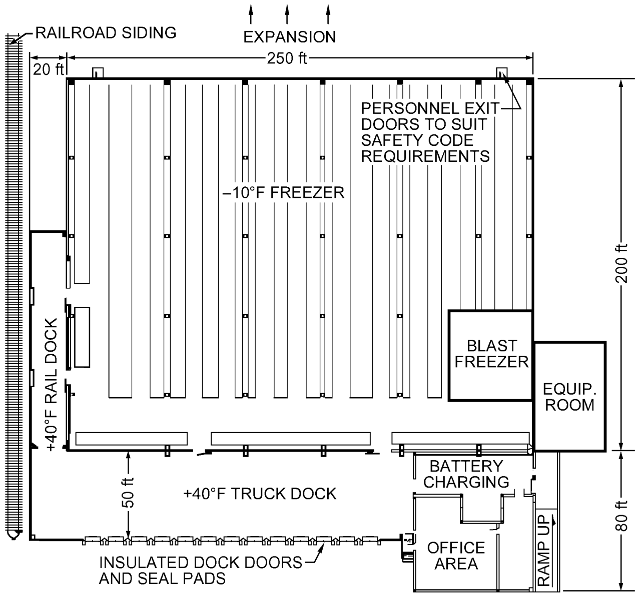

Fig. 1 Typical Plan for One-Story Refrigerated Facility

expense, including amortization, refrigeration, and labor. Mechanization must be considered, as well. In areas where land availability or cost is a concern, a high-rise refrigerated storage building may be a viable option.

Designs that provide minimum overall costs restrict office facilities and utility areas to a minimum. They also include ample dock area to ensure efficiency in loading and unloading merchandise.

Shipping and Receiving Docks

Temperature control regulations for all steps of product handling have led to designing the trucking dock as a refrigerated anteroom to the cold storage area. Dock refrigeration is an absolute necessity in humid and warm climates. Typically, loading and unloading transport vehicles is handled by separate work crews. One crew moves the product in and out of the vehicles, and a warehouse crew moves the product in and out of the refrigerated storage. This procedure may allow merchandise to accumulate on the shipping dock. Maintaining the dock at 35 to 45°F offers the following advantages:

- Refrigeration load in the low-temperature storage area, where energy demand per unit capacity of refrigeration is higher, is reduced.
- Less ice or frost forms in the low-temperature storage because less humid and warm air infiltrates the area.
- Refrigerated products held on the dock maintain a more favorable temperature, thus maintaining product quality.
- Packaging remains in good condition because it stays drier. Facility personnel are more comfortable because temperature differences are smaller.
- Less maintenance on forklifts and other equipment is required because condensation is reduced.
- Need for anterooms or vestibules to the freezer space is reduced or eliminated.
- Floor areas stay drier, particularly in front of freeze door areas. This assists in housekeeping and improves safety.

Utility Space

Space for a general office, locker room, and machinery room is needed. A superintendent's office and a warehouse records office should be located near the center of operations, and a checker's office should be in view of the dock and traffic arrangement. Rented space should be isolated from warehouse operations.

The machinery room should include ample space for refrigeration equipment and maintenance, adequate ventilation, standby capacity for emergency ventilation, and adequate segregation from other areas. Separate exits are required by most building codes. A maintenance shop and space for parking, charging, and servicing warehouse equipment should be located adjacent to the machinery room. Electrically operated material-handling equipment is used to eliminate inherent safety hazards of combustion-type equipment. Battery-charging areas should be designed with high roofs and must be ventilated, because of the potential for combustible fumes from charging.

Specialized Storage Facilities

Material handling methods and storage requirements often dictate design of specialized storage facilities. Automated material handling within the storage, particularly for high stack piling, may be an integral part of the structure or require special structural treatments. Controlled-atmosphere and minimal-air-circulation rooms require special building designs and mechanical equipment to achieve design requirements. Drive-in and/or drive-through rack systems can improve product inventory control and can be used in combination with stacker cranes, narrow-aisle high stacker cranes, and automatic conveyors. Mobile racking systems may be considered where space is at a premium.

In general, specialized storage facilities may be classified as follows:

- Public refrigerated facility with several chambers designed to handle all commodities. Storage temperatures range from 35 to 60°F (with humidity control) and to –20°F (without humidity control).
- Refrigerated facility area for case and break-up distribution, automated to varying degrees. The area may incorporate racks with pallet spaces to facilitate distribution.
- Facility designed for a processing operation with bulk storage for frozen ingredients and rack storage for palletized outshipment of processed merchandise. An efficient adaptation frequently seen is to adjoin the refrigerated facility to the processing plant.
- Public refrigerated facility serving several production manufacturers for storing and inventorying products in lots and assembling outshipments.
- Mechanized refrigerated facility with stacker cranes, racks, infeed and outfeed conveyors, and conveyor vestibules. Such a facility may have an interior ceiling 60 to 100 ft high. Evaporators should be mounted in the highest internal area to help remove moisture from outside air infiltration. A penthouse to house the evaporators can be accessed through doorways on the roof for maintenance, providing a means to control condensate drip, and allowing added rack storage space in the freezer area.

Controlled-Atmosphere Storage Rooms

Controlled-atmosphere (CA) storage rooms may be required for storing some commodities, particularly fresh fruits and vegetables that respire, consuming oxygen (O_2) and producing carbon dioxide (CO_2) in the process. The storage life of such products may be greatly lengthened by a properly controlled environment, which includes control of temperature, humidity, and concentration of noncondensable gases (O_2, CO_2, and nitrogen). Hermetically sealing the room to provide such an atmosphere is challenging, often requiring special gastight seals. Although information is available for some commodities, the desired atmosphere usually must be determined experimentally for the commodity as produced in the specific geographic location that the storage room is to serve.

Commercial application of controlled-atmosphere storage has historically been limited to fresh fruits and vegetables that respire. Storage spaces may be classified as having either (1) product-generated atmospheres, in which the room is sufficiently well sealed that the natural oxygen consumption and CO_2 generation by the fruit balance infiltration of O_2 into the space and exhaust of CO_2 from the space; or (2) externally generated atmospheres, in which nitrogen generators, CO_2 scrubbers, or O_2 consumers supplement normal respiration of the fruit to create the desired atmospheric composition. The second type of system can cope with a poorly sealed room, but the cost of operation may be high; even with the external gas generator system, a hermetically sealed room is desired.

In most cases, a CO_2 scrubber is required, unless the total desired O_2 and CO_2 content is 21%, which is the normal balance between O_2 and CO_2 during respiration. Carbon dioxide may be removed by (1) passing room air over dry lime that is replaced periodically; (2) passing air through wet caustic solutions in which the caustic (typically sodium hydroxide) is periodically replaced; (3) using water scrubbers, in which CO_2 is absorbed from the room air by a water spray and then desorbed from the water by outdoor air passed through the water in a separate compartment; (4) using monoethanolamine scrubbers, in which the solution is regenerated periodically by a manual process or continuously by automatic equipment; or (5) using dry adsorbents automatically regenerated on a cyclic basis.

Systems of room sealing to prevent outside air infiltration include (1) galvanized steel lining the walls and ceiling of the room and interfaced into a floor sealing system; (2) plywood with an impervious sealing system applied to the inside face; and (3) carefully applied sprayed urethane finished with mastic, which also serves as a fire retardant.

A room is considered sufficiently sealed if, under uniform temperature and barometric conditions, 1 h after the room is pressurized to 1 in. of water (gage), 0.1 to 0.2 in. remains. A room with external gas generation is considered satisfactorily sealed if it loses pressure at double the above rate, and the test prescribed for a room with product-generated atmosphere is about one air change of the empty room in a 30 day period.

Extreme care in all details of construction is required to obtain a seal that passes these tests. Doors are well sealed and have sills that can be bolted down; electrical conduits and special seals around pipe and hanger penetrations must allow some movement while keeping the hermetic seal intact. Structural penetrations through the seal must be avoided, and the structure must be stable. Controlled-atmosphere rooms in multifloor buildings, where the structure deflects appreciably under load, are extremely difficult to seal.

Gasket seals are normally applied at the cold side of the insulation, so that they may be easily maintained and points of leakage can be detected. However, this placement causes some moisture entrapment, and the insulation materials must be carefully selected so that this moisture causes minimal damage. In some installations, cold air with a dew point lower than the inside surface temperature is circulated through the space between the gas seal and the insulation to provide drying of this area. Chapters 22 and 24 have additional information on conditions required for storage of various commodities in controlled-atmosphere storage rooms.

Automated Warehouses

Automated warehouses usually contain tall, fixed rack arrangements with stacker cranes under fully automatic, semiautomatic, or manual control. The control systems can be tied into a computer system to retain a complete inventory of product and location.

The following are some of the advantages of automation:

- First-in, first-out inventory can be maintained.
- Enclosure structure is high, requiring a minimum of floor space and providing favorable cost per cubic foot.
- Product damage and pilfering are minimized.
- Direct material handling costs are minimized.

The following are some of the disadvantages:

- First cost of the racking system and building are very high compared to conventional designs.
- Access may be slower, depending on product flow and locations.
- Cooling equipment may be difficult to access for maintenance, unless installed in a penthouse.
- Air distribution must be carefully evaluated.

Refrigerated Rooms

Refrigerated rooms may be appropriate for long-term storage at temperatures other than the temperature of the main facility, for bin storage, for controlled-atmosphere storage, or for products that deteriorate with active air movement. Mechanically cooled walls, floors, and ceilings may be economical options for controlling the temperature. Embedded pipes or air spaces through which refrigerated air is recirculated can provide the cooling; with this method, heat leakage is absorbed into the walls and prevented from entering the refrigerated space.

The following must be considered in the initial design of the room:

- Initial cooldown of the product, which can impose short-term peak loads
- Service loads when storing and removing product
- Odor contamination from products that deteriorate over long periods
- Product heat of respiration

Supplementary refrigeration or air-conditioning units in the refrigerated room that operate only as required can usually alleviate such problems.

Construction Methods

Cold storage, more than most construction, requires correct design, high-quality materials, good workmanship, and close supervision. Design should ensure that proper installation can be accomplished under various adverse job site conditions. Materials must be compatible with each other. Installation must be done by careful workers directed by an experienced, well-trained superintendent. Close cooperation between the general, roofing, insulation, and other contractors increases the likelihood of a successful installation.

Enclosure construction methods can be classified as (1) insulated structural panel, (2) mechanically applied insulation, or (3) adhesive or spray-applied foam systems. These construction techniques seal the insulation within an airtight, moisturetight envelope that must not be violated by major structural components.

Three methods are used to achieve an uninterrupted vapor retarder/insulation envelope. The first and simplest is total encapsulation of the structural system by an exterior vapor retarder/insulation system under the floor, on the outside of the walls, and over the roof deck (Figure 2). This method offers the least number of penetrations through the vapor retarder, as well as the lowest cost.

The second method is an entirely interior system in which the vapor retarder envelope is placed within the room, and insulation is added to the walls, floors, and suspended ceiling (Figure 3). As with an exterior system, the moisture barrier is best applied to the outside of the enclosures. This technique is used where walls and ceilings must be washed, where an existing structure is converted

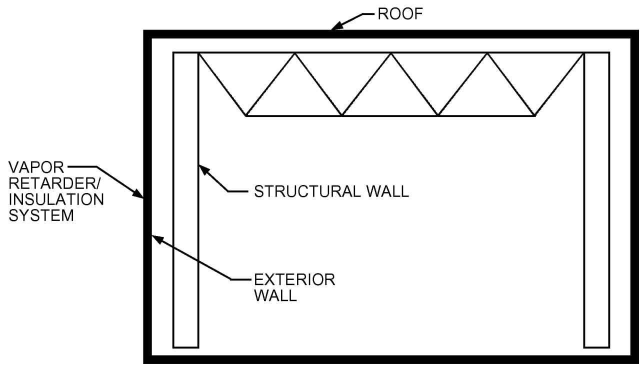

Fig. 2 Total Exterior Vapor Retarder/Insulation System

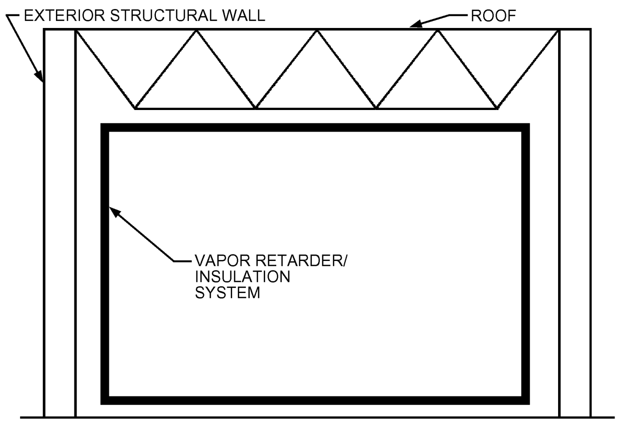

Fig. 3 Entirely Interior Vapor Retarder/Insulation System

to refrigerated space, or for smaller rooms that are located within large coolers or unrefrigerated facilities or are part of a food-processing facility. Special-purpose rooms require separate analysis to determine proper moisture barrier location.

The third method is interior/exterior construction (Figure 4), which involves an exterior curtain wall of masonry or similar material tied to an interior structural system. Adequate space allows the vapor retarder/insulation system to turn up over a roof deck and be incorporated into a roofing system, which serves as the vapor retarder. This method is a viable alternative, although it allows more interruptions in the vapor retarder than the exterior system.

The total exterior vapor retarder system (see Figure 2) is best because it has the fewest penetrations and the lowest cost. Areas of widely varying temperature should be divided into separate envelopes to retard heat and moisture flow between them (Figure 5).

Space Adjacent to Envelope

Condensation at the envelope is usually caused by high humidity and inadequate ventilation. Poor ventilation occurs most often within a dead air space such as a ceiling plenum, hollow masonry unit, through-metal structure, or beam cavity. All closed air spaces should be eliminated, except those large enough to be ventilated adequately. Ceiling plenums, for instance, are best ventilated by mechanical vents that move air above the envelope, or with mechanical dehumidification. See the section on Suspended Ceilings and Other Interstitial Spaces for more information.

If possible, the insulation envelope and vapor retarder should not be penetrated. All steel beams, columns, and large pipes that project through the insulation should be vapor-sealed and insulated with a 4 ft wrap of insulation. Conduit, small pipes, and rods should be insulated at four times the regular wall insulation thickness. In both cases, the thickness of insulation on the projection should be half that on the regular wall or ceiling. Voids within metal projections should be filled. Where practicable, the wrap insulation should be located, and the metal projection sealed, on the warm side. Vapor sealing on the inside of conduits prevents moisture flow through the conduits.

Other considerations include the following:

- Vapor retardants should be placed on the warm side of insulation systems.
- Prefabricated, self-locking wall panels also serve as vapor barriers.
- Roof vapor membranes are often used; these large rubber sheets are laid over roof insulation, overlapped, sealed, and attached to the roof with nonpenetrating fasteners or covered with small stone ballast, which is light-colored to help reflect solar heat.

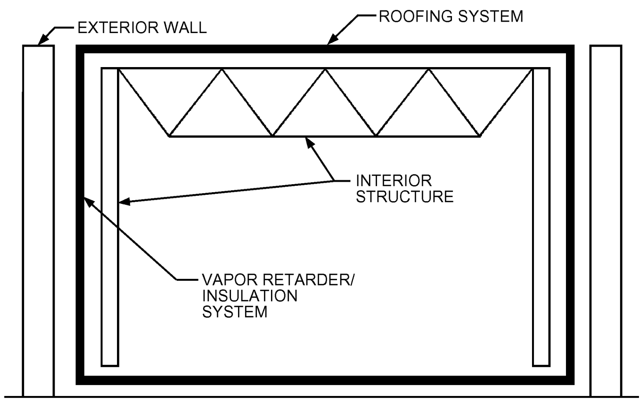

Fig. 4 Interior/Exterior Vapor Retarder/Insulation System

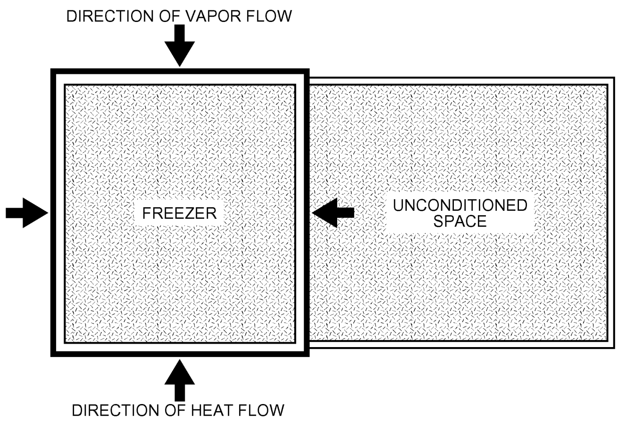

Fig. 5 Separate Exterior Vapor Retarder Systems for Each Area of Significantly Different Temperature

Air/Vapor Treatment at Junctions

Air and vapor leakage at wall/roof junctions is perhaps the predominant construction problem in cold storage facilities.

When a cold room of interior/exterior design (see Figure 4) is lowered to operating temperature, the structural elements (roof deck and insulation) contract and can pull the roof away from the wall. Negative pressure in the space of the wall/roof junction can cause warm, moist air to leak into the room and form frost and ice. Therefore, proper design and construction of the air/vapor seal is critical.

An air/vapor flashing sheet system (a transition from the roof vapor retarder to the exterior wall vapor retarder) is best for preventing leakage. A good corner flashing sheet must be flexible, tough, airtight, and vaportight. Proper use of flexible insulation at overlaps, mastic adhesive, and a good mastic sealer ensure leak-free performance. To remain airtight and vaportight during the life of the facility, a properly constructed vapor retarder should

- Be flexible enough to withstand building movements that may occur at operating temperatures
- Allow for thermal contraction of the insulation as the room is pulled down to operating temperature
- Be constructed with a minimum of penetrations that might cause leaks (wall ties and structural steel that extend through the corner flashing sheet may eventually leak no matter how well sealed during construction; minimize these, and make them accessible for maintenance)
- Have corner flashing sheet properly lapped and sealed with adhesive and mechanically fastened to the wall vapor retarder
- Have corner flashing sealed to roof without openings
- Have floor to exterior vapor retarders that are totally sealed

The interior/exterior design (see Figure 4) is likely to be unsuccessful at the wall/roof junction because of extreme difficulty in maintaining an airtight or vaportight environment.

The practices outlined for the wall/roof junction apply for other insulation junctions. The insulation manufacturer and designer must coordinate details of the corner flashing design.

Poor design and shoddy installation cause moist air leakage into the facility, resulting in frost and ice formation, energy loss, poor appearance, loss of useful storage space, and, eventually, expensive repairs.

Floor Construction

Refrigerated facilities held above freezing need no special underfloor treatment. A below-the-floor vapor retarder is needed in facilities held below freezing, however. Without underfloor heating, the subsoil eventually freezes; any moisture in this soil also freezes and causes floor frost heaving. In warmer climates, underfloor tubes vented to ambient air may be sufficient to prevent heaving. Artificial heating, either by air circulated through underfloor ducts or by glycol circulated through plastic pipe, is the preferred method to prevent frost heaving. Electric heating cables installed under the floor can also be used to prevent frost formation. The choice of heating method depends on energy cost, reliability, and maintenance requirements. Air duct systems should be screened to keep rodents out and sloped for drainage to remove condensation.

Future facility expansion must be considered when underfloor heating systems are being designed. Therefore, a system including artificial heating methods that do not require building exterior access is preferred. Wearing-slab heating under the dock area in front of the freezer doors helps eliminate moisture at the door and floor joints.

Surface Preparation

When an adhesive is used, the surface against which the insulating material is to be applied should be smooth and dust-free. Where room temperatures are to be below freezing, masonry walls should be leveled and sealed with cement back plaster. Smooth poured concrete surfaces may not require back plastering.

No special surface preparation is needed for a mechanical fastening system, assuming that the surface is reasonably smooth and in good repair.

The surface must be warm and dry for a sprayed-foam system. Any cracks or construction joints must be prepared to prevent projection through the sprayed insulation envelope. All loose grout and dust must be removed to ensure a good bond between the sprayed foam insulation and the surface. Very smooth surfaces may require special bonding agents.

No special surface preparation is needed for insulated panels used as a building lining, assuming the surfaces are sound and reasonably smooth. Grade beams and floors should be true and level where panels serve as the primary walls.

Finishes

Insulated structural panels with metal exteriors and metal or reinforced plastic interior faces are prevalent for both coolers and freezers. They keep moisture from the insulation, leaving only the joints between panels as potential areas of moisture penetration. They are also available with surface finishes that meet government requirements.

For sanitary washdowns, a scrubbable finish is sometimes required. Such finishes generally have low permeance; when one is applied on the inside surface of the insulation, a lower-permeance treatment is required on the outside of the insulation.

All insulated walls and ceilings should have an interior finish. The finish should be impervious to moisture vapor and should not serve as a vapor retarder, except for panel construction. The permeance of the in-place interior finish should be significantly greater than the permeance of the in-place vapor retarder.

To select an interior finish to meet the installation's in-use requirements, consider the following factors: (1) fire resistance, (2) washdown requirements, (3) mechanical damage, (4) moisture and gas permeance, and (5) government requirements. All interior walls of insulated spaces should be protected by bumpers and curbs wherever there is a possibility of damage to the finish.

Suspended Ceilings and Other Interstitial Spaces

It is not uncommon to have interstitial spaces above or adjacent to cold spaces in refrigerated facilities. The reason for the space may be design (e.g., an older facility with an air space used as insulation, a drop ceiling, or a production space that requires a cleanable ceiling surface), or facility expansion (e.g., adding freezer space next to an existing freezer that cannot structurally support what would be the common wall). Regardless, if air in the space has no ventilation or conditioning, moisture in the air will condense onto the cold surface, and can lead to structural failure of the envelope through corrosion, frost penetration in the cold space, or other forms of deterioration if not kept in check.

Several methods are available to deal with the moisture. The space could be sealed airtight, with a dehumidifier inside to maintain a low dew point in the space. This method is preferable in warm and humid climates. The sealed space could also be heated to ensure the cold surface is always above the air's dew point. This is uncommon because of the heat load it transmits to the refrigerated space.

The most common method used to prevent condensation is continuously ventilating outside air into the interstitial space. This keeps the insulated surface temperature above the dew point of the interstitial space, thus preventing moisture condensing from the air on the surface. Roof-mounted exhaust fans and uniformly spaced vents around the perimeter of the plenum are typically used to ventilate suspended ceilings; similar arrangements can be used for other spaces. Be certain, though, that fan and inlet louvers are placed to provide good air distribution across the entire cold surface. The cold surface should also be covered with a vapor retarder attached with flashing to the wall insulation on the top or warm side. Finally, beware of overventilating the space: this only reduces the insulating effect of the dead air space.

Suspended ceilings are often designed for light foot traffic for inspection and maintenance of piping and electrical wiring. Fastening systems for ceiling panels include spline, U channel, and camlock. To minimize problems with ceiling penetrations during both installation and ongoing maintenance, wall panel penetrations may be preferable when possible.

Floor Drains

Floor drains should be avoided if possible, particularly in freezers. If they are necessary, they should have short, squat dimensions and be placed high enough to allow the drain and piping to be installed above the insulation envelope.

Electrical Wiring

Electrical wiring should be brought into a refrigerated room through as few locations as possible (preferably one), piercing the wall vapor retarder and insulation only once. Plastic-coated cable is recommended for this service where codes permit. If codes require conduit, the last fitting on the warm side of the run should be explosionproof and sealed to prevent water vapor from entering the cold conduit. Light fixtures in the room should not be vapor-sealed but should allow free passage of moisture. Take care to maintain the vapor seal between the outside of the electrical service and the cold-room vapor retarder.

Heat tracing is suggested inside the freezer only from the air-handling unit drain outlet panel to the insulated wall panel. Heat tracing within the wall could be a possible fire hazard and also cannot be serviced. Drain tracing can continue external to the freezer on a separate electrical circuit.

Tracking

Cold-room product suspension tracking, wherever possible, should be erected and supported within the insulated structure, entirely independent of the building itself. This eliminates flexure of the roof structure or overhead members, and simplifies maintenance.

Cold-Storage Doors

Doors should be strong yet light enough for easy opening and closing. Hardware should be of good quality, so that it can be set to compress the gasket uniformly against the casing. All doors to rooms operating below freezing should be equipped with heaters.

In-fitting doors are not recommended for rooms operating below freezing unless they are provided with heaters, and they should not be used at temperatures below 0°F with or without heaters.

See the subsection on Doors in the section on Applying Insulation for more information.

Hardware

All metal hardware, whether within the construction or exposed to conditions that will rust or corrode the base metal, should be heavily galvanized, plated, or otherwise protected. It is best to choose materials not subject to corrosion or rust from exposure to vapor condensation and cleaning agents used in the facility.

Refrigerated Docks

The purpose of the refrigerated facility (e.g., distribution, in-transit storage, or seasonal storage) dictates the loading dock requirements. Shipping docks and corridors should provide liberal space for (1) movement of goods to and from storage, (2) storage of pallets and idle equipment, (3) sorting, and (4) inspecting. The dock should be at least 30 ft wide. Commercial-use facilities usually require more truck dock space than specialized storage facilities because of the variety of products handled.

Floor heights of refrigerated vehicles vary widely but are often greater than those of unrefrigerated vehicles. Rail dock heights and building clearances should be verified by the railroad serving the plant. A dock height of 54 in. above the rail is typical for refrigerated rail cars. Three to five railroad car spots per million cubic feet of storage should be planned.

Truck dock heights must comply with the requirements of fleet owners and clients, as well as the requirements of local delivery trucks. Trucks generally require a 54 in. height above the pavement, although local delivery trucks may be much lower. Some reefer trucks are up to 58 in. above grade. Adjustable ramps at some truck spots will partly compensate for height variations. If dimensions permit, seven to ten truck spots per million cubic feet should be provided in a public refrigerated facility.

Refrigerated docks maintained at temperatures of 35 to 45°F require about 5 tons of refrigeration per 1000 ft^2 of floor area; however, actual load calculation should be done per ASHRAE methodology (see Chapter 13). Cushion-closure seals around the truck doorways reduce infiltration of outside air. Be sure to avoid gaps, particularly beneath the leveling plate between the truck and the dock. An inflatable or telescoping enclosure can be extended to seal the space between a railcar and the dock. Insulated doors for docks must be mounted on the inside walls. The relatively high costs of doors, cushion closures, and refrigeration influence dock size and number of doors.

Schneider System

The Schneider system, and modifications thereof, is a cold-storage construction and insulation method primarily used in the western United States, with most of the installations in the Pacific Northwest. It is an interior/exterior vapor retarder system, as illustrated in Figure 4. The structure uses concrete tilt-up walls and either glue-laminated wood beams or bowstring trusses for the roof. Fiberglass batts coupled with highly efficient vapor retarders and a support framework are used to insulate the walls and roof. The floor slab construction, insulation, and underfloor heat are conventional for refrigerated facilities.

The key to success for the Schneider system is an excellent vapor retarder system that is professionally designed and applied, with special emphasis on the wall/roof junction. Fiberglass has a high permeability rating and loses its insulating value when wet. It is therefore absolutely essential that the vapor retarder system perform at high efficiency. Typical wall vapor retarder materials include aluminum B foil and heavy-gage polyethylene, generously overlapped and adhered to the wall with a full coating of mastic. The roofing materials act as a vapor retarder for the roof. The vapor retarder at the wall/roof junction is usually a special aluminum foil assembly installed to perform efficiently in all weather conditions.

Fiberglass insulation applied to the wall is usually 10 to 12 in. thick for freezers and 6 to 8 in. for coolers. It is retained by offset wood or fabricated fiberglass-aluminum sheathed studs on 24 in. centers. Horizontal girts are used at intervals for bracing. The inside finish is 1 in. thick perforated higher-density fiberglass panels that can breathe to allow any moisture that passes through the vapor retarder to be deposited as frost on the evaporator coils.

Fiberglass insulation applied to the roof structure is usually 12 to 14 in. thick for freezers and 8 to 10 in. for coolers, and is applied between 2 by 12 in. or 2 by 14 in. joists that span the glue-laminated wood beams, purlins, or trusses. The exterior finish is the same as described for walls. Battens attached to the underside of the joists hold the finish panels and insulation in place.

Advantages of the Schneider system over insulated panels, assuming equal effectiveness of the vapor retarder/insulation envelopes over time, include lower first cost for structures over 40,000 ft^2, lower operating cost, and fewer interior columns. Disadvantages include a less clean appearance, unsuitability where washdown is required, impracticality where a number of smaller rooms are required, and a smaller number of capable practitioners (i.e., architects, engineers, contractors) available.

REFRIGERATION SYSTEMS

Types of Refrigeration Systems

Refrigeration systems can be broadly classified as unitary or applied. In this context, *unitary* systems are designed by manufacturers, assembled in factories, and installed in a refrigerated space as prepackaged units. Heat rejection and compression equipment is either within the same housing as the low-temperature air-cooling coils or separated from the cooling section. Such units normally use hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) refrigerants.

Applied units denote field-engineered and -erected systems and form the vast majority of large refrigerated (below-freezing) facility systems. Installations generally have a central machinery room or series of machinery rooms convenient to electrical distribution services, outside service entrance, etc., located as close to the refrigerated space as possible to reduce piping losses (pressure drop), piping costs, refrigerant charge, and thermal losses. Essentially made to order, applied systems are generally designed and built from standard components obtained from one or more suppliers. Key components include compressors, motors, fan-coil units, receivers, pump circulation systems, controls, refrigerant condensers (evaporative and shell-and-tube), and other pressure vessels.

The refrigeration system for a refrigerated facility should be selected in the early stages of planning. If the facility is a single-purpose, low-temperature storage building, most types of systems can be used. However, if commodities to be stored require different temperatures and humidities, a system must be selected that can meet the demands using isolated rooms at different conditions.

Using factory-built packaged unitary equipment may have merit for the smallest structures and for a multiroom facility that requires a variety of storage conditions. Conversely, the central compressor room has been the accepted standard for larger installations, especially where energy conservation is important.

Multiple centrally located, single-zone condensing units have been used successfully in Japan and other markets where high-rise refrigerated structures are used or where local codes drive system selection.

Direct refrigeration, either a flooded or pumped recirculation system serving fan-coil units, is a dependable choice for a central compressor room. Refrigeration compressors, programmable logic controllers, and microprocessor controls complement the central engine room refrigeration equipment.

Choice of Refrigerant

The choice of refrigerant is a very important decision in the design of refrigerated facilities. Typically, ammonia has been used, particularly in the food and beverage industries, but R-22 has been and is used, as well. Some low-temperature facilities now also use R-507A or R-404A, which are replacements of choice for R-502 and R-22. Factors to consider when choosing refrigerants include

- Cost
- Safety code issues, (e.g., code requirements regarding the use of refrigerant in certain types of occupied spaces)
- System refrigerant charge requirements [e.g., charges above 10,000 lb of NH_3 may require government-mandated process safety management (PSM) and risk management plan (RMP)]
- State and local codes, which may require full- or part-time operators with a specific level of expertise
- Effects on global warming and ozone depletion (ammonia has no effect on either)

Load Determination

Loads for refrigerated facilities of the same capacity vary widely. Many factors, including building design, indoor and outdoor temperatures, and especially the type and flow of goods expected and the daily freezing capacity, contribute to the load. Therefore, no simple design rules apply. Experience from comparable buildings and operations is valuable, but any projected operation should be analyzed. Compressor and room cooling equipment should be designed for maximum daily requirements, which will be well above any monthly average.

Load factors to be considered include

- Heat transmission through insulated enclosures
- Heat and vapor infiltration load from warm air passing into refrigerated space and improper air balance
- Heat from pumps or fans circulating refrigerant or air, power equipment, personnel working in refrigerated space, product-moving equipment, and lights
- Heat removed from goods in lowering their temperatures from receiving to storage temperatures
- Heat removed in freezing goods received unfrozen
- Heat produced by goods in storage
- Other loads, such as office air conditioning, car precooling, or special operations inside the building
- Refrigerated shipping docks
- Heat released from automatic defrost units by fan motors and defrosting, which increases overall refrigerant system requirements
- Blast freezing or process freezing

High humidity, warm temperatures, or manual product handling may dramatically affect design, particularly that of the refrigeration system.

A summation of the average proportional effect of the load factors is shown in Table 1 as a percentage of total load for a facility in the southern United States. Both the size and the effect of the load factors are influenced by the facility design, usage, and location.

Heat leakage or transmission load can be calculated using the known overall heat transfer coefficient of various portions of the insulating envelope, the area of each portion, and the temperature difference between the lowest cold-room design temperature and highest average air temperature for three to five consecutive days at the building location. For freezer storage floors on ground, the average yearly ground temperature should be used.

Heat infiltration load varies greatly with the size of room, number of openings to warm areas, protection on openings, traffic through openings, and cold and warm air temperatures and humidities. Calculation should be based on experience, remembering that most of the load usually occurs during daytime operations. Chapter 13 presents a complete analysis of refrigeration load calculation.

Heat from goods received for storage can be approximated from the quantity expected daily and the source. Generally, 10 to 20°F of temperature reduction can be expected, but for some newly processed items and for fruits and vegetables direct from harvesting, 60°F or more temperature reduction may be required. For general public cold storage, the load may range from 4 to 8 tons of cooling capacity per million cubic feet to allow for items received direct from harvest in a producing area.

Table 1 Refrigeration Design Load Factors for Typical 100,000 ft^2 Single-Floor Freezer*

Refrigeration Load Factors	Long-Term Storage Cooling Capacity Tons	%	Short-Term Storage Cooling Capacity Tons	%	Distribution Operation Cooling Capacity Tons	%
Transmission losses	98	49	98	43	98	36
Infiltration	10	5	20	9	40	15
Internal operation loads	50	25	56	24	62	22
Cooling of goods received	7	3	15	6	30	11
Other factors	35	18	41	18	45	16
Total design capacity	200	100	230	100	275	100

Note: Based on a facility located in the southern United States using a refrigerated loading dock, automatic doors, and forklift material handling.

*See Chapter 13.

The freezing load varies from zero for the pure distribution facility, where the product is received already frozen, to the majority of the total for a warehouse near a producing area. The freezing load depends on the commodity, the temperature at which it is received, and method of freezing. More refrigeration is required for blast freezing than for still freezing without forced-air circulation.

Heat is produced by many commodities in cooler storage, principally fruits and vegetables. Heat of respiration is a sizable factor, even at 32°F, and is a continuing load throughout the storage period. Refrigeration loads should be calculated for maximum expected occupancy of such commodities.

Manual handling of product may add 30 to 50% more load to a facility in tropical areas due to constant interruption of the cold barriers at doors and on loading docks.

Unit Cooler Selection

Fan-Coil Units. These units may have direct-expansion, flooded, or recirculating liquid evaporators with either primary or finned-coil surfaces or a brine spray coolant. Storage temperature, packaging method, type of product, etc., must be considered when selecting a unit. Coil surface area, temperature difference between the refrigerant coil and the return air, and volumetric airflow depend on the application. Brine spray systems circulate a chemical mixture and water over the coil by spraying onto the coil upstream on the air side of the coil, to prevent frost formation on the coil. Filtration and other brine conditioning equipment are located outside of controlled-temperature areas. The sprayed brine is not a salt-water brine but rather a water-based glycol solution. Manufacturers claim these units can reduce microbial levels to help protect product from contamination. The units work well if they are maintained, but can be more expensive to purchase and operate and require additional room (for the regeneration equipment). They do not add defrost heat to the room and can often be placed above doorways to remove moisture in troublesome facilities to keep infiltration down to tolerable levels. Failure to maintain units can lead to contamination from dust, odor, and biological pollutants.

Fans are normally of the axial propeller type, but may be centrifugal if a high static discharge loss is expected. In refrigerated facilities, fan-coil units are usually draw-through (i.e., room air is drawn through the coil and discharged through the fan). Blow-through units are used in special applications, such as fruit storages, where refrigerant and air temperatures must be close. Heat from the motor is absorbed immediately by the coil on a blow-through unit and does not enter the room. Motor heat must be

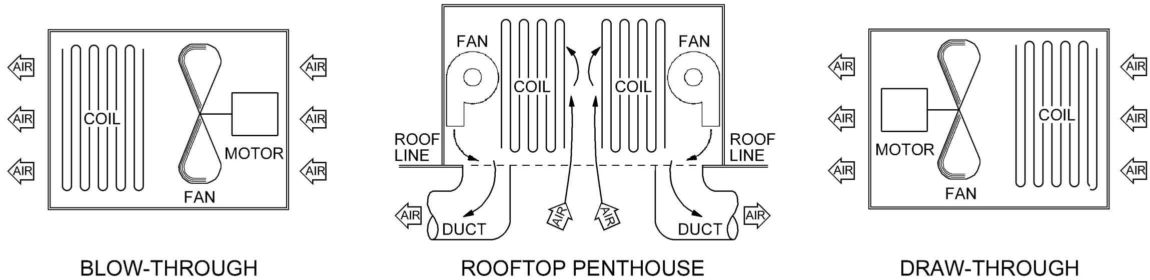

Fig. 6 Typical Fan-Coil Unit Configurations for Refrigerated Facilities

added to the room load with both draw-through and blow-through units. Figure 6 illustrates fan-coil units commonly used in refrigerated facility construction.

When selecting fan-coil units, consider the throw, or distance air must travel to cool the farthest area. Failure to properly consider throw and unit location can result in areas of stagnant air and hot spots in the refrigerated space (Crawford et al. 1992). Consult manufacturers' recommendations in all cases. Do not rely on guesses or rules of thumb to select units with proper airflow. Units vary widely in fan type, design of the diffuser leaving the fan-coil, and coil air pressure drop.

Defrosting. All fan-coils normally operate below room dew-point conditions. Fan coils operating below approximately 38°F will require some defrosting. Common methods of defrost in rooms 36°F and above include

- Air defrost
- Hot-gas defrost
- Electric defrost
- Water defrost

Rooms colder than 36°F normally use

- Hot-gas defrost
- Electric defrost

Units located above entrances to a refrigerated space tend to draw in warm, moist air from adjacent spaces and frost the coil quickly. If this occurs, more frequent defrosting is required to maintain the efficiency of the cooling coil. When the coil approach line crosses into the supersaturated region, a particularly unfavorable frost almost immediately clogs the coil, very rapidly decreasing performance (Sherif et al. 2001). Cleland and O'Hagan (2003) developed criteria to estimate when this will occur, providing a way to avoid this problem through redesign of the coil and/or the facility (e.g., so the load has a higher sensible heat ratio).

A properly engineered and installed system can be automatically defrosted successfully with hot gas, desiccant dehumidifier, water, electric heat, or continuously sprayed brine. The sprayed-brine system has the advantage of producing the full refrigeration capacity at all times; however, it does require a supply and return pipe system with a means of boiling off the absorbed condensed moisture, and can be subject to contamination with odors, biological pollution, or airborne dust.

Condensate Drains. When coils defrost, condensate that has formed as ice or frost on the coils melts. This new condensate collects in a pan beneath the coil and flows into collection drains outside of the freezer space. Because the space is cold, condensate pans are connected to the hot-gas defrost system or otherwise heated to prevent ice formation. Likewise, all condensate drain lines must be wrapped in heat-tracing tape and trapped outside of the refrigerated space to ensure that condensate can drain unrestricted.

Valve Selection. Refer to Chapter 44 and manufacturers' literature for specific information on control valve type and selection (sizing).

Valving Arrangements. Proper refrigerant feed valve, block valve, and defrosting valve arrangements are critical to the performance of all fan-coil units.

Various valve piping schemes are used. See Chapter 3 for typical piping arrangements.

Valve Location. Good valve location ensures convenient maintenance of control and service block valves. The owner/designer has some options in most plants. If penthouse units are used, all valves are generally located outside the penthouse and are accessible from the roof. Fan-coil units mounted in the refrigerated space are generally hung from the ceiling and must be accessed via personnel lift cage on a forklift or other service vehicle. It is recommended that valve stations be located outside the freezer storage area if possible to ensure that refrigerant leaks do not enter storage areas and also to facilitate maintenance.

System Considerations. For refrigerated temperatures below –25°F, two-stage compression is generally used. Compound compressors having capacity control on each stage may be used. For variable loads, separate high- and low-stage (or booster) compressors, each with capacity control or of different capacities, may provide better operation. Depending on the degree of capacity redundancy desired, two or more compressors can be selected at each suction temperature level. This also permits shutting one or more compressors down during colder months when load is reduced. Redundancy can also be provided on many systems by cross-connecting the piping such that a nonoperating high-stage compressor can also be run as a temporary low-stage single-stage compressor in case a booster compressor is down. Other combinations of cross connection are possible. If blast freezers are included, pipe connections should be arranged so that sufficient booster capacity for the blast freezers can be provided by the low-stage suction pressure compressor, while the other booster is at higher suction pressure for the freezer room load. Interstage pressure and temperatures are usually selected to provide refrigeration for loading dock cooling and for rooms above 32°F.

In a two-stage system, liquid refrigerant should be precooled at the high-stage suction pressure (interstage) to reduce the low-stage load. An automatic purger to remove air and other noncondensable gases is essential. Almost all compressors used in the refrigeration industry for facility designs use oil for lubrication. All these compressors lose a certain amount of oil from the compressor unit into the condenser and the low side of the system. Both halocarbon and ammonia plants should have means of recovering oil from all low-side vessels and heat exchangers where oil tends to accumulate. This includes low-pressure receivers, suction accumulators, pumper drums, shell and tube evaporators, surge tanks on gravity recirculation systems, intercoolers, subcoolers, and economizers. The compressor should have a good discharge oil separator. The means of recovering oil are different for halocarbons and ammonia. Oil is usually recovered from ammonia systems manually and then discarded, whereas oil can be recovered manually or automatically from halocarbon systems and is usually reused in the system. Refer to Chapters 1 to 7 in this volume for more information. Oil logs should be kept to record both the amount of oil added to the system and the amount of oil removed.

Use of commercial, air-cooled condenser, packaged halocarbon refrigerant, or factory preassembled units is common, especially in smaller plants. These units have lower initial cost, smaller space requirements, and no need for a special machinery room or operating engineer. However, they use more energy, have higher operating and maintenance costs, and have a shorter life expectancy for components (usually compressors) than central refrigeration systems.

Multiple Installations. To distribute air without ductwork, installations of multiple fan-coil units have been used. For single-story buildings, air-handling units installed in penthouses with ducted or nonducted air distribution arrangements have been used to make full use of floor space in the storage area (Figure 7). Either prefabricated or field-erected refrigeration systems or cooling units connected to a central plant can be incorporated in penthouse design.

Unitary cooling units are located in a penthouse, with distributing ductwork projected through the penthouse floor and under the insulated ceiling below. Return air passes up through the penthouse floor grille. This system avoids the interference of fan-coil units hung below the ceiling in the refrigerated chamber and facilitates maintenance access.

Condensate drain piping passes through the penthouse insulated walls and onto the main storage roof. Refrigerant mains and electrical conduit can be run over the roof on suitable supports to the central compressor room or to packaged refrigeration units on the adjacent roof. Thermostats and electrical equipment can be housed in the penthouse.

A personnel access door to the penthouse is required for convenient equipment service. The inside insulated penthouse walls and ceiling must be vaportight to keep condensation from deteriorating the insulation and to maintain the integrity of the building vapor retarder. Some primary advantages of penthouses are

- Cooling units, catwalks, and piping do not interfere with product storage space and are not subject to physical damage from stacking truck operations.
- Service to all cooling equipment and controls can be handled by one individual from a grated floor or roof deck location.
- Maintenance and service costs are minimized.
- Main piping, control devices, and block valves are located outside the refrigerated space.
- If control and block valves are located outside the penthouse, any refrigerant leaks will occur outside the refrigerated space.

Freezers

Freezers within refrigerated facilities are generally used to freeze products or to chill products from some higher temperature to storage temperature. Failure to properly cool the incoming product transfers the product cooldown load to the facility, greatly increasing facility operating costs. Of perhaps greater concern is that dormant storage in a cold area may not cool the product fast enough to prevent bacterial growth, which causes product deterioration. In addition, other stored, already frozen products may be affected by localized warming.

For this reason, many refrigerated facilities have a **blast freezer** that producers can contract to use. Blast freezing ensures that the products are properly frozen in minimum time before they are put into storage and that their quality is maintained. Modern control systems allow sampling of inner core product temperatures and printout of records that customers may require. The cost of blast freezer service can be properly apportioned to its users, allowing higher efficiency and lower cost for other cold-storage customers.

Although there are many types of freezers, including belt, tray, contact plate, spiral, and other packaged types, the most common arrangement used in refrigerated facilities is designed to accept pallets of products from a forklift. The freezing area is large and free from obstructions, and has large doors. See Chapter 16 for more information on freezing systems.

Figure 8 illustrates a typical blast freezer used in a refrigerated facility. Air temperatures are normally about −30°F, but may be higher or lower, depending upon the product being frozen. Once the room is filled to design capacity, it is sealed and the system is started. The refrigeration process time can be controlled by a time clock, by manual termination, or by measuring internal product temperature and stopping the process once the control temperature is reached. The last method gives optimum performance. Once the product is frozen, the pallets are transferred to general refrigerated storage areas.

Because the blast freezer normally operates intermittently, freezer owners should try to operate it during the times when energy cost is lowest. Unfortunately, food products must be frozen as quickly as possible, and products are usually delivered during times of peak electrical rates. Alternative power sources, such as natural gas engines or diesel drives, should be considered. Although these normally have first cost and maintenance cost premiums, they are not subject to time-varying energy rates and may offer savings.

Defrost techniques for blast freezers are similar to normal defrost methods for refrigerated facility fan-coil units. Coils can often be defrosted after the product cooling cycle is completed or while the freezer is being emptied for the next load.

Pumped refrigerant recycling systems and flooded surge drum coils have both been used with success. Direct-expansion coils may be used, but the designer should be careful with expansion valve systems to address coil circuitry, refrigerant liquid overfeed, oil return,

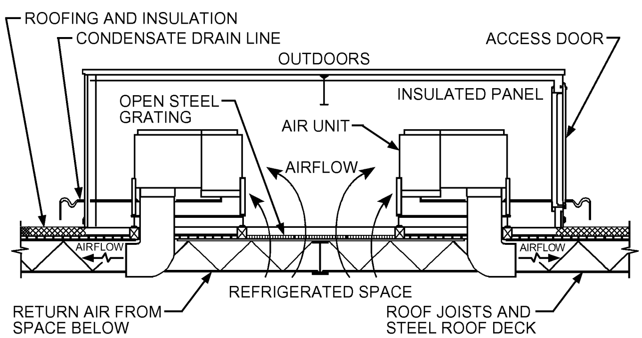

Fig. 7 Penthouse Cooling Units

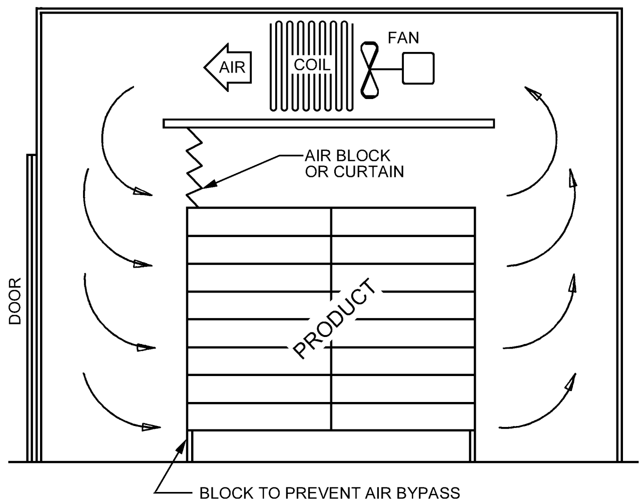

Fig. 8 Typical Blast Freezer

defrost, shutdown liquid inventory management, and so forth. Conventional oil removal devices should be supplied on flooded coil and pumped systems, because the blast freezer is normally the lowest-temperature system in the facility and may accumulate oil over time. Materials of construction for systems operating below –20°F and subject to ASME code conformance should comply with the latest ASME *Standard* B31.5. See Chapter 40 for further information on low-temperature materials. Floor heating may be convenient if products are damp or wet during loading.

Most blast freezers are accessed from a refrigerated space, so that products can be moved directly from the freezer to storage racks. Also, blast freezers can be used for storage when not operating.

Controls

The term *controls* refers to any mechanism or device used to start, stop, adjust, protect, or monitor the operation of a moving or functional piece of equipment. Controls for any system can be as simple as electromechanical devices such as pressure switches and timer relays or as complex as a complete digital control system with analog sensors and a high-speed communications network connected to a supervisory computer station. Because controls are required in every industry, there is a wide variety from which to choose. In recent years, the industrial refrigeration industry has moved away from the use of electromechanical devices and toward the use of specialized microprocessors, programmable logic controllers, and computers for unit and system control.

Electromechanical devices for control will continue to be used for some time and may never be replaced entirely for certain control functions (e.g., use of relays for electrical high current isolation and float switches for refrigerant high level shutdowns). See Chapter 44 for more information.

Microprocessor controls and electronic sensors generally offer the following advantages over electromechanical control:

- More accurate readings and therefore more accurate control
- Easier operation
- Greater flexibility through adjustable set points and operating parameters
- More information concerning operating conditions, alarms, failures, and troubleshooting
- Capability for interfacing with remote operator stations

There are four main areas of control in all refrigerated facility systems with a central compressor room:

- **Compressor package control.** Minimum requirements: orderly start-up, orderly shutdown, capacity control to maintain suction pressure, alarm monitoring, and safety shutdown.
- **Condenser control.** Minimum requirements: fan and water pump start and stop to maintain a reasonable constant or floating refrigerant discharge pressure.
- **Evaporator control.** Minimum requirements: control of air unit fans and refrigerant liquid feed to maintain room air temperatures and staging of air unit refrigerant valve stations to provide automatic coil defrosts.
- **Refrigerant flow management.** Minimum requirements: maintenance of desired refrigerant levels in vessels, control of valves and pumps to transfer refrigerant as needed between vessels and air units in the system, and proper shutdowns in the event of refrigerant overfeed or underfeed.

Other areas of control, such as refrigerant leak detection and alarm, sequencing of multiple compressors for energy efficiency, and underfloor warming system control, may be desired.

Because of the wide variety and fast-changing capabilities of control components and systems available, it is impossible to define or recommend an absolute component list. However, it is possible to provide guidelines for the design and layout of the overall control system, regardless of the components used or the functions to be controlled. This design or general layout can be termed a control system architecture.

All control systems consist of four main building blocks:

- **Controller(s):** Microprocessor with control software
- **Input/outputs (I/Os):** Means of connecting devices or measurements to the controller
- **Operator interface(s):** Means of conveying information contained in the controller to a human being
- **Interconnecting media:** Means of transferring information between controllers, I/Os, and operator interfaces

The control system architecture defines the quantity, location, and function of these basic components. The architecture determines the reliability, expandability, operator interface opportunities, component costs, and installation costs of a control system. Therefore, the architecture should be designed before any controls component manufacturers or vendors are selected.

The following are the basic steps in designing a refrigerated facility control system:

Step 1. Define the control tasks. This step should provide a complete and detailed I/O listing, including quantity and type. With this list and a little experience and knowledge of available hardware, the type, quantity, and processing power of the necessary controllers can be determined.

Step 2. Determine physical locations of controlled devices and measurements to be taken. If remote I/Os or multiple controllers are located close to the devices and sensors, field wiring installation costs can be reduced. To avoid extra costs or impracticalities, the environments of the various locations must be compared with the environmental specifications of the hardware to be placed in them. Maintenance requirements can also affect the selection of physical location of the I/Os and controller.

Step 3. Determine control task integration requirements. Control tasks that require and share the same information (such as a discharge pressure reading for starting both a condenser fan and a condenser water pump) must be accomplished either with the same controller or with multiple controllers that share information via interconnecting media. Tasks that do not share information can be performed by separate controllers. Using multiple controllers minimizes the chance of catastrophic control failures. With multiple controllers that share information, the interconnecting media must be robust, with minimal chance of failure for critical tasks. In particular, the speed of data transfer between controllers must be suitable to maintain the control accuracy required.

Step 4. Determine operator interface requirements. This includes noting which controllers must have a local or remote interface, how many remote interface stations are required, and defining the hardware and software requirements of the interfaces.

Step 5. Select the interconnecting media between controllers and their remote I/Os, between different controllers, and between controllers and operator interfaces. The interconnecting medium to remote I/Os is typically defined by the controller manufacturer; it must be robust and high-speed, because controllers' decisions depend on real-time data. The interconnecting medium between controllers themselves is also typically defined by the controller manufacturer; speed requirements depend on the tasks being performed with the shared information. For media connecting controllers and operator interfaces, speed is typically not as critical because the control continues even if the connection fails. For the operator interface connection, speed of accessing a controller's data is not as critical as having access to all the available data from the controller.

Step 6. Evaluate the architecture for technical merit. The first five steps should produce a list of controllers, their locations, their operator interfaces, and their control tasks. Once the list is complete, the selected controllers should be evaluated for both processor memory available for programming and processor I/O capacity available for current and future requirements. The selected interconnecting media should be evaluated for distance and speed limitations. If any weaknesses are found, a different model, type, or even manufacturer of the component should be selected.

Step 7. Evaluate the architecture for software availability. The best microprocessor is of little good if no software exists to make it operate. It must be ascertained that software exists or can easily be written to provide (1) information transfer between controllers and operator interfaces; (2) the programming functions needed to perform the control tasks; and (3) desired operator interface capabilities such as graphics, historical data, reports, and alarm management. Untested or proprietary software should be avoided.

Step 8. Evaluate the architecture for failure conditions. Determine how the system will operate with a failure of each controller. If the failure of a particular controller would be catastrophic, more controllers can be used to further distribute the control tasks, or electromechanical components can be added to allow manual completion of the tasks. For complex tasks that are impossible to control manually, it is essential that spare or backup control hardware be in stock and that operators be trained in the troubleshooting and reinstallation of control hardware and software.

Step 9. Evaluate the proposed architecture for cost, including field wiring, components, start-up, training, downtime, and maintenance costs. All these costs must be considered together for a fair and proper evaluation. If budgets are exceeded, then Steps 1 through 8 must be repeated, removing any nonessential control tasks and reducing the quantity of controllers, I/Os, and operator interfaces.

Once the control system architecture is designed, specifics of software operation should be determined. This includes items such as set points necessary for a control task, control algorithms and calculations used to determine output responses, graphic screen layouts, report layouts, alarm message wording, and so forth. More detail is necessary, but excessive time spent determining the details of software operation may be better applied to further definition and refinement of the system architecture. If the system architecture is solid, the software can always be modified as needed. With improper architecture, functional additions or corrections can be costly, time consuming, and sometimes impossible.

For more information on controls and their design and application, see Chapter 15 of the 2005 *ASHRAE Handbook—Fundamentals* and Chapters 41 and 46 of the 2003 *ASHRAE Handbook—HVAC Applications*.

INSULATION TECHNIQUES

The two main functions of an insulation envelope are to reduce the refrigeration requirements for the refrigerated space and to prevent condensation. See Chapter 33 for further information.

Vapor Retarder System

The primary concern in the design of a low-temperature facility is the vapor retarder system, which should be as close to 100% effective as is practical. The success or failure of an insulation envelope is due entirely to the effectiveness of the vapor retarder system in preventing water vapor transmission into and through the insulation.

The driving force behind water vapor transmission is the difference in vapor pressure across the vapor retarder. Once water vapor passes a vapor retarder, a series of detrimental events begins. Water migrating into the insulation may condense or solidify, which diminishes the thermal resistance of the insulation and eventually destroys the envelope. Ice formation inside the envelope system usually grows and physically forces the building elements apart to the point of failure.

Another practical function of the vapor retarder is to stop air infiltration, which can be driven by atmospheric pressure or ventilation.

After condensing or freezing, some water vapor in the insulation revaporizes or sublimes and is eventually drawn to the refrigeration coil and disposed of by the condensate drain, but the amount removed is usually not sufficient to dry out the insulation unless the vapor retarder break is located and corrected.

The vapor retarder must be located on the warm side of the insulation. Each building element inside the prime retarder must be more permeable than the last to permit moisture to move through it, or it becomes a site of condensation or ice. This precept is abandoned for the sake of sanitation at the inside faces of coolers. However, the inside faces of freezers are usually permitted to breathe by leaving the joints uncaulked in panel construction, or by using less permeable surfaces for other forms of construction. Factory-assembled insulation panels endure this double vapor retarder problem better than other types of construction.

In walls with insufficient insulation, the temperature at the inside wall surface may, during certain periods, reach the dew point of the migrating water vapor, causing condensation and freezing. This can also happen to a wall that originally had adequate insulation but, through condensation or ice formation in the insulation, lost part of its insulating value. In either case, ice deposited on the wall gradually pushes the insulation and protective covering away from the wall until the insulation structure collapses.

It is extremely important to properly install vapor retarders and seal joints in the vapor retarder material to ensure continuity from one surface to another (i.e., wall to roof, wall to floor, or wall to ceiling). Failure of vapor retarder systems for refrigerated facilities is almost always caused by poor installation. The contractor must be experienced in installation of vapor retarder systems to be able to execute a vaportight system.

Condensation on the inside of the cooler is unacceptable because (1) the wet surface provides a culture base for bacterial growth, and (2) any dripping onto the product gives cause for condemnation of the product in part or in whole.

Stagnant or dead air spots behind beams or inside metal roof decks can allow localized condensation. This moisture can be from within the cooler or freezer (i.e., not necessarily from a vapor retarder leak).

No vapor retarder system is 100% effective. A system is successful when the rate of moisture infiltration equals the rate of moisture removal by refrigeration, with no detectable condensation.

Types of Insulation

Rigid Insulation. Insulation materials, such as polystyrene, polyisocyanurate, polyurethane, and phenolic material, have proven satisfactory when installed with the proper vapor retarder and finished with materials that provide fire protection and a sanitary surface. Selection of the proper insulation material should be based primarily on the economics of the installed insulation, including the finish, sanitation, and fire protection.

Panel Insulation. Use of prefabricated insulated panels for insulated wall and roof construction is widely accepted. These panels can be assembled around the building structural frame or against masonry or precast walls. Panels can be insulated at the factory with either polystyrene or urethane. Other insulation materials do not lend themselves to panelized construction.

The basic advantage, besides economics, of using insulated panel construction is that repair and maintenance are simplified because the outer skin also serves as the vapor retarder and is accessible. This is of great benefit if the structure is to be enlarged in the future. Proper vapor retarder tie-ins then become practical.

Foam-in-Place Insulation. This application method has gained acceptance as a result of developments in polyurethane insulation and equipment for installation. Portable blending machines with a spray or frothing nozzles feed insulation into the wall, floor, or ceiling cavities to fill without joints the space provided for monolithic insulation

Table 2 Recommended Insulation R-Values

Type of Facility	Temperature Range, °F	Thermal Resistance R, °F·ft²·h/Btu		
		Floors	Walls/Suspended Ceilings	Roofs
Coolers[a]	40 to 50	Perimeter insulation only[c]	25	30 to 35
Chill coolers[a]	25 to 35	20	24 to 32	35 to 40
Holding freezer	−10 to −20	27 to 32	35 to 40	45 to 50
Blast freezers[b]	−40 to −50	30 to 40	45 to 50	50 to 60

Note: Because of wide variation in cost of energy and insulation materials based on thermal performance, a recommended R-value is given as a guide in each area of construction. For more exact values, consult a designer and/or insulation supplier.
[a]If a cooler may be converted to a freezer in the future, the owner should consider insulating the facility with higher R-values from the freezer section.
[b]R-values shown are for a blast freezer built within an unconditioned space. If the blast freezer is built within a cooler or freezer, consult a designer and/or insulation supplier.
[c]If high room relative humidity is desired, then floor insulation at least equal to that in the walls is recommended.

construction. This material does not provide significant vapor resistance; its application in floor construction should be limited.

Precast Concrete Insulation Panels. This specialized form of construction has been successful when proper vapor retarder and other specialized elements are incorporated. As always, vapor retarder continuity is the key to a successful installation.

Insulation Thickness

The R-value of insulation required varies with the temperature held in the refrigerated space and the conditions surrounding the room. Table 2 shows recommended R-values for different types of facilities. The range in R-values is due to variations in energy cost, insulation materials, and climatic conditions. For more exact values, consult a designer and/or insulation supplier. Insulation with R-values lower than those shown should not be used.

APPLYING INSULATION

The method and materials used to insulate roofs, ceilings, walls, floors, and doors need careful consideration.

Roofs

The suspended ceiling method of construction is preferred for attaining a complete thermal and vapor envelope. Insulating materials may be placed on the roof or floor above the refrigerated space rather than adhered to the structural ceiling. If this type of construction is not feasible, and the insulation must be installed under a concrete or other ceiling, then the vapor retarder, insulation, and finish materials should be mechanically supported from the structure above rather than relying on adhesive application only. Suspending a wood or metal deck from the roof structure and applying insulation and a vapor retarder to the top of the deck is another method of hanging ceiling insulation. Skill of application and attention to positive air and vapor seals are essential to continued effectiveness.

Suspended insulated ceilings, whether built-up or prefabricated, should be adequately ventilated to maintain near-ambient conditions in the plenum space; this minimizes both condensation and deterioration of vapor retarder materials (see the section on Suspended Ceilings). Permanent sealing is needed around insulating hanger rods, columns, conduit, and other penetrations.

The structural designer usually includes roofing expansion joints when installing insulation on top of metal decking or concrete structural slabs for a building larger than 100 by 100 ft. Because the refrigerated space is not normally subject to temperature variations, structural framing is usually designed without expansion or contraction joints if it is entirely enclosed within the insulation envelope. Board insulation laid on metal decking should be installed in two or more layers with the seams staggered. An examination of the coefficients of linear expansion for typical roof construction materials illustrates the need for careful attention to this phase of the building design.

Although asphalt built-up roofs have been used, loosely laid membrane roofing has become popular and requires little maintenance.

Walls

Wall construction must be designed so that as few structural members as possible penetrate the insulation envelope. Insulated panels applied to the outside of the structural frame prevent conduction through the framing. Where masonry or concrete wall construction is used, structural framing must be independent of the exterior wall. The exterior wall cannot be used as a bearing wall unless a suspended insulated ceiling is used.

Where interior insulated partitions are required, a double-column arrangement at the partition prevents structural members from penetrating the wall insulation. For satisfactory operation and long life of the insulation structure, envelope construction should be used wherever possible.

Governing codes for fire prevention and sanitation must be followed in selecting a finish or panel. For conventional insulation materials other than prefabricated panels, a vapor retarder system should be selected.

Abrasion-resistant membranes, such as 10 mil thick black polyethylene film with a minimum of joints, are suitable vapor retarders. Rigid insulation can then be installed dry and finished with plaster or sheet finishes, as the specific facility requires. In refrigerated facilities, contraction of the interior finish is of more concern than expansion because temperatures are usually held far below installation ambient temperatures.

Floors

Freezer buildings have been constructed without floor insulation, and some operate without difficulty. However, the possibility of failure is so great that this practice is seldom recommended.

Underfloor ice formation, which causes heaving of floors and columns, can be prevented by heating the soil or fill under the insulation. Heating can be by air ducts, electric heating elements, or pipes through which a liquid is recirculated (see the section on Floor Construction).

The air duct system works well for smaller storages. For a larger storage, it should be supplemented with fans and a source of heat if the pipe is more than 100 ft long. The end openings should be screened to keep out rodents, insects, and any material that might close off the air passages. The ducts must be sloped for drainage to remove condensed moisture. Perforated pipes should not be used.

The electrical system is simple to install and maintain if the heating elements are run in conduit or pipe so they can be replaced; however, operating costs may be very high. Adequate insulation should be used because it directly influences energy consumption.

The pipe grid system, shown in Figure 9, is usually best because it can be designed and installed to warm where needed and can later be regulated to suit varying conditions. Extensions of this system can be placed in vestibules and corridors to reduce ice and wetness on floors. The underfloor pipe grid also facilitates future expansion. A heat exchanger in the refrigeration system, steam, or gas engine exhaust can provide a source of heat for this system. The temperature of the recirculated fluid is controlled at 50 to 70°F, depending on design requirements. Almost universally, the pipes are made of plastic.

The pipe grid system is usually placed in the base concrete slab directly under the insulation. If the pipe is metal, a vapor retarder should be placed below the pipe to prevent corrosion. The fluid should be an antifreeze solution such as propylene glycol with the proper inhibitor.

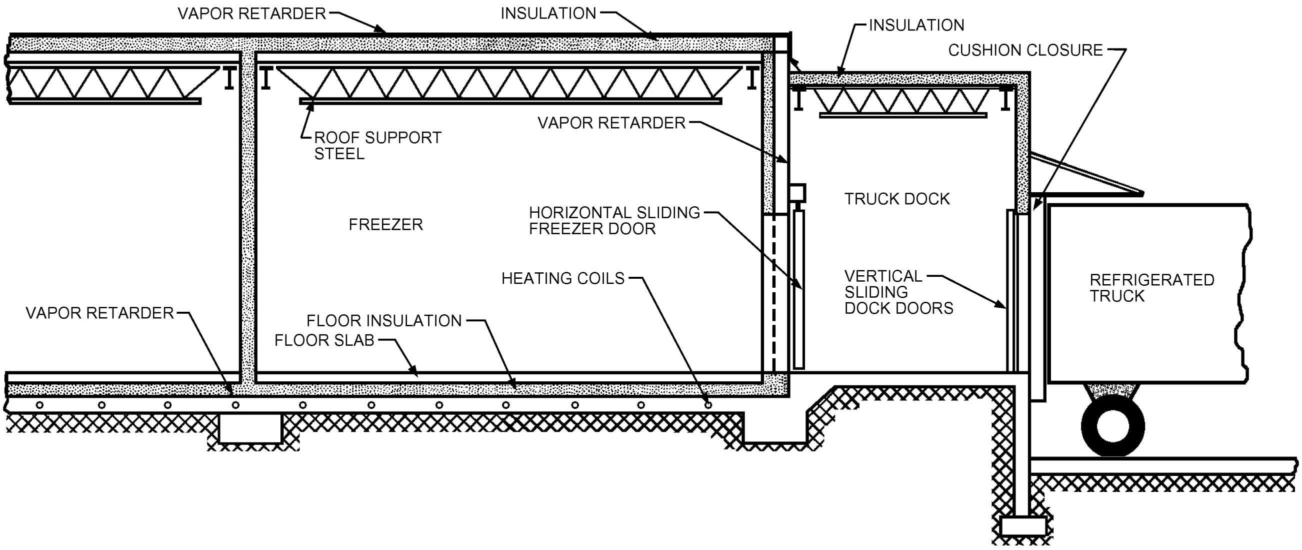

Fig. 9 Typical One-Story Construction with Underfloor Warming Pipes

The amount of warming for any system can be calculated and is about the same for medium-sized and large refrigerated spaces regardless of ambient conditions. The calculated heat input requirement is the floor insulation leakage based on the temperature difference between the 40°F underfloor earth and room temperature (e.g., 50°F temperature difference for a –10°F storage room). The flow of heat from the earth, about 1.3 Btu/h per square foot of floor, serves as a safety factor.

Freezer Doorways

An important factor in warehouse productivity is maintaining safe working conditions at doorways in high-usage freezers. At doorways, infiltration air mixes with air inside the freezer, forming airborne ice crystals. These crystals can accumulate on walls, ceilings, and nearby appurtenances, and can cause icy conditions on the floor. Consequences include danger to pedestrians, damage from skidding vehicles, premature frost clogging of nearby evaporators, and decreased productivity.

A **freezer vestibule** is any small room or airlock device with properly designed air curtains that impose little restriction on traffic flow but still counter adverse effects by reducing outside air infiltration.

Electrically heated traffic doors effectively eliminate doorway frost and ice.

Whether freezer vestibules or electrically heated doors are used, to calculate loads properly, see the section on Infiltration Air Load in Chapter 13, for door-open time per doorway pass-through and for time required to reach fully established flow upon each door opening.

Doors

The selection and application of cold-storage doors are a fundamental part of cold-storage facility design and have a strong bearing on the overall economy of facility operation. The trend is to have fewer and better doors. Manufacturers offer many types of doors supplied with the proper thickness of insulation for the intended use. Four basic types of doors are swinging, horizontal sliding, vertical sliding, and double-acting. Door manufacturers' catalogs give detailed illustrations of each. Doors used only for personnel cause few problems. In general, a standard swinging personnel door, 3 ft wide by 6.5 ft high and designed for the temperature and humidity involved, is adequate.

The proper door for heavy traffic areas should provide maximum traffic capacity with minimum loss of refrigeration and require minimum maintenance.

The following are factors to consider when selecting cold storage doors:

- Automatic doors are a primary requirement with forklift and automatic conveyor material-handling systems.
- Careless forklift operators are a hazard to door operation and effectiveness. Guards can be installed but are effective only when the door is open. Photoelectric and ultrasonic beams across the doorway or proximity loop control on both sides of the doorway can provide additional protection by monitoring objects in the door openings or approaches. These systems can also control door opening and closing.
- Selection of automatic door systems to suit traffic requirements and building structure may require experienced technical guidance.
- To ensure continuous door performance, the work area near the doors must be supervised, and the doors must have planned maintenance.
- Cooled or refrigerated shipping platforms increase door efficiency and reduce door maintenance, because the humidity and temperature difference across the doorway is lower. Icing of the door is lessened, and fogging in traffic ways is reduced.

Biparting and Other Doors. Air curtains, plastic or rubber strip curtains, and biparting doors give varied effectiveness. Strip curtains are not accepted by USDA standards if open product moves through the doorway. Often, the curtain seems to the forklift driver to be a substitute for the door, so the door is left open with a concurrent loss of refrigerated air. Quick-operating powered doors of fabric or rigid plastic are beneficial for draft control.

Swinging and Sliding Doors. A door with hinges on the right edge (when observed from the side on which the operating hardware is mounted) is called a right-hand swing. A door that slides to the right to open (when observed from the side of the wall on which it is mounted) is called a right-slide door.

Vertical Sliding Doors. These doors, which are hand- or motor-operated with counterbalanced springs or weights, are used on truck receiving and shipping docks.

Refrigerated-Room Doors. Doors for pallet material handling are usually automatic horizontal sliding doors, either single-slide or biparting.

Metal or Plastic Cladding. Light metal cladding or a reinforced plastic skin protects most doors. Areas of abuse must be further protected by heavy metal, either partial or full-height.

Heat. To prevent ice formation and resultant faulty door operation, doors are available with automatic electric heat, not only in the sides, head, and sill of the door or door frame, but also in switches and cover hoods of power-operated units. Such heating elements are necessary on all four edges of double-acting doors in low-temperature rooms. Safe devices that meet electrical codes must be used.

Bumpers and Guard Posts. Power-operated doors require protection from abuse. Bumpers embedded in the floor on both sides of the wall and on each side of the passageway help preserve the life of the door. Correctly placed guard posts protect sliding doors from traffic damage.

Buck and Anchorage. Effective door operation is impossible without good buck and anchorage provisions. Recommendations of the door manufacturers should be coordinated with wall construction.

Door Location. Doors should be located to accommodate safe and economical material handling. Irregular aisles and blind spots in trafficways near doors should be avoided.

Door Size. A hinged insulated door opening should provide at least 1 ft clearance on both sides of a pallet. Thus, 6 ft should be the minimum door width for a 4 ft wide pallet load. Double-acting doors should be 8 ft wide. Specific conditions at a particular doorway can require variations from this recommendation. A standard height of 10 ft accommodates all high-stacking forklifts.

Sill. A concrete sill minimizes the rise at the door sill. A thermal break should be provided in the floor slab at or near the plane of the front of the wall.

Power Doors. Horizontal sliding doors are standard when electric operation is provided. The two-leaf biparting unit keeps opening and closing time to a minimum, and the door is out of the way and protected from damage when open. Also, because leading edges of both leaves have safety edges, personnel, doors, trucks, and product are protected. A pull cord is used for opening, and a time-delay relay, proximity-loop control, or photoelectric cell controls closing. Potential for major door damage may be reduced by proper location of pull-cord switches. Doors must be protected from moisture and frost with heat or baffles. Preferably, low-moisture air should be introduced near door areas. Automatic doors should have a preventive maintenance program to check gaskets, door alignment, electrical switches, safety edges, and heating circuits. Safety releases on locking devices are necessary to prevent entrapment of personnel.

Fire-Rated Doors. Available in both swinging and sliding types, fire-rated doors are also insulated. Refrigerated buildings have increased in size, and their contents have increased in value, so insurance companies and fire authorities are requiring fire walls and doors.

Large Door Openings. Door openings that can accommodate forklifts with high masts, two-pallet-high loads, and tractor-drawn trailers are large enough to cause appreciable loss of refrigeration. Infiltration of moisture is objectionable because it forms as condensate or frost on stacked merchandise and within the building structure. Door heights up to 10 or 12 ft are frequently required, especially where drive-through racks are used. Refrigeration loss and infiltration of moisture can be particularly serious when doors are located in opposite walls of a refrigerated space and cross flow of air is possible. It is important to reduce infiltration with enclosed refrigerated loading docks and, in some instances, with one-way traffic vestibules.

OTHER CONSIDERATIONS

Temperature Pulldown

Because of the low temperatures in freezer facilities, contraction of structural members in these spaces will be substantially greater than in any surrounding ambient or cooler facilities. Therefore, contraction joints must be properly designed to prevent structural damage during facility pulldown.

The first stage of temperature reduction should be from ambient down to 35°F at whatever rate of reduction the refrigeration system can achieve.

The room should then be held at that temperature until it is dry. Finishes are especially subject to damage when temperatures are lowered too rapidly. Portland cement plaster should be fully cured before the room is refrigerated.

If there is a possibility that the room is airtight (most likely for small rooms, 20 by 20 ft maximum), swinging doors should be partially open during pulldown to relieve the internal vacuum caused by the cooling of the air, or vents should be provided. Permanent air relief vents are needed for continual operation of defrosts in small rooms with only swinging doors. Both conditions of possible air heating during defrost and cooling should be considered in design of air vents and reliefs.

The concrete slab will contract during pulldown, causing slab/wall joints, contraction joints, and other construction joints to open. At the end of the holding period (i.e., at 35°F), any necessary caulking should be done.

An average time for drying is 72 h. However, there are indicators that may be used, such as watching the rate of frost formation on the coils or measuring the rate of moisture removal by capturing the condensation during defrost.

After the refrigerated room is dry, the temperature can then be reduced again at whatever rate the refrigeration equipment can achieve until the operating temperature is reached. Rates of 10°F per day have been used in the past, but if care has been taken to remove all the construction moisture in the previous steps, faster rates are possible without damage.

Material-Handling Equipment

Both private and public refrigerated facilities can house high-volume, year-round operations with fast-moving order pick areas backed by in-transit bulk storage. Distribution facilities may carry 300 to 3000 items or as many as 30,000 lots. Palletized loads stored either in bulk or on racks are transported by forklifts or high-rise storage/retrieval machines in a 0 to −20°F environment. Standard battery-driven forklifts that can lift up to 25 ft can service one-deep, two-deep reach-in, drive-in, drive-through, or gravity flow storage racks. Special forklifts can lift up to 60 ft.

Automated storage/retrieval machines make better use of storage volume, require fewer personnel, and reduce the refrigeration load because the facility requires less roof and floor area. This equipment operates in a height range of 23 to 100 ft to service one-deep, two-deep reach-in, two- to twelve-deep roll pin, or gravity flow pallet storage racks. Computers and bar code identification allow a system to automatically control the retrieval, transfer, and delivery of products. In addition, these systems can record product location and inventory and load several delivery trucks simultaneously from one order pick conveyor and sorting device.

A refrigerated plant may have two or more material-handling systems if the storage area contains fast- and slow-moving reserve storage, plus slow-moving order pick. Fast-moving items may be delivered and order-picked by a conventional forklift pallet operation with up to 30 ft stacking heights. In the fast-moving order pick section, the storage room internal height is raised to accommodate storage/retrieval machines; reserve pallet storage; order pick slots; multilevel palletizing; and the infeed, discharge, and order pick conveyors. Mezzanines may be considered to provide maximum access to the order pick slots. Intermediate-level fire protection sprinklers may be required in the high rack or mezzanine areas above 14 ft high.

Fire Protection

Ordinary wet sprinkler systems can be applied to refrigerated spaces above freezing. In rooms below freezing, entering water freezes if a sprinkler head malfunctions or is mechanically damaged.

If this occurs, the affected piping must be removed. In lower-temperature spaces, a dry air or nitrogen-charged system should be selected.

Designing a dry sprinkler system operating in areas below 32°F requires special knowledge and should not be undertaken without expert guidance. Freezer storage with rack storages 30 ft high or higher may require special design, and the initial design should be shown to the insuring company.

Local regulations may require ceiling isolation smoke curtains and smoke vents near the roof in large refrigerated chambers. These features allow smoke to escape and help firefighters locate the fire. If the building does not have a sprinkler system, central reporting or warning systems are available for hazardous areas.

Inspection and Maintenance

Buildings dimensions can change because of settling, temperature change, and other factors; thus, cold-storage facilities should be inspected regularly to spot problems early, so that preventive maintenance can be performed in time to avert serious damage.

Inspection and maintenance procedures fall into two areas: basic system (floor, wall, and roof/ceiling systems); and apertures (doors, frames, and other access to cold storage rooms).

Basic System

- Stack pallets at a sufficient distance (18 in.) from walls or ceiling to permit air circulation.
- Examine walls and ceiling at random every month for frost buildup. If build-up persists, locate the break in the vapor retarder.
- For insulated ceilings below a plenum, inspect the plenum areas for possible roof leaks or condensation.
- If condensation or leaks are detected, make repairs immediately.

Apertures

- Remind personnel to close doors quickly to reduce frosting in rooms.
- Check the rollers and door travel periodically to ensure that the seal at the door edge is effective. If leaks are detected, adjust the door to restore a moisture- and airtight condition.
- Check doors and door edges to detect damage from forklifts or other traffic. Repair any damage immediately to prevent door icing or motor overload due to excessive friction.
- Lubricate doors according to the maintenance schedule from the door manufacturer to ensure free movement and complete closure.
- Periodically check seals around openings for ducts, piping, and wiring in the walls and ceiling.

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