Construction of Energy-Efficient and Moisture-Proof Cold Storage

A pre-engineered cold storage structure

By Ramesh Paranjapey
Distinguished 50-Year Member, ASHRAE

Introduction

In the September-October 2019 *Cold Chain* issue, we had published an article on load calculations for cold storages. Now, in this article, we will discuss how to build an efficient and moisture-proof cold storage so that refrigeration load is minimized with savings in capital cost as well as running cost of the refrigeration plant.

The cooling load for cold storages depends on transmission load due to heat gain from ambient temperature inside the cold storage as one of the cooling load's factors. The heat gain by transmission is again divided into sensible heat gain load due to temperature difference and latent heat gain load because of vapor pressure difference.

While calculating the transmission load, we do not consider moisture transmission load and assume that the cold storage is constructed to ensure there is no vapor or moisture transmission load. However, in actual practice if one visits, let us say ten working cold storages, he will invariably find that more than half the cold storages have moisture dripping either from ceiling, excessive coil frosting though the doors, fog formation and in extreme cases ice accumulated on the floor, clearly indicating that moisture has penetrated inside the cold room and needs to be removed.

About the Author

Ramesh Paranjpey is a mechanical engineer with an M. Tech. in refrigeration from IIT Bombay, having over 35 years' experience. He has worked in very senior positions with Kirloskar Pneumatic in Pune, Carrier Transicold in Bangalore and Singapore, and Voltas-Air International in Pune. Presently he works as a technical advisor and consultant, based out of Pune. He is a Distinguished 50-Year Member and Fellow, ASHRAE; Past President, ASHRAE W.I. Chapter; and Past President, ISHRAE Pune Chapter.

Figure 1: Moisture penetration into a cold room

The pictures in *Figure 1* show how the moisture has penetrated in the cold room and is creating problems.

Adverse Effect of Moisture Penetration Inside a Cold Storage due to Vapor Pressure Difference

Moisture leads to problems in cold storages, and it is essential to construct building with appropriate vapor barrier material, provided on the right side of the surface. Since moisture ingress is invisible, it is normally overlooked. However, it can affect the cold room performance adversely. Moisture also seeps in when doors are opened for loading or unloading the product and outside warm air containing moisture in superheated condition enters the room.

The designers of comfort air conditioning plants are normally less concerned with this moisture penetration aspect as the temperature or vapor pressure differences between outdoor and indoor are smaller as compared to cold storages, and thus, moisture penetration through structure is an insignificant issue.

The success or failure of cold storage construction and its insulation however, is dependent on the effectiveness of the vapor barrier in preventing vapor transmission through the building envelope and its insulation.

Table 1 shows moisture content and vapor pressures at various temperatures and relative humidities normally encountered in the cold storage and freezing rooms to make the point clear.

Table 1: Moisture content and vapor pressure at various temperatures

Air Temperature, C	R.H., %	Moisture Content, g/kg	Vapor Pressure, mm Hg
40 (Outside)	30	13.968	16.6262
+4 (inside)	95	6.06768	5.7965
-20 (inside)	95	0.84368	0.7358
-40 (inside)	95	0.0753	0.0915

Table 1 indicates that as we go on reducing the temperature inside a cold room, both the vapor pressure and actual moisture content (popularly known as absolute humidity) reduces and moisture penetration then becomes an important consideration due to large vapor pressure difference.

Figure 2 shows that by installing vapor barrier, the water vapor pressure drops so low on the left side of vapor barrier that it remains below the saturation pressure throughout the wall and thereby, prevents the condensation taking place in the cold room. The importance of excluding moisture can be seen from comparison.

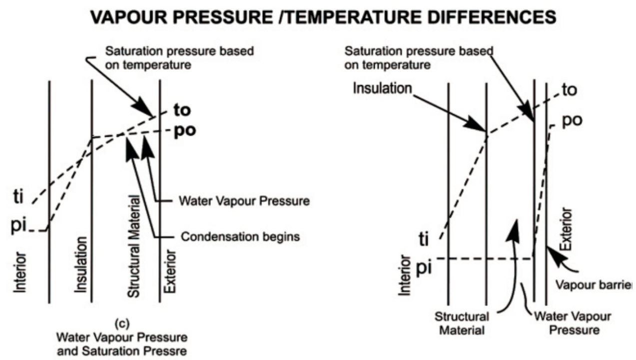


Figure 2: Installing vapor barrier

Comparison of Latent Heat and Sensible Heat Load

To cool one kg of dry air requires 1.006 kJ/kg_{da}. K energy (sensible heat)

To condense one kg of vapor requires 2500.77 kJ/kg_{da}. k energy (latent heat)

In terms of FPS units,

To cool one pound of air, one requires only 0.24 Btu, whereas to condense one pound of air requires 970 Btu (4,041 times more energy required to condense one pound of water). It is, therefore, necessary to provide a proper vapor barrier on the warmer side of the walls where the vapor pressure is higher. Similarly, the inside surface should never be made vapor tight, otherwise moisture, which has entered the insulation through the outer walls due to cracks or holes or gaps or porosity etc. will remain trapped inside and would spoil the insulation. The inside surface should, therefore, be made in such a manner that it should be allowed to breathe freely. This will ensure that any moisture present in the insulation is carried to the cooling apparatus and is then subsequently removed while defrosting the coils.

If insulation retains moisture, it also acts as a breeding ground for bacteria, fungus, etc. besides losing its insulating properties. If there is excessive moisture, it may drip on the product and cause spoilage of the product.

A properly designed vapor barrier system is one, in which rate of moisture infiltration, if at all it is taking place, should be equal to the rate of moisture removal by the refrigeration plant (air coolers) without detectable condensation on the internal surfaces of a cold room or on products.

It is strongly recommended that cold storage owners, consultants and contractors seriously consider this important aspect of providing a proper vapor barrier while designing and constructing cold rooms, failing which even a well-designed refrigeration plant may not deliver the desired performance. We shall now discuss briefly the various methods of providing vapor barriers.

Methods of Providing Vapor Barriers

Plastic Coatings or Thin Fluids

Examples of materials of this category are asphalt, bituminous emulsions and polymer resins. These types of vapor retarders are applied on the exterior surface of insulation, usually before the insulation is installed.

Sealing Sheets

Examples in this category include asphalt paper, plastic sheets, and metal films. Metal films like aluminum foil are inexpensive and excellent vapor barriers, but are difficult to install, and it is impossible to make a fool-proof seal without considerable punctures occurring. Also, if applied to walls directly, there is the possibility of corrosion as well. Polyethylene installation is comparatively easier due to the reduced number of joints and ease of overlapping and bonding wherever required. Also, polyethylene is quite stretchable before fracture occurs unlike metal foil. This characteristic is highly desirable in a cold storage vapor barrier in order to absorb building movement without rupture. It should be also noted that two thin layers of film are not as good as one thick layer since there are twice as many chances of failure of the vapor barrier and it would require double the labor, seals and joint overlaps.

Table 2: Typical permeance values for selected material (IARW 1995)

Material	Perm value
Concrete block 8" thick	2.4
Exterior grade plywood ¼" thick	0.7
Hot melt asphalt 2 oz/sq.ft.	0.5
Reinforced concrete slab 8" thick	0.4
Polyethylene film 0.20 mm thick	0.04
Polyethylene film 0.25 mm	0.03
Metal foil –aluminum	0.0

IARW: International Association of Refrigerated Warehouses
The lower the permeability value, the better is the vapor retarder.
Polyethylene film of 0.25 mm is, therefore, recommended.

Reduction in Air Penetration

- If possible and the construction plan allows, the loading or unloading areas should not be in the direction of wind due to wind velocity, when the doors are opened, there would be lot of warm air entering cold spaces.
- The loading bays should have anterooms, air vestibules or air locks so that there is a barrier between outside ambient air and cold spaces when the doors are opened for product loading or unloading. The air locks consist of a short corridor with doors at each end and ideally, only one side door is opened at any time. Vestibules promote significant local mixing of warm ambient air and the cold refrigerated air, thus, reducing heat and mass infiltration into refrigerated space.
- Strip curtains of 2" thick PVC or air curtains are generally provided on the doors to further reduce infiltration.
- The flow of material in or out of the cold rooms should be properly planned so that the door opening or closing cycles and the duration for which door remains open, is minimized by installing door opening or closing sensors.
- The loading of product should be done preferably at night when the ambient temperatures are low.
- Many cold storages provide dehumidification systems in the anteroom to remove a substantial quantity of moisture before the air enters the cold room thus, reducing latent heat load as well as defrosting frequency.

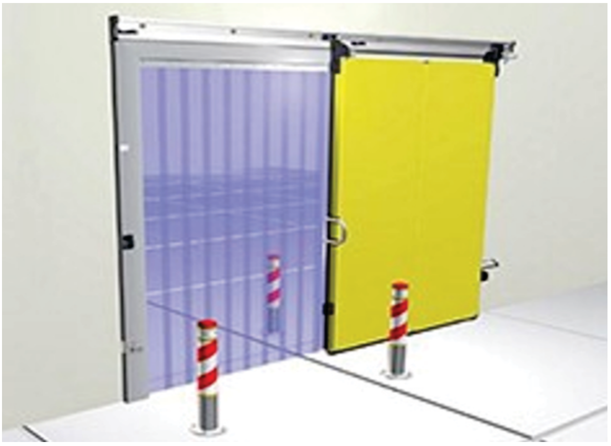


Figure 3: PVC curtain prevents cold air escaping as well as warm air entering

We shall now discuss other aspects of good cold storage construction.

Importance of Size and Shape of Cold Storage

While selecting the cold room size, it should be kept in mind that the heat from outside at high ambient temperature conditions penetrates through walls, roof and flooring. The outside exposed area should, therefore, be kept as less as possible. The ideal shape is a cubical design for which the surface area to volume ratio is smallest.

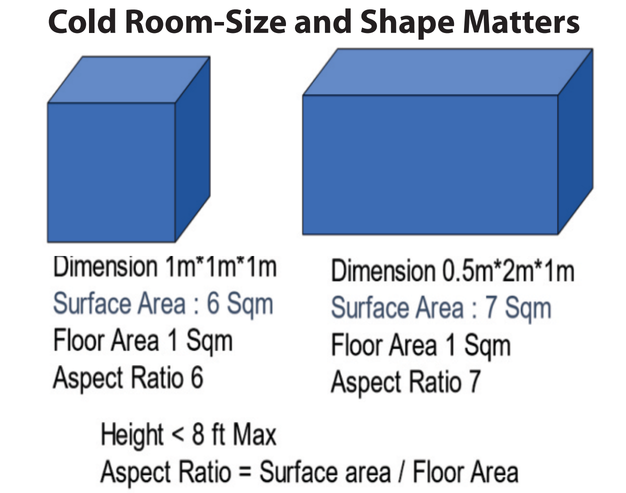


Figure 4: Cubical shape is preferred

A room with one cubic meter volume having each side of one meter would have exposed surface area of six squares meters, whereas a room with the same one cubic meter volume but with one side of two meter and another side of half meter having same height of one meter will have exposed area of seven square meter and thus, heat gain from a rectangular shaped room would be much higher compared to cubical structure. Efforts should be made to design cold storage of cubical shape having same length, width and height as far as possible.

If the cold storage has to be rectangular with two longer walls, the longer walls should be preferably on north and south side and shorter walls on east and west side, since the sun travels from the east to west and there is more heat gain from the east and west side walls.

Most cold storages are single story structures with heights from 5 meter to 12 meter. This type of construction suffers from high thermal losses due to less favorable surface area to volume ratio. However, the advantages of single-story construction outweigh the disadvantages as the initial installation and operating costs are usually much lower than that of a multi-story facility.

Bulk cold storages have a smaller number of large sized chambers whereas multi-purpose units have a large number of small sized chambers designed for simultaneous storage of a variety of items in different rooms based on the product compatibility.

Due to shortage of available space and with the advent of highly mechanized automated storage and handling techniques, nowadays the cold stores are constructed with 24 meter to 30 meter height. These types are preferred when a large storage capacity is required to handle large turnovers. With this type of construction and with mechanized automatic handling systems, a significant reduction in thermal losses can be achieved by provision of efficient doors and LED lighting. Such modern cold storages combine the advantages of multi-story and single-story configurations, as the surface area to volume ratio is greatly improved, thus, reducing thermal losses.

Important Aspects during Construction of Cold Storages

The exterior surfaces should be of light color that absorbs less heat compared to dark surfaces. The surfaces or panels should use reflective material, which has higher reflectivity of light and thus, minimum radiation heat gain. The east side and west side should be shaded with overhangs to reduce direct solar radiation heat. Tall trees planted on the east and west side help in providing shading effect. Maximum heat gain comes from roofs exposed to sunlight. This happens with concrete roof slabs. One can reduce considerable heat gain if reflective tiles are used. Heat gain can also be reduced by covering roof with green grass or lawns. In many instances, the easier method is to cover the roof with stone pebbles or similar material so that direct solar radiation heating the roof is avoided. The roofs constructed with insulated panels are generally not exposed to sun and there is attic space, which should be ventilated to avoid accumulation of hot trapped air.

The construction of modern cold storages uses polyurethane foam (PUF) panels, whereas earlier it used to be a brick wall structure with polystyrene insulation and finished with sand and cement plaster. The modern construction is with a pre-engineered building (PEB).

Figure 5: Modern PEB cold storage

It is essential to ensure that no steel member penetrates the cold room box. If steel penetrates, it becomes a conducting medium for heat to leak in as well as cause condensation. Hence, it is essential that the cold rooms should be either box-out design or box-in design as shown in *Figure 6* and *7*.

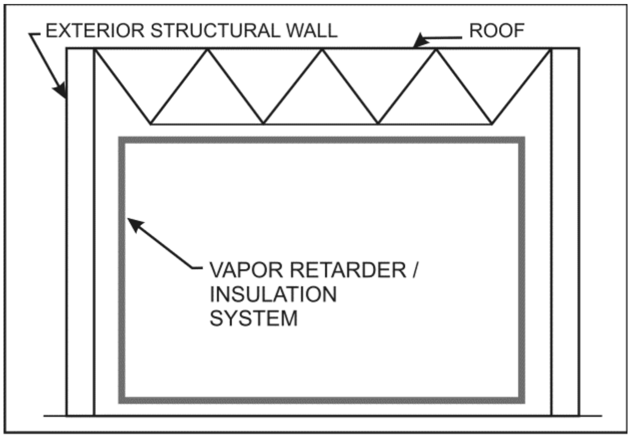


Figure 6: Box-in design

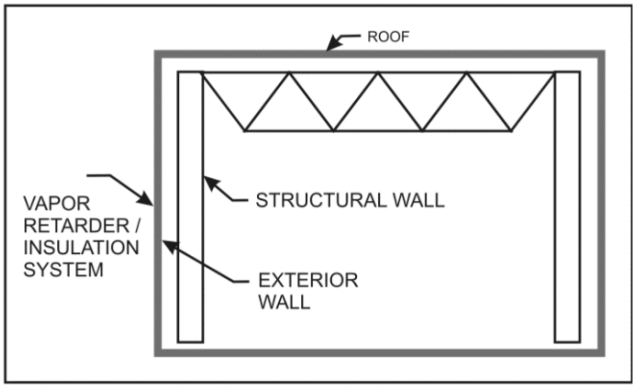


Figure 7: Box-out design

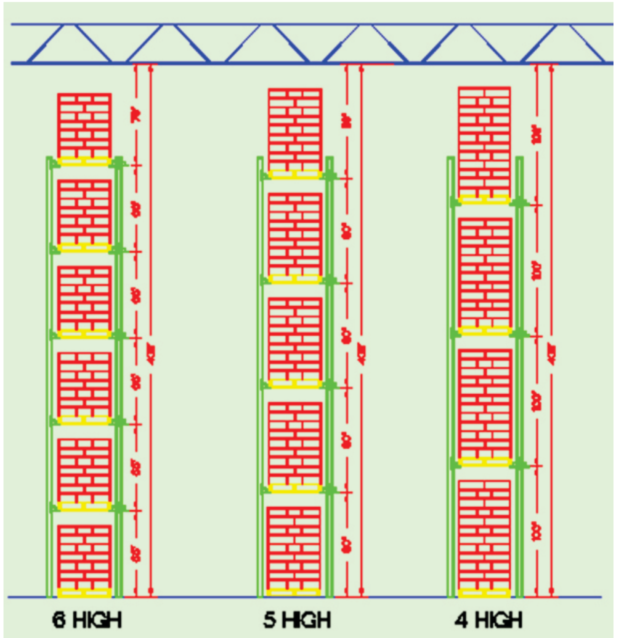


Figure 8: 34' clear height plus refrigeration units

Figure 9: Racking for storing the products

Installation of Panels: Box-Out Construction

PEB Structure

The columns are usually placed at four to five meter. These steel structures are lighter than conventional steel structure. The steel columns and rafters are tapered, reducing the steel consumption. Wall panels are fixed vertically to these purlins. Wall panels can have a maximum length of 12 to13 meter length. Here, horizontal purlins will be on top and bottom, fixed to the columns. The entire steel fabrication is done at the factory and brought to a site in knock-down condition, thereby, reducing any welding function at site. This makes construction faster without site welding.

While constructing and planning the building, try to

- Minimize columns
- Provide high ceilings to accommodate rack structure
- Provide racking for storing the products
- The equipment or machinery room should be separate and properly built as per standard
- Use pre-coated panels to avoid painting of panel structure
- Inside the cold room, minimize flat edges and corners to avoid air turbulence.

We shall now look at how to select proper PUF panel and how to construct walls, ceilings and flooring.

Selection of Proper PUF Panel

We shall look at proper construction of the insulated panels.

Panel Construction

The panel system consists of basic pre-fabricated panels made to very tight specification and the full range of accessories required, including insulated doors, pressure relief valves, sealants, mastics, PVC and aluminium profiles, ceiling suspensions and plastic components.

The inner and outer surface of each pre-fabricated panel is made of a 0.5 / 0.6 mm thick hot dipped galvanized steel sheet and sandwiched between them is a 40+2 kg/m^3 layer of rigid CFC-free close cell and also HCFC-free and zero ODP polyurethane foam. Each panel is furnished with a tongue and groove joint and is optionally provided with cam locks jointing arrangements to ensure rigid interlocking between panels.

Each panel is painted with a colour coating of 20-25 microns of architectural polyester on a minimum 175 gm/m^2 base of zinc coating. PVC and plastisol coatings of 200-micron thickness are also available as an option. The standard color is off-white and the surface of the steel sheets has light-cutting grooves both to enhance their strength as well as to provide an aesthetic appearance. Plain panels are also available. Panels are usually approximately one meter wide and transportable length of 12 to13 meter.

There are two types of panels used for cold storages.

Cam Lock Panels

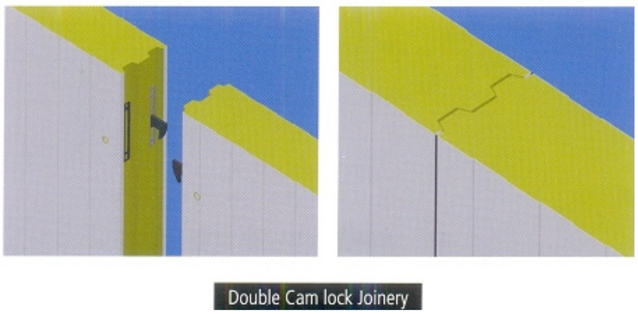


Figure 10: Panels manufactured with cam lock

Panels manufactured with cam lock have the advantage of locking each other firmly. These panels are mainly used for small cold rooms, blast freezers where air pressures inside the chamber are high. The panels can be manufactured in any size and of any thickness as per the requirement.

Continuous PUF Panels

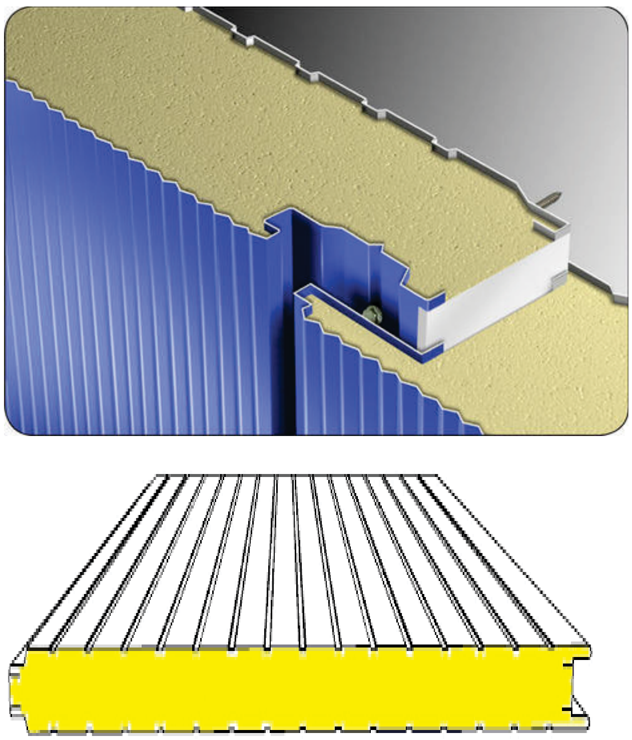


Figure 11: Continuous sandwich panels

Continuous sandwich panels are single piece, pre-fabricated, modular, factory-made units, which consist of an insulating layer of rigid polyurethane foam between two layers of metal sheets. As indicated by the blue arrow in *Figure 11*, ensure that the panels you purchase have metal covering on the edges and PUF is not directly exposed.

The specifications are as follows:

- The galvanized steel sheet skin material shall conform to Indian Standards, viz, IS 277, IS 513 and IS 14246. Galvalume steel shall conform to AS 1346.
- Total galvanized zinc coating surface: 120 to 275g/m^2.
- Plate thickness: 0.4 to 0.6 mm base metal thickness and 0.45 to 0.65 m total coated thickness.
- Paint coating: 25 microns on exposed side and 5-7 micron on back side.
- Core: PU rigid foam, density: 40±2kg/cm^3.
- Thermal conductivity: .023W/m.K.

Cold Room Wall Construction Details Using PUF Panels

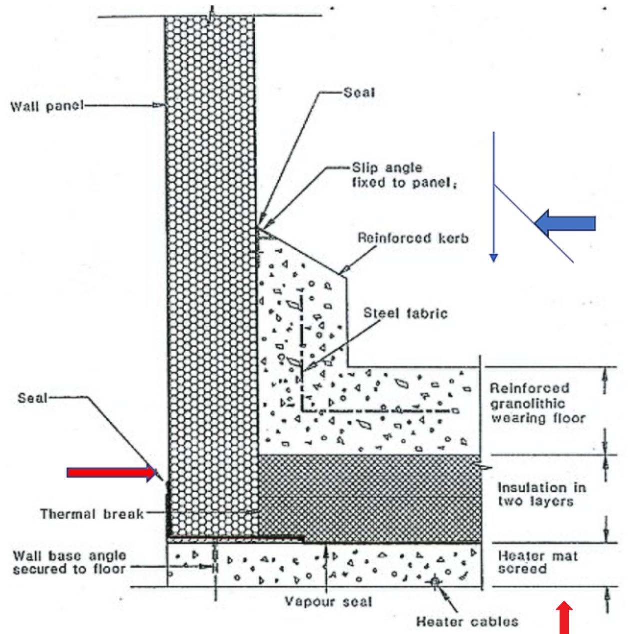


Figure 12: Vapor sealing for wall-to-floor

In one method, after fixing the panels horizontally, the joints on the column are covered by a flashing. In the other type, the panels are fixed with a hidden fastening arrangement, which gives an absolutely flush finish. In both cases, panels are fixed horizontally and the columns are visible from the inside only. From the outside, only a smooth wall is seen. In *Figure 12*, the blue arrow indicates steel fabricated section, which is fixed to the wall and extends in between the panel and the inner concrete protection wall. The purpose of this section is to ensure that water dripping on the panels does not enter the space between the concrete wall and panel to drip down on this steel section inside the cold room. Thus, water dripping or freezing between the concrete wall and panel is avoided.

The red arrows indicate fixing of vapor barrier and sealing between PUF panel wall and PUF flooring. The vapor seal extends above the concrete flooring before the PUF floor panels are placed. These two construction details are important finer points to ensure good installation, but are often neglected.

In order to protect the panels from damage due to fork lifts, products, or any other operations hitting the panels, concrete curbs of sufficient height are essential, as shown in the *Figure 13* with the red arrow.

Figure 13: Concrete curbs of essential heights

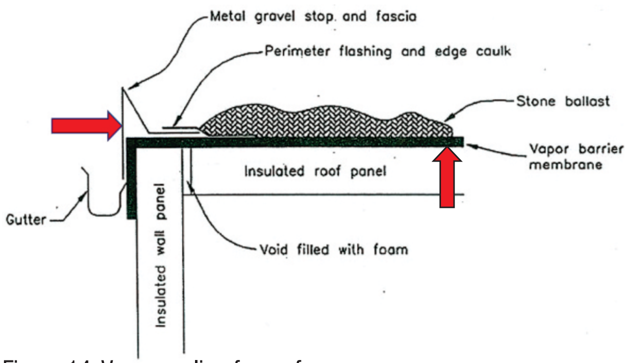


Figure 14: Vapor sealing for roof

Roof Panel Construction

The red arrow in *Figure 14* points to a metal section. This section ensures that the rain water falling on the roof does not drip on the vertical PUF panel structure, but drains in to the gutter section and the drained off, thus protecting the vertical panels. A vapor barrier membrane is also shown by the second red arrow.

As indicated earlier, maximum heat ingress is from the roof as it is constantly exposed to sun. In order to reduce this load, the roof can be covered with stone pebbles as they absorb and reflect the heat as shown in *Figure 15.*

Another important point to be noted from *Figure 15* is that all the refrigeration controls have been taken out from the cold room onto the roof as it is easier to adjust or replace

Figure 15: Stone pebbles on the roof absorb and reflect the heat

them from outside. Controls inside the cold room if provided they would be at considerable height and it is difficult for the operator to reach the controls. Not only this, but the temperature inside being much lower than operator comfort, operators are generally reluctant to finetune them properly.

Also, another important point while taking out the controls is to ensure that all openings are made on the vertical walls of panels, and openings on the roof should be strictly avoided. For uneven surfaces on the roof, in addition to normal insulation, a spray insulation layer also can be used effectively instead of stone pebbles.

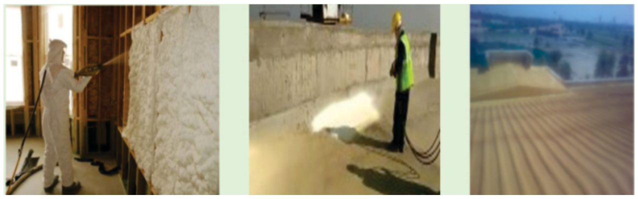


Figure 16: Spray insulation layer for uneven surfaces on the roof

Requirement of Good Floor Construction

The floor wearing surface requires particular care. In addition to the wear, other industrial floors have to stand, it is exposed to low temperature. All other parts of the cold store can be repaired whilst most of the space is still used for storage, but not the floor. Most commonly, the floor wearing surface is a concrete slab cast on the floor insulation with a thickness of 100-150 mm. In cases where heavy traffic is foreseen, a special hard-wearing top-finish is recommended. Good flooring should have following characteristics:

- To ensure safety for staff and site visitors, facilities subject to wet service conditions must provide flooring that is slip-resistant.
- Flooring in cold storage environments must be strong enough to withstand the traffic associated with deliveries and outgoing goods as well as the weight of goods stored in the racking.

- Often in cold storage areas, there will be water runoff from cleaning processes, so that drainage integrated into the flooring is imperative.
- Continuous cyclic movement, heavy tools and materials can impact the floor. Moisture under the floor can freeze and expand, causing the concrete to rise and split. Thermal shock can cause cracks and de-bond the floor. Condensation can lead to microbial growth.

Low-temperature stores built directly on the ground may require special precautions to prevent the build-up of ice below the freezing chamber floor. The ice formation causes distortion known as frost heave and in particularly bad cases, it can lead to the complete destruction of the chamber and structure of the building. Ice formation results in the frost heave of the freezing chamber.

The conditions that give rise to frost heave are rather complex since they are related to the type and texture of soil, the insulation properties, the availability of moisture, the dimensions of a store, seasonal climatic variations and other factors.

When the cold storage operates below zero degree Celsius, the water seeps into the cracks of concrete and freezes, thus causing heaving of the floor.

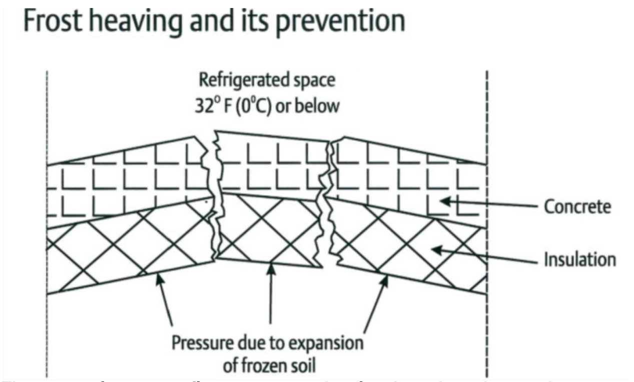


Figure 17: Incorrect floor construction leads to heaving and cracking of the floor

Figure 17 shows incorrect floor construction and thus, heaving and cracking of floor. The most common approach is:

- Under-floor heating system
- Concrete sub-slab
- 10 mill thick poly vapor barrier
- Two layers of extruded polystyrene (5″-6″-7″)
- Six mill poly slip sheet
- Concrete finish floor (5″- 8″)
- Slope (⅛ in - ¼ in)
- Drains 1/400 square feet

Before casting the wearing surface, the floor insulation should be protected by bituminous paper or plastic sheeting, the function of which is two-fold. Firstly, to prevent the water from the fresh concrete penetrating the floor insulation, and secondly to provide a slip-sheet, which will reduce the friction when the concrete contracts. It is of great importance that the floor wearing surface be level to enable high stacking and easy traffic. The top-finish should provide a reasonable anti-slip surface.

Cementitious resin flooring can be easily sloped to allow for water runoff. Resin flooring can be installed more quickly than tiles, minimizing downtime. Cementitious resin flooring often provides a lower lifecycle cost than alternative flooring materials. Cementitious resin flooring is durable, meaning the need for repair and its associated cost and downtime are reduced.

Under floor heating system could be by circulating a heated liquid such as glycol through a pipe grid built into the foundation. The heat for glycol is usually obtained from the compressor hot gas through a heat exchanger.

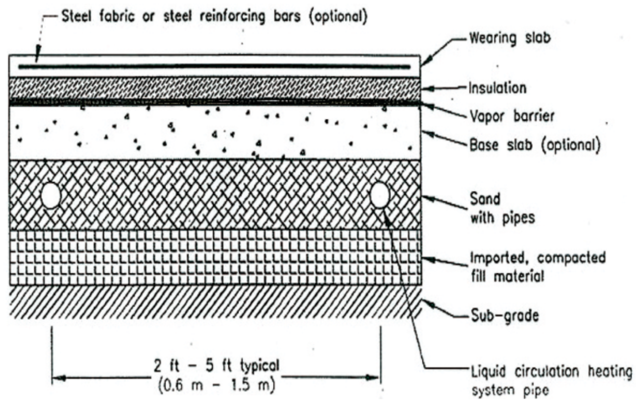


Figure 18: Floor construction showing Glycol circulation pipes (25 mm diameter) and vapor barrier

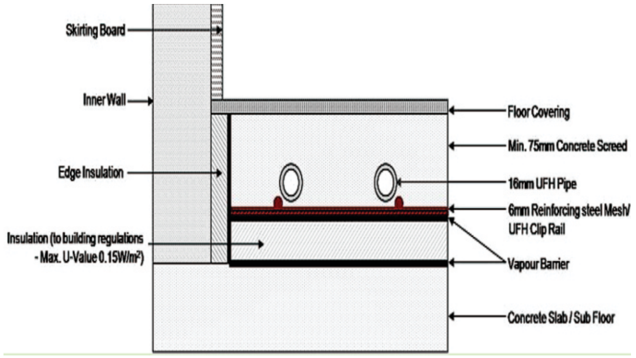


Figure 19: Frost heave prevention using underfloor ventilation (100 to 150 mm diameter PVS pipes)

Figure 19: Frost heave prevention using underfloor ventilation (100 to 150 mm diameter PVS pipes)

The provision of a vapor barrier and the prevention of frost heave are probably the two most important requirements in the construction of flooring of a freezing chamber. We shall now deal with some minor but very important points, which must be paid due attention. We have indicted above PUF panels for construction, however to be more specific, it is recommended the following:

- Walls may be constructed of polyurethane foam.
- Roof should be constructed with polyisocyanurate panels as they are stronger and can take more load.
- Flooring should be insulated with extruded polystyrene.


Figure 21: A cold storage under construction

Constructing a good cold storage that is pressure tight and leaves no chance of any leakage through the envelope, it is essential to provide pressure equalizing valves.

Pressure Equalization Relief Valves and Ports

Modern cold storages utilizing panel systems are usually very effectively sealed. The changes in the pressure within a refrigerated storage facility due to a change in temperature or humidity may cause catastrophic damage to the insulated structure if pressure equalization devices are not fitted to the cold storage rooms. Substantial pressure differentials between the inside and outside of an insulated envelope can be caused by evaporator defrosting, influx of warm product, or rapid change in barometric pressure. If vents are not fitted, movement of insulation panels, disruption of vapor retarders, and structural damage may occur. The panel structure is likely to cave in and may collapse if the initial rapid temperature pull-down takes place.

The pressures are safely equalized by providing relief valves or doors strategically located in the walls of the panels at high level opening and closing to ambient. The required vent area in m^2 is calculated by using the equation:

$$A=0.063Q/\sqrt{\Delta P(T+273)}$$

Where Q is the rate of heat removal in kW
T is the temperature of refrigerated space in °C

ΔP is the design pressure differential between the interior and exterior of the insulated envelope in (Pa), which is normally 125Pa.

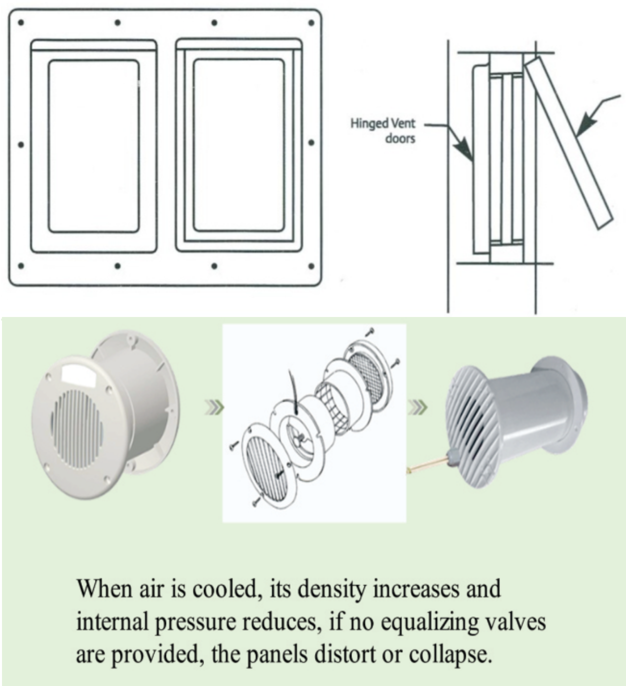


Figure 22: Pressure equalizing vent traps and valves

Whenever the cold storage requires some openings to take out air cooler piping or drain piping, it is generally observed that after the installation of the air cooler, the hole is made in the vertical panel behind the air cooler through which the drain pipe is taken out. This hole is normally of bigger size than the pipe and the opening is filled up with loose insulation pieces and it not only looks shabby but allows air and moisture to leak in. Instead, if one uses the regular fitting available, it is a much better installation.

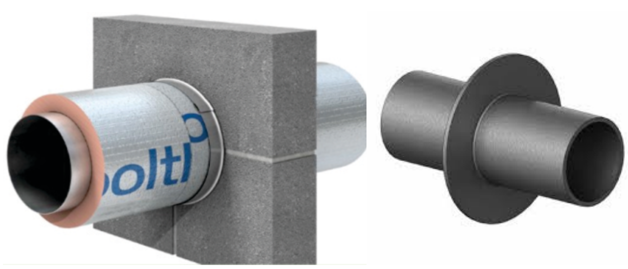


Figure 23: Fittings

Door Protectors

The cold storage doors are often opened and closed for the entry of trolleys, fork lifts or transport vehicles approaching the doors. The cold storage doors are expensive and little damage could lead to big losses. It is, therefore, prudent practice to protect them by installing flexible barriers as shown in *Figure 24*.

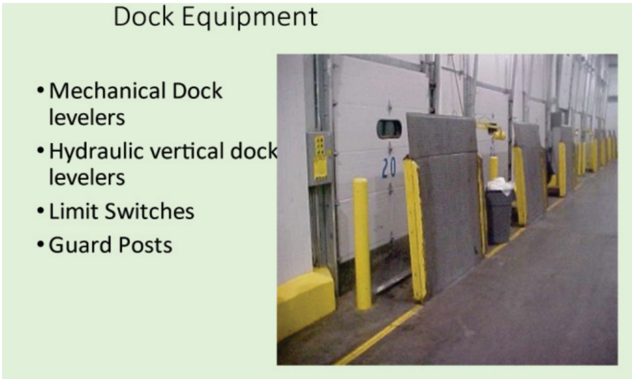
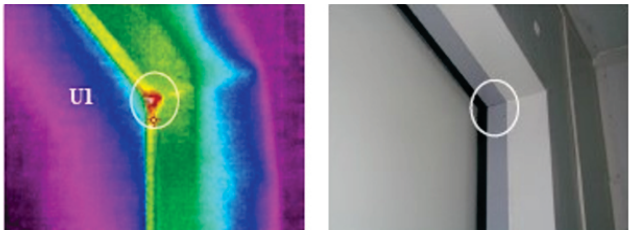


Figure 24: It is prudent practice to protect cold storage doors by installing flexible barriers

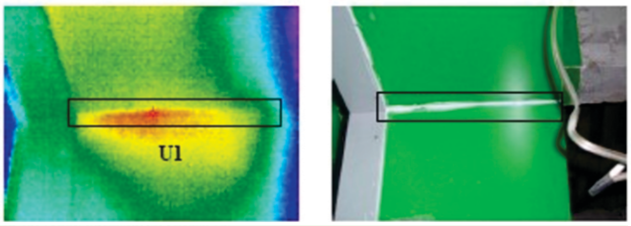
The last point that is not visible to the naked eye is thermography. In this, we take infrared photographs of working cold storage to detect leakage points not visible to the naked eye. The photographs given below will show these heat leaking areas



TEMPERATURE MEASUREMENTS

LABEL	RATED VALUE (°C)	TEMP. INCREASED BY (°C)	OUTLINED AREA TEMP.		
			MIN. (°C)	AVG. (°C)	MAX. (°C)
U1	0	10	2.2	5.8	10.0

Figure 25: Photographs showing leakage points near the door corners



TEMPERATURE MEASUREMENTS

LABEL	RATED VALUE (°C)	TEMP. INCREASED BY (°C)	OUTLINED AREA TEMP.		
			MIN. (°C)	AVG. (°C)	MAX. (°C)
U1	5	7.9	8.8	11.4	12.9

Figure 26: Photograph showing internal cavity

Photographs in *Figure 25* and *26* show leakage points near the door corners and the third slide shows that there is an internal cavity in the panel itself.

Conclusion

Once the thermography is done and we ensure that leakage points have been rectified, we can be totally satisfied that the cold storage that we have constructed is moisture- and heat-resistant and most efficient, and can proceed to calculate cooling loads and select efficient refrigeration equipment.