Greencold
Refrigeration & Air-Conditioning Engineers

Frost Free Operation of Large and High Rise Cold Storage

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Introduction

Why is it some cold stores maintain temperature with very little problem of frost and ice formations, yet others turn into ice palaces within a few weeks of start up?

There are cold stores that directly load from an ambient dock with only a strip curtain (often damaged with strips missing and other strips only half the original length) yet the store does not have excessive icing problems.

Figure 1. Snow and ice covered floor.

Other cold stores have enclosed loading docks, air locks and good door management, yet they create frost and snow in quantities that could be used in a ski snow dome.

Snow, ice and frost are a safety hazard they are responsible for over 90% of accidents in cold storage areas, from personnel slipping and damage to and caused by, the mechanical handling equipment (MHE).

Figure 2. Iced up evaporator coil and snow-covered ceiling.

There have been a number of accidents involving mechanical handling equipment losing control on ice-covered floors in cold storage areas.

More distressingly there have been accidents involving personnel who have slipped on an icy floor or, have come into accidental contact with MHE plant that is out of control.

Information from the HSE identifies that 3% of all accidents reported to them for the distribution industry were in cold stores. In the last five years there have 359 accidents reported one of which was a fatality.

Statistics show that whilst the numbers of accidents fell through the 1990’s, there has been a disappointing increase of accidents since the year 2000. 75% of the reported accidents have occurred in the last two of a five-year review.
There are ways of eliminating “ice palaces” and creating safe working environments. In doing so, other advantages become available to the refrigeration engineer.

Figure 3 Iced up drip

Dehumidification, to reduce frost formations is not a new idea. The next step in the use of this equipment is to develop its application to operate the cooling units frost-free.

Air Psychrometric Conditions

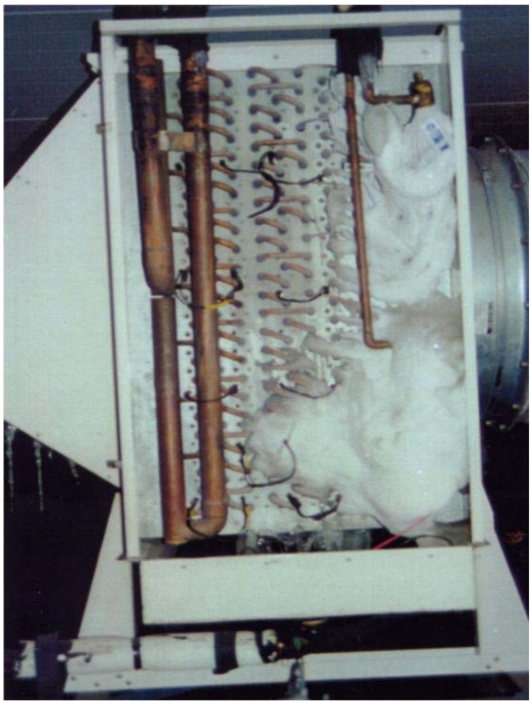

Figure 4 Iced up coil block

Moisture moves due to the difference in vapour pressure. Typical vapour pressures found in cold storage application design are:

-25°C	and	80% rh	0.38	kPa	vapour pressure
-22°C	and	80% rh	0.5	kPa	vapour pressure
+5°C	and	80% rh	0.7	kPa	vapour pressure
+32°C	and	40% rh	1.96	kPa	vapour pressure

The moisture content of air, at the same conditions is:

–25°C	0.31	g/kg
-22°C	0.42	g/kg
+5° C	4.33	g/kg
32° C	12.31	g/kg

Other environmental conditions that are used in this paper are:

Dry Bulb Temp °C	Relative Humidity %	Dew Point °C	Enthalpy kj/kg
32	40	22	63.7
5	80	2	15.9
-22	80	-24	-21
-25	80	-27	-24.3

It is the difference in vapour pressure that draws moisture into the store. This will happen even if the store is at a positive pressure. Moisture will move in the opposite direction to airflow.

Psychrometric Charts.

Published psychometric charts are of little use when the dry bulb temperature is below 5°C.

Software is available which enables psychrometric charts to be produced down to -40°C. Having this information and the associated psychrometric data for air at low temperatures is essential for the design of frost-free operating conditions.

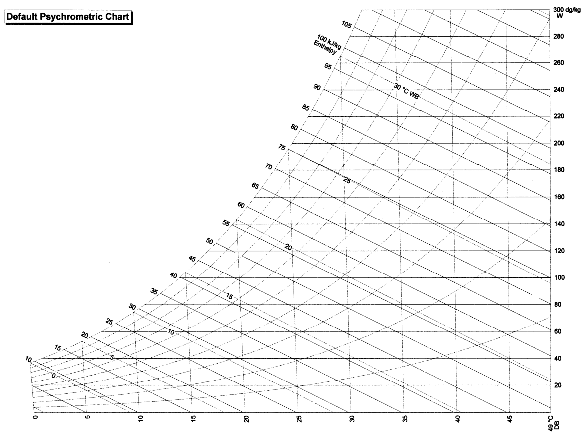

Figure 5 Typical Psychrometric chart

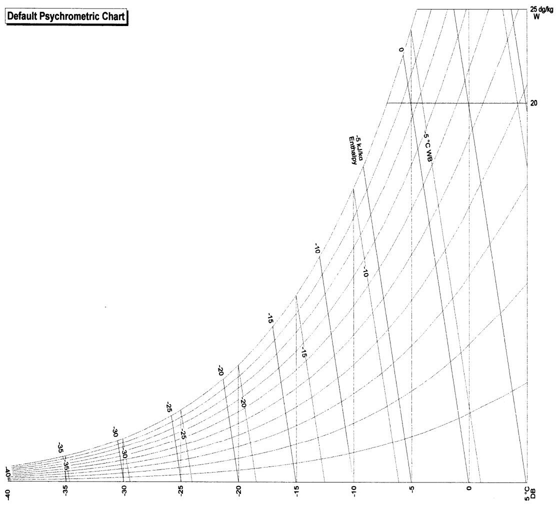

Figure 6 Low Temperature Psychrometric chart

Operating Conditions

Cold storage areas operate at a negative pressure; this is due to the cooling effect of the air passing through the evaporator coil block.

This pressure difference draws outside ambient air into the store, with its associated moisture.

Air Infiltration

Air also infiltrates into the store from door openings where high velocity air currents can be created. These air currents increase, as the height of the door and store increase. The rate of increase is not linear, it increases, almost by the square.

The infiltration air velocity through an open cold store door will be between 0.5 m/s and up to 2 m/s depending on door size and cold store height.

If a pallet truck door has dimensions of 2.2 m x 3.2 m. The cross sectional area is 7.04 m^2.

If there are two doors each with 300 traffic movements per day each of 30 seconds, then doors are open 18,000 seconds per day.

The resulting infiltration at 1.0 m/s is:

$7.04(m^2)x18,000(s)x1.0(m/s)= 126,720\ m^3/d$

If the store measures 50 m x 70 m x 10 m high equal to a volume of 35,000 m^3. The rate of air change is 3.6 per day.

For the typical store described above the plant capacity required would be about 500 kW. Of this 80 kW (16%) is for infiltration, if the frozen area has a temperature controlled loading facility. ASHRAE, for distribution cold stores suggest 15% as the infiltration load.

If the air is infiltrating from ambient then the total load rises to 680 kW of which 200 kW (29%) is the infiltration load.

Figure 7 Frosted air-lock prior to dehumidification

Figure 8 Frost and snow bound ceiling

Door Operation

In Wakefield there is a frozen goods distribution store of approximately 5,000 m^3.

This store has a single entry truck and combined personnel door. A counter was fitted to the door. The average number of openings per day was recoded as 1006 over a six-month period.

The quantity of ice around the door was a safety hazard and a number of reportable accidents had occurred. The Health and Safety Executive issued an improvement notice.

This store was fitted with desiccant dehumidification equipment and a rapid movement fabric door. The store is now frost-free.

Air infiltration into a cold store is often the largest single load for the refrigeration plant to deal with. It is a load that can be controlled by door design and door management.

Cold storage areas that do not have loading facilities directly to ambient can be constructed to operate frost-free.

Cold storage areas with direct loading to an ambient or constructed with through loading, can be constructed with a considerable reduction in frost and snow limiting ice formations on cooler surfaces.

How Bad Can The Problem Be?

The formation of snow and ice in a cold store can be such that the coolers close to the main truck door or doors are almost non-effective.

- Snow and ice fall from the ceiling to the ground making the area a skating rink.
- Condensation forms on the ceiling in front of the coolers and drips as moisture onto the floor and then freezes.
- Icicles form in front of the coolers and drop to the floor, creating a safety hazard.
- The coolers have so much moisture to deal with. The drip trays fill with ice that cannot be cleared.
- Drip trays overflow onto the floor and adjacent product in the store.
- Tubes in coil blocks can be damaged, beyond repair, requiring coil block replacement.
- Fan blades freeze in place and motors fail.
- Drip tray heater elements fail.
- Doors ice up and do not seal.

- Product is covered in frost and snow making bar code reading difficult.

These are just some of the problems that frost, snow and ice cause.

Figure 9 Air-lock in figure 7 now frost free

Fogging

A further problem of air infiltration is fogging. This can occur in the goods in area and in the

Figure 10 Internally fog bound cold store

cold store.
Fogging can be as dangerous as ice on the floor with visibility reduced to only a few metres.

Other problems, associated with fogging include condensation, on the ceiling just inside the door and in front of the coolers.

Figure 11 Entrance to a fog bound cold store

Advantages of Frost Free Cold Storage

Operating frost-free achieves a number of benefits, typically

- The safest operation possible for both trucks and personnel.
- Product in store is frost and snow free.
- There is no snow on the walls or ceilings.
- There is no ice on the floor.
- Drain line problems are eliminated.
- Drip tray problems are eliminated.
- Reductions in evaporator defrost cycles.
- Doors close and seal effectively.

These operating conditions can be achieved by designing into the original installation or retrospectively fitting desiccant wheel dehumidification equipment.

If a cold storage area could be operated totally frost free, the benefits are available would be:

- There is no requirement to defrost the coolers.

- It may not be necessary to install a defrost installation for the cooling units.
- Drain lines are not required.
- Not having a defrost system can save 15% to 20% of the initial capital investment.
- The use of 16 or 18 hour a day running time in design to accommodate defrosting is not required.
- Frost-free cold stores can be designed for 20 or 22 hour per day running time, reducing plant size.
- There is a 15% to 20% reduction in electrical maximum demand.
- Compressors run at the design suction pressures on a continuous basis, maintaining optimum coefficient of performance.
- Cooler fin spacing can be increased from 3 fpi to 4 fpi reducing cooler size, cost and weight.
- Because there is no temperature cycling from defrosting the cooling units warmer store temperatures can be maintained.
- For example –22 °C can be maintained on a continuous basis. Whereas with traditional installation the store would be at –25°C to avoid rising to –20°C or warmer during a defrost cycle.

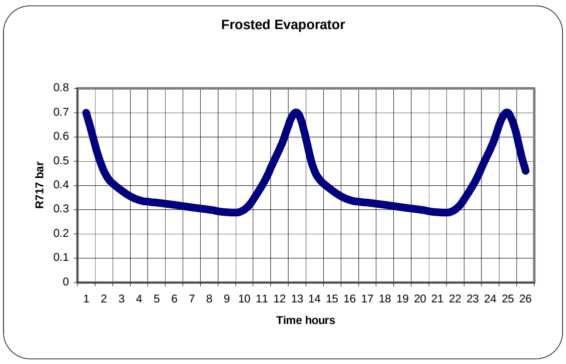

Figure 12 Typical Conventional Suction Pressure Cycle

Compressor Operation.

For a cold storage area, designed to maintain –22°C on a continuous basis, compressor operation is far more efficient with a frost-free coil compared to a system defrosting twice per day.

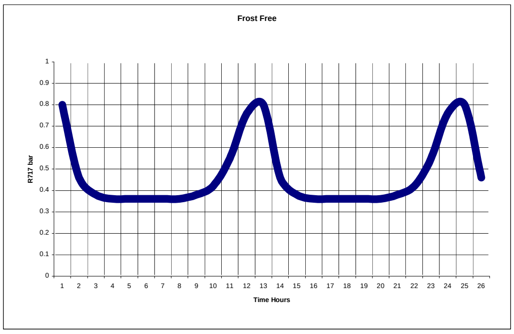

Figure 13 Frost Free Suction Pressure Cycle

Compressor Operating Costs.

Taking a typical single stage screw compressor operating with an economizer and using Refrigerant R717, the following are a selection of the performance characteristics based on condensing at 35 °C.
For a room temperature of –22°C operating

Saturated Suction °C	Duty kW	Power kW	cop	% Change
-26	109.1	49.1	2.22	1.067
-27	104.3	48.5	2.15	1.034
-28	99.7	48.0	2.08	1.000
-29	95.2	47.4	2.01	0.967
-30	90.8	46.9	1.94	0.933
-31	86.7	46.3	1.87	0.899
-32	82.7	45.7	1.81	0.870
-33	78.9	45.0	1.75	0.841
-34	75.2	44.4	1.69	0.813

frost free with a 5°K evaporator temperature difference and a 1°K pressure drop, the suction condition is –28°C. The compressor duty is 99.7 kW power 48 kW.

If the coil was not frost-free the compressor suction condition would be about –32 °C. At these conditions the duty would be 82.7 kW and the power 45.7 kW.
To achieve the 100 kW duty required the

frosted operation would be required to operate 21 % longer.

The reduction in energy is 15% based on the 21% additional running time at the reduced power.

How is Frost Free Operation Achieved?

Figure 14 Iced up door and threshold before replacement

Desiccant wheel dehumidification equipment will remove almost all the moisture from an air stream. The leaving moisture content of the air is a function of the entering air temperature, in particular the dry bulb temperature.

If process air enters the dehumidifier at 5°C the leaving moisture content will be between 0.3 g/kg and certainly less than 0.5 g/kg. Air at this condition has an approximate dew point temperature of -28°C. The leaving dry bulb temperature will be between 20°C and 25°C.

- Frost free operation can be achieved by having available dry air and consideration to the following.
- Drying the area to a dew point temperature of –-28°C.
- Selecting the coolers with a 5°K temperature difference.
- Cooler fin spacing can be reduced to 6 mm (4 fpi). As a cooler operating at 5°K Δ T is no larger or any more expensive than a cooler with fins spaced at 8.5 mm (3 fpi) at 6.5°K Δ T.
- Maintaining the design suction pressure in all ambient conditions.
- Constructing access facilities to limit infiltration to the cold store and provide dehumidification at this point.

Cooler Comparison.

Figure 15 Cold store entrance of picture 14 after the fitting of a rapid movement door and dehumidifier.

The following compares the operation of two coolers both having six row coils in direction of airflow and duty of 50 kW.

The first operates frost free, the other frosting in the traditional manner.

With frost free the fins are spaced at 4 mm and the coil has a basic rating of 10.16 kW/°K with a nominal temperature difference is 5.0°K the duty is obtained.

For the traditional application the fins are spaced at 6 mm and the same coil has a basic rating of 8.177 kW/°K with a temperature difference of 6.1°K the duty is obtained.

The frost-free coil weighs 13 % less.

High Rise Cold Storage Areas.

There are two main applications of high-rise cold storage applications.
The first is bulk storage with access to the stored goods by means of a fully automated

MHE system. These areas can have well designed air locks for the entry of product that is usually fully palletised.

As such this type of storage area does not usually suffer from frost and snow problems.

The high-rise cold storage areas used for Internet distribution have a number of mezzanine floors and picking facilities at each level.

These areas are subject to large frost formations, due to the number of occupants carrying out the picking process and the installation of entry and leaving access facilities for the conveyor system.

To satisfy the required movement of product, in the picking process it may be necessary to have two or three doors one above each other, in the same face of the cold storage area.

These doors can be in both ends of the store creating the possibility of cross airflow and high air infiltration rates. Therefore, to limit infiltration to acceptable levels and control frost formations, the internal pressure must be carefully controlled and dry air introduced at strategic points.

Installation of Dehumidification Systems

There are a number of ways of providing the correct environmental conditions to achieve frost-free operation. Each application has to be considered on merit.

The design of any installation will depend if air locks are available.

With air locks installed total frost and defrost free operation is possible.

Without air locks non-defrosting installations are not recommended.

Dehumidification Equipment

Desiccant wheel dehumidifiers are compact in construction. Equipment for a pair of pallet truck doors would have nominal dimensions of 1350 mm long x 800 mm wide x 850 mm high and weigh in the region of 200 kg. A 16-amp three-phase power supply would be required.

The unit can be mounted on the floor, but this can give rise to dirty filter problems if located in picking or marshalling areas.

Figure 16 Large floor mounted dehumidifier

The preference is to wall mount or locate on the air lock or cold store ceiling.

Dehumidification Equipment Process

There are two air streams through the unit,

Figure 17 Wall mounted dehumidifier

process air (the dry air) and regeneration air.
Regeneration air should be taken from outside temperature-controlled areas, roof voids are a good source as this helps with air movement in

the void.

Discharged regeneration air must be taken to ambient, as it is moisture laden.

This duct should be insulated if installed vertically. If horizontal it should slope towards the outlet, as condensation may occur in low ambient temperatures.

If the duct runs through a chill area again it must be insulated.
Process air (the dry air) is best taken from an adjacent chill or marshalling area. This will not cause infiltration problems into the marshalling

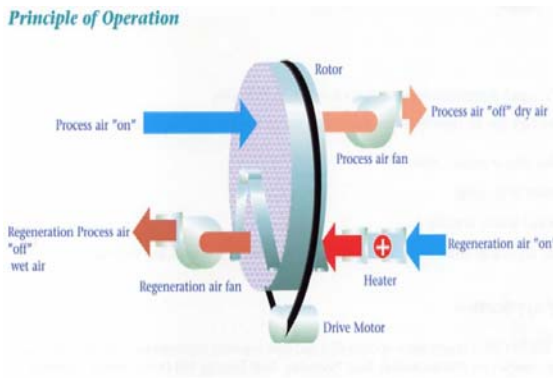

Figure 18 Dehumidification process picture

or chill area, as the process air will find its way back into these areas from the cold store.

The process air leaves the unit virtually moisture free, and can have as little as 0.3 g/kg of moisture present.

If the configuration of the installation does not permit pre cooled air being available, then a pre cooler needs to be installed at the process air entry of the dehumidifier. Taking ambient air directly into the dehumidifier will result in the outlet process air having to high a moisture content to reduce cold store frost levels.

This would apply to dehumidifying dock entry pods of a direct loading cold store. A central plant is possible supplying air to all of the dock facilities. The pods must have both internal and external doors to be successful.

Operating Costs

The energy savings achieved by operating a cold storage area frost free, have to be offset by the energy consumed by the dehumidification installation.

An example would be a cold store of 35,000 m^3 capacity held at –25°C.

If air infiltration, for conventional design is taken as 3.6 air changes per day, with the air coming from an adjacent marshalling area at nominally 5°C the infiltration load would be:

The air change is

35,000 (m^3) ^{x} 3.6(air change) / 0.8 (m^3/kg)

= 157,500 kg/day

The cooling load is

157,500 (kg/day){15.9-(-24.3)} / 86,400

= 84.5 kW.

This is very close to the empirical calculation used for the earlier example.

If the store has two air locks, each supplied with 600 m3/h of dehumidified air and all of this air is assumed to enter the cold store (which is unlikely), then cooling load would be:

600 (m^3/h) x 2 (doors) x 24 /0.8 (m^3/kg)

= 36,000 kg/day

The cooling load is

36,000(kg/day)x 1.0(kj/kg)x{20-(-25)}/86,400

= 18.75 kW.

To this the energy required to regenerate the desiccant wheel has to be added.

Typically descant wheel dehumidifiers, of the size used on cold storage applications with electric heaters for regeneration, require in the region of 1.0 kW of energy for each 100 m^3/h of dry air supplied.

The energy for the above example would be

600 (m^3/door) x 2 (doors) x 1 kW

= 12 kW

There are the process and regeneration air circulation fans of the dehumidifier to be taken into account. These would be typically rated at 0.37 kW each i.e. 0.74 kW

The total energy required to provide dry air is:

Dry air		18.75
Regeneration heat		12 .00
Fans		0.74
	Total	31.49 kW

Compared to the anticipated 84.5 kW from traditional infiltration.

This presumes that a pre cooling installation is not required.

Some of the dry air will be supplied directly to the cold store and some supplied to the marshalling area.

The heat to be removed from the dry air in a marshalling area, at nominally 5°C, is less than in the cold store. This will further enhance the savings for frost-free operation with the associated benefits.

The advantage of a dry air installation, with correct door configuration, avoids negative store pressures. The infiltration allowances, made in calculating refrigeration plant, will be found in practice.

Pressure Relief Valves

These valves are fitted to prevent the potential of over pressure, from defrosting and under pressure from pull down, damaging the vapour seal of insulation panels and possible panel delamination.

Refrigeration engineers and cold store operators either love them or hate them. The installation of these valves has created much debate over the years.

If they are installed care must be taken in locating them.

If they are behind coolers they draw in moist air, due to the negative pressure in this area, creating frost and snow problems.

If located close to traffic, or pedestrian ways, falling snow is a safety problem.

By introducing air in a controlled manner through the dehumidification system negative internal cold store pressures do not occur.

By the use of twin rapid movement doors at each end of an air lock, any over pressure is released.

I can therefore see no reason or advantage in fitting pressure relief valves through the insulated panels if construction is as proposed in this paper.

Doors and Traffic Management

To operate frost free appropriate door design and traffic management is essential.

Traffic has to be segregated, firstly into pallet trucks and reach trucks, with each group having its own entry and exit facility.

Having segregated the traffic it is then necessary to introduce one-way flow.

For large stores a six-door installation is a good configuration. It can handle large volume of traffic efficiently and safely and have degree of redundancy.

Two one way doors deal with reach trucks.

Two pairs of smaller one-way doors are used for pallet trucks.

All the entry facilities are through air locks about six metres long. Strip curtains should be avoided for safety reasons.

Each end of the air lock has a rapid movement fabric door. The doors can be vertical or horizontal in operation, often a combination of both gives the best result.

The latest technology for rapid movement doors will open and close the door at speeds of 3 m/s or faster.

The door installation for reach trucks needs careful consideration, as these entrances may be 4.5 m high.

Low temperature rapid roll doors for door heights up to 5 m are now available.

Review

The supply of dry air must be the correct volume and distributed approximately to the correct location. This is the secret of a successful installation.

With the experience of over twenty installations, from 600 m^3 (20,000 cubic feet) to 100,000 cubic m^3 (3×10^6 cubic feet) carried out over the last two years, I am convinced of the benefits.

Experience shows that each application is different and has to be considered on its merits. The number of doors, their size and location will differ, as will the way the doors are configured.

Satisfactory projects can be achieved without air locks, but these need to be carefully considered in the design and installation arrangement.

Large cold stores with direct out loading benefit significantly from dehumidification but, running totally frost-free is difficult. These areas still require cooler defrosting.

Whilst there are energy savings to be made, no cost can be put on having a safe cold store environment with the floor, racks and coolers ice-free.

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