COLD STORAGE DESIGN

Often Overlooked Aspects

While designing cold storage as a green field project, before proceeding to detailed design it is essential to have series of interactions with customer to understand correct requirements and come to common understanding. Many times the designer/contractor assumes certain things which are not clearly spelled out to customer as also customer believes that the designer/contractor understands what he wants without making it explicitly clear. It is therefore necessary to come to common understanding as a first step.

The important aspects which should be discussed and joint statement of agreement on basis of assumptions should therefore be prepared before the design & selection of equipment. This document known as DBR (Design Basis Review) should become the starting point before proceeding to undertake further work.

Initial survey: the designer involved in heat load calculations needs information in order to accurately predict the heat load on refrigerated cold rooms. The more complete the information, the better would be the calculations. More accurate calculations are the first step in ensuring optimum refrigeration capacity and equipment selection for the project.

Assumptions to be agreed upon should cover following:

Basis of Design:

- Location-City-Place of Installation from main communication/ Transportation facilities
- Adequate infrastructure available: Water availability, it's quality- whether mains or tube well and Electricity
- Type of Product to be stored
- Whether multi product and multi temperature facility is required or single commodity storage is envisaged.
- Qty to be stored - in Tons
- Dimensions of cold room based on density of product to be stored
- Type of Insulation and Thickness & cold room construction details
- Product incoming temperature and expected storage temperature and duration of storage
- Product Loading Rate & temperature pull Down Period
- Frequency of Door Openings- entries/exits during the day/week
- Product loading /unloading methods
- Method of Internal/ External Packaging and material handling methods
- Storage rack types and configuration

The aspects often overlooked from above assumptions are:

Type of Operation: Only storage or processing

It is necessary to understand the requirements of end user as to whether he is going to rent the store only or going to use it for his own production and for processed products.

Some of the common applications are given hereunder:

- Holding coolers or Freezers- Storage only
- Blast cooling or Freezing- batch production
- Trolley Freezing- continuous output at fixed interval
- Spiral Freezing- continuous production
- IQF –inline freezing
- Preparation, processing or cutting rooms
- Pre cooling operations- Fast cool down
- Distribution ware houses
- Reach in or walk in coolers
- Display cabinets in super markets & Hyper stores- frequency of door openings.

Product loading rate & cool down period: The designer/contractor generally asks only the quantity of product to be stored. Loading rate of product per day is very important consideration for load estimating. The customer, normally, believes that as the material arrives, the total product can be loaded in cold rooms immediately and would be cooled to desired temperature in short time of 24 hours. If the refrigeration load is calculated on the basis of total stored quantity to be cooled in 24hrs then the refrigeration load would be huge to take care of initial cool down load and the temperature holding load would be very low. The capital cost would be prohibitive and most of the machinery would remain unutilized during holding period. For example for potatoes, once the farm heat is removed quickly by lowering the temperature to 15^{0}C in 24 hrs then they can be can be cooled to desire temperature over a considerably longer period at a slow rate of 0.5^{0}C per day till storage temperature of 3-4^{0}C is reached (NHB standard). This

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means one has a period of nearly 20 days available for the product is cooled slowly. Normally 4% to 5% of storage capacity as loading rate per day is considered optimum for fresh vegetables which takes care of initial refrigeration cooling as well as holding loads at an economical cost. As against this the products like grapes, strawberries, and mushrooms, milk and many other need very fast cooling to storage temperature to avoid deterioration. This aspect needs to be discussed and loading rate agreed upon based on the type of product.

Product incoming temperature: This is an important aspect especially for commodities like ice cream or frozen products to be stored. Many times when the product is loaded in the cold room only the skin or outer temperature or temperature of cold room from where the product has arrived is considered. In reality the product contains lot of heat as its inner core is still not frozen. When such product is loaded in the cold room chambers, since the refrigeration units are not designed to further cool the product, product becomes soggy/ soft and customer starts blaming the cold room facility design. The most important temperature to be measured therefore before the product is taken in for storage is the core or the center temperature of product. It is therefore essential to inspect product before loading in the cold rooms for its core temperatures, quality etc. It should be remembered that cold storages are not designed to improve the quality of product, but would try to maintain quality in which it has been loaded. Many litigations and arguments take place if this aspect of measuring the core temperature of product is not checked by either party while accepting the product in the cold rooms.

Stored Quantity: It is important to know how the product is packed and going to be stored. The density and size of individual pack needs to be understood. The aspect mostly overlooked is to remember that it is air which cools the product and it is therefore essential to ensure that cold air is enveloping each

In most of the cold storages one would observe that products are stacked in such a manner that only the top portion is exposed to cold air whereas rest of the product has hardly any contact with cold air. The designer and cold storage owner must therefore provide air space of at least 30% of total room volume.

package or individual product totally. In most of the cold storages one would observe that products are stacked in such a manner that only the top portion is exposed to cold air whereas rest of the product has hardly any contact with cold air. The designer and cold storage owner must therefore provide air space of at least 30% of total room volume when he is calculating amount of products to be stored. 70% space only should be earmarked for product storage. It is also important to ensure that the products are stored in such a manner that cold air is not bypassed directly from supply side to coil inlet and short circuit paths are avoided so that the total quantity of cold air is fully utilized for the entire stored product.

Frequency of Door Openings: Identical products stored at different locations will have different cooling loads based on its usage & door openings. The products stored at bulk cold storages will have different frequency of door openings as against same product stored at super markets and thus the refrigeration requirements would change assuming all other parameters remain identical. Hence the kind of operation of cold storage needs to be understood before refrigeration load are estimated. Most of the designers, instead of going in to calculations of air infiltration load based on door sizes, number of doors and frequency of openings; prefer some assumptions based on given tables, factors & thumb rules.

As an alternate to these assumptions, calculating air volume and then method and using the psychrometric chart, one may calculate the infiltration load resulting from natural ventilation (no wind) through door openings more precisely.

The equation for calculations is as under

The average velocity in either half of a door 2.13m (7ft) high and at 600F (330C) temperature differential is 30.48m/m (100 fpm). Considering this as basis the velocity in m/s would be

Vel m/m = $30.48 \times (\sqrt{H} / \sqrt{2.13}) \times (\sqrt{TD}/\sqrt{33})$

Vel m/m = $3.637 \times \sqrt{H} \times \sqrt{TD}$

Or Vel m/s = $0.0606 \times \sqrt{H} \times \sqrt{TD}$

The area of door opening is normally divided by 2 since maximum velocity would be when either half of the door is open.

An example given below shows how to calculate infiltration load

The velocity through a typical door of 2.44 m (8ft) wide and 2.74 m (9ft) high, with a temperature differential of 55 0C (100 0F) is

Velocity = $0.0606 \times \sqrt{2.74} \times \sqrt{55}$ = 0.744 m/s (146.4 fpm)

If the door remains open for 15 min (15 x 60 sec) per hour in a shift of 12 hour operation per day, then the 24 hour infiltration would be

Cu.m.= Vel. x Door area in m2/2 x 15 x 60 x 12

Cu.m. = 0.744 x (2.44 x 2.74)/2 x 15 x 12 x 60 = 26860 m3

m3 per Sec. = 26860 / (24 x 3600) = 0.31 m3/ s

To calculate heat gain by use of psychrometric chart, one can plot the values of outside air temperature and humidity to determine the enthalpy h2

Similarly taking inside condition of temperature and assuming saturation condition of air we can also determine enthalpy of inside air h1.

Then using formula we can calculate heat gain as

Heat Gain in kW = Density in (kg / m3) x m3/s x Δ(h2-h1) kJ/kg

Let us assume room condition as 30C (380F approx).and 90% RH as conditions inside the cold room and

Room designed RH%	50-65	65-80	80-85	90	95
Recommended T.D. deg C	(9-12)	(6-9)	(5.5-6)	(3.8-5)	(2.8)
Typical product	Candy	Onions/ melons	Potato	Flowers	Grapes

and would settle on the product and cause product damage.

Utmost care therefore should be taken to keep water loss from the product to bare minimum. This of course requires more careful design and selection of equipment. The temperature difference between air outlet temperature from coil and cold room should be minimum so that moisture from product does not get absorbed by air and subsequently travels to the coil, due to vapour pressure difference between commodity and surrounding atmosphere. This means higher Apparatus Dew Point (ADP) selection and larger air volume needs to be provided.

The perishable products require high humidity around 95% at a temperature near 00C. It is practically impossible to have evaporator coil temperature lower than circulating air temperature by say 2 to 3^{0}C without water condensing on the coil surface, thereby lowering R.H.

Maintenance of correct humidity and temperature therefore reduces water loss. As an example to stress the point if we consider a 10 Ton of apples and with water loss of 6%, we will have a product weight coming out as 9.4 Tons which means 0.6 Ton loss. At the rate of Rs. 140/Kg, this means a loss of Rs.84000, isn't it a huge loss?

R.H. is also a misleading indicator of moisture content, because warm air may contain more moisture than cool air for similar R.H. e.g.

90% R.H. At 5^{0}C has 0.6 g/kgda moisture

Whereas 90% R.H. At 15^{0}C has 1.2 g/kgda moisture, twice the amount.

Similarly for the same moisture content in g/kgda lower the dry bulb temperature means more RH and higher the temperature means lower is the RH e.g. At 5^{0}C with 0.6 g/kgda moisture has 90% R.H.

Whereas with same moisture content of 0.6 g/kgda at 30^{0}C has R.H. is only 20%.

Selection of Product Coolers:

Evaporator selection is most important factor is ensuring product quality is maintained and there is minimum weight loss during storage.

Temperature Difference (T.D.): 'T.D.' is defined as air on temperature on coil or cold room temperature minus refrigerant evaporating temperature.

The nature of product determines the desirable relative humidity to be maintained for storage room. The desirable humidity in turn dictates the approximately design T.D. between the air in the storage room and refrigerant in the cooler. Most of the manufacturer's catalogue show cooler capacity in kW (Btu/hr) for a given air flow rate expressed in M3/hr (cfm) and evaporator TD.

Type of Application	Recommended Number of air changes/hr	
	MINIMUM	MAXIMUM
Holding Freezer	40	80
Packaged holding cooler	40	80
Cutting rooms	20	30
Meat chill room	80	120
Boxed banana ripening	120	200
Vegetable and fruit storage	30	60
Blast freezer	150	300
Work areas	20	30
Unpacked meat storage	30	60

Over sizing the evaporator may reduce TD, and controlling the evaporator by use of pressure regulator is the proper method of maintaining TD and the relative humidity and reducing product weight loss.

The table below gives suggested T.D. to be taken for coil designing for various commodities and R.H. to be maintained.

On the basis of these two important parameters cooler selection can be made.

For example, let us assume we need to select cooler and system for 20C cold room storing fruits/vegetables

Since fruits and vegetables require higher humidity to avoid weight loss, first select humidity requirements.

Assuming humidity to be maintained above 85%, take TD as 5^{0}C for selection. This TD is not the mean TD, but difference between air on temperature to the coil, which is normally the cold room temperature and saturated evaporating temperature leaving the coil as mentioned above.

There is no industry standard for rating coolers, and some cooler manufacturer's rate coolers at TD mean, which results in smaller cooler than required for the duty. One must therefore select cooler always based on TD which is room temperature minus saturated evaporating temperature at the evaporator outlet.

It should also be kept in mind that any cooler selection should generally be restricted to not more than 5^{0}C TD to ensure adequate area of the coil, even when requirement of room temperature is high and operating temperature of system at compressor suction is low. If this is not done, it could result in not achieving room designed conditions since the cooler selected would be too small in area and inadequate air quantity.

The designer should also know the difference between SST (Saturated Suction Temperature of compressor) and

40 0C (1040F) and 20% RH as outside conditions which are typical in Delhi.

From the properties of air, h2 would be 64.63 kJ/kg and h1 would be 13.91 kJ/kg

Heat gain by infiltration would therefore be 1.2 x 0.31 x (64.63 – 13.91) = 18.86 kW = 5.3 TR

We can thus determine more accurately heat gain due to air infiltration. If the air curtains or other barriers are provided then based on the restricting factor the load would reduce further. Ideal solution would be to provide door sensors so that the door remains open only during trolley movement for loading and unloading of material.

Method of Internal and external packaging: Many times it is observed that if this aspect is not discussed in the beginning, then it creates problems. For example product which is to be cooled after it has been put in plastic pouch with no possibility of air coming in contact with the product would take much longer time to reach desired temperatures than the one which is kept in a tray for cooling and finally packaged in plastic bags. In some cases the plastic bags or boxes are provided with holes for air to enter and get in contact with the product. Typical case is with processed chicken, boxed bananas, grapes etc.

Also Certain commodities are fragile in nature such as red dried chilies which need to be stored in racks or if bags are stackedon one above the other, then the entire product due to weight of top bags gets crushed or turns into powder form and loses its market value.

The external and internal packing material also plays important role for commodities like apples, bananas, mangoes, etc. The material should be strong enough to withstand weight as also should withstand moisture damage. Many times one would have observed that inferior material if used for packing and storing, the boxes nearly are collapsed or distorted when taken out of cold rooms due to spoilage with moisture.

The external packaging should be able to withstand at least height of 2.5m of loaded products & the packaging should not collapse due to high humidity. It should allow adequate air flow over the product. The ventilation holes should not be limited only to sides but air flow coming from beneath is more effective so holes should be also on top and bottom to keep air passage free.

The internal packaging has the advantages of protecting the product against rough handling.

The choice of packaging should therefore be based on the individual requirements.

Insulation Selection in Cold Storage Design as per IS 661

Storage Temp. Range (°C)	Maximum "R" Value (m^2K/W) or x 5.678=$ft^2.h.^oF/Btu$			
	Exposed walls	Intermediate walls	Roofs	Floors
-30 to -20	5.88	2.12	7.14	5.00
-20 to -15	4.76	2.12	5.88	4.34
-15 to -4	4.34	2.12	4.76	3.70
-4 to +2	3.70	1.72	4.16	3.44
+ 2 to 10	2.85	1.07	3.44	2.12
10 to 16	2.12	1.07	3.44	1.56
16 and above	0.78	0.68	0.95	0.61

Recommended "R" Value for cold storage structure

Insulation requirements & construction practices: The desired characteristics of insulation are:-

- Low thermal conductivity
- Low moisture permeability and retention
- Fire resistant
- Light weight
- Sufficient strength
- Durability
- Ease of application
- Retain shape at extreme temperature conditions without cracking, crumbling, shifting or packing from shocks, vibrations and flexing of body structure.

From the above table one can notice that the standard recommends overall resistance value. How to achieve this value should be left to individual cold storage designer/owner depending upon available material and cost.

For example let us take a case of exposed wall which requires 3.7 m2K/W as maximum 'R' value for temperature ranging from -40C to +20C.

The conventional cold storages using brick walls and (Polystyrene) or popularly known as thermocole insulation covered with sand & cement plaster would have overall Resistance calculated as under

Taking 'R' values from the ASHRAE book

- Outside surface resistance with 25Km/h air velocity, R-0.02923m2K/W, based on outside surface conductance of 6 W/m2.K
- 12.5 mm cement plaster has Resistance as, R-0.0176 m2K/W
- 18" Brick construction wall with 100 lb/cu.ft density resistance would be, R-0.6339 m2K/W
- 100mm Expanded Polystyrene insulation, R-3.0625 m2K/W
- 12.5 mm cement plaster inside wall Resistance, R-0.0176 m2K/W
- Inside surface resistance based on still air & conductance of 1.6 W/m2.k, R=0.11 m2K/W

The total resistance to heat flow would be addition of all resistances = R1 + R2 + R3 + R4 + R5 + R6

=0.02923+0.0176+0.6339+3.0625+0.0176+0.11=3.87 m2K / W

As against this if one wishes to construct a cold room from pre insulated sandwiched, stand alone PUF panels, then assuming conductivity as 0.16 W/m2.K for PUF as per ASHRAE then overall resistance would be 3.30 m2K/W for 80 mm PUF panels. These panels are constructed with 0.5 mm galvanized sheets on either side &

powder coated or also many times in different finishes and if we add resistance to PUF thickness offered by these materials as 0.3522 m2K/W

Total Resistance will be 0.02933+3.30+0.3522+0.11 = 3.7915 m2K/W

As can be seen from above by using different materials one can achieve similar resistances, which is far more important than insisting end user to use only one type of insulation material.

Vapour Barrier: This is often neglected aspect. Designer should remember that it takes much more energy to condense water vapour compared to reducing air temperature by one deg C

To Cool 1 kg of dry air through one deg C requires only 1.006 kJ/kgda.K energy

Whereas to condense one kg of Vapor at the same temperature it Requires 2500.77 kJ/kgda.k energy

Most of the designers consider only the thickness of the insulation to be provided on the basis of temperature difference between ambient & inside conditions to reduce heat gains, since the temperature being measurable parameter, but they do not pay enough attention in providing adequate measures in preventing moisture penetration. The designers of comfort air conditioning plants are normally less concerned with this aspect as the temperature/vapour pressure differences between outside air and inside conditions are small and thus moisture penetration through structure is insignificant, however for cold rooms working at -20^{0}C, the vapour pressure difference is very high and it becomes the driving force for moisture penetration.

Similarly in blast freezers operating at -400C/95% RH (Vapour pr. 0.0915 mm of Hg and moisture content 0.0753g/kgda, with outside ambient temperatures of +400C (vapour pressure 30.9382 mm Hg and moisture content 26.51168 gm/kgda) or more, there is thus big difference in vapour pressures which is a driving force for moisture ingress in the cold storages. Since moisture ingress is invisible, it is normally overlooked but it can significantly affect the cold room conditions adversely.

It is therefore necessary to provide proper vapour barrier on the warmer side of the walls. Similarly the inside surface should never be made vapour tight, otherwise moisture entered into the insulation though outer walls 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 the moisture entered in the insulation is carried to the cooling apparatus and is then subsequently removed while defrosting the coils.

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

The properly designed vapour barrier system is the one in which rate of moisture infiltration, should be equal to rate of moisture removal by refrigeration plant without detectable condensation.

It is strongly recommended that cold storage owners/consultants and contractors seriously consider this important aspect of providing proper vapour barrier while designing/ and constructing the cold rooms, otherwise well designed refrigeration plant also may not deliver the desired performance. The cold rooms thus constructed should not only be thermally tight leak proof but also moisture vapour leak proof.

To illustrate following example would serve the purpose

Based on 2 air changes/24 hrs-Latent Load having cold Room Size -21mx16mx13 m high as per NHB standard.

Quantity of air would be room volume x2/24/3.6=4368x2/24x3.6=101 L/s and the refrigeration load due to air changes would be

= 3x L/S X Δ g/kgda

= 3x101x22.27/1000=6.86 kW or 1.95 TR

For 5000 Ton Storage- with 4 rooms additional Load 27.44 kW or 7.8 TR

The success or failure of insulation is thus entirely dependent on effectiveness of vapour barrier in preventing vapour transmission through the insulation besides serving as thermal barrier.

Evaporation & Water Loss - Importance of Humidity: Moisture removal from product leads to weight loss of the product and thus loss of revenue. All of us know that cooling coil removes moisture. From where does this moisture come from? It either comes from the trapped air inside the space or from the product. As the air is cooled it sheds moisture and the same settles on the coil, however this is a small quantity compared to water loss from the product.

Refrigeration engineers and designers must keep this important point always in our mind. If we design and select equipment so that moisture loss from the product is to be kept bare minimum then we will not be guilty of taking out moisture from the product, allow it to settle on cooling coil and then remove it from room with efficient defrost methods and then try to device ways and means to inject additional moisture to increase humidity. Majority of such efforts fail miserably since when air is saturated additional moisture injected will always be suspended moisture in mist form

Latent heat Gain from outside Air

	Db/Wb-0C	RH%	Vapour Pressure -mm Hg	Moisture content gm/kgda
OA	40.8/31.8	53.5	30.9382	26.51169
Cold Room	3/2.355	90	5.1171	4.2326
Difference			25.82	22.27

Room designed RH%	50-65	65-80	80-85	90	95
Recommended T.D. deg C	(9-12)	(6-9)	(5.5-6)	(3.8-5)	(2.8)
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SET (Saturated Evaporating Temperature at coil outlet) while selecting compressors and evaporators. SST for compressor should be selected at slightly lower temperature to take care of suction line pressure drop and heat gain, especially when the suction line is long.

Air Circulation Requirements: Many times air coolers are selected on the basis of calculated refrigeration capacity and then from the manufacturers catalogue the quantity of air is automatically provide. In low temperature applications where the product is loaded in pre cooled condition there is hardly any product load and the refrigeration unit capacity is based only on infiltration, transmission and equipment load.

The cooler capacity is therefore very small and accordingly the cfm of the fan is also less. If the room volume is sufficiently large then the air quantity provided becomes in adequate and the uniform room temperature maintenance becomes a problem. Such complaints are very common in practice. It is therefore important to provide adequate air quantity and circulation to maintain uniform room temperatures throughout the space.

ASHARE has given general guide lines for minimum air circulation rates for different applications and these should be followed over and above after checking the cooling load to ensure proper refrigeration capacity as well as adequate air volumes.

When to use Gravity feed systems and when to use Pump circulation systems: The industrial refrigeration handbook by W. F. Stoecker page 184 states. "Properly designed flooded evaporators and evaporators operating with liquid recirculation operate with equal effectiveness. What is then is the basis for choosing between flooded coils and a liquid recirculation system serving multiple coils?"

The book on Design Essentials for Refrigerated Storage Facilities page 120 sums it up nicely in few words

"The dominant refrigeration system for intermediate to large storage facilities is the liquid overfeed ammonia refrigeration system. This system is suitable for low and medium temperature cold storage."

> Positive temperature coolers should never accumulate frost. Frosting means not only loss of cooler efficiency but also excess power consumption as the compressor would be working at lower evaporating pressures.

The important words to be noted are -medium and low temperature as also intermediate and large cold storages. This means where lengthy refrigerant distribution pipe work and/ or specialized process evaporators are required. So the decision making is very simple. We need to look at our requirements and decide whether it fits into one of the above norms, if not installing a pump circulation system may not bring necessary benefits and on the other hand would increase the first cost which is difficult to recover in low priced consumables like potatoes, vegetables or other similar commodities.

One would also readily agree that cold storages for fresh fruits and vegetables commodities do not fit into bracket of medium or low temperature and choice therefore then narrowed to decide whether it is a medium or large capacity cold storage.

Having arrived at the proper decision based on above we shall now look at both advantages and disadvantages of pump circulation systems.

The use of liquid overfeeds system is therefore advantageous:

- When there are more than 4 to 6 evaporators of larger capacity in medium or large cold size cold storages.
- Plant room is located far away from the processing area where evaporators are located involving lengthy refrigerant distribution pipe work.
- Special evaporators like spiral freezers/IQF or plate freezers are involved.
- The requirement is for medium or low temperature commodity storage.

If these conditions do not exist then it would be more appropriate to go in for standard gravity flooded system design.

Defrosting of air coolers: The word 'defrost' needs to be understood clearly. Most of the cold storages, especially working on negative temperatures require defrosting periodically. It is generally observed that instead of defrosting when the frost is formed operators continue to run the plant till thick layer of ice is formed. The coil performance is best when the coil is free from frost and any frost/ice buildup drops the heat transfer ability of the coil. Hence the coolers should be defrosted more frequently to keep the coil clean as long as possible. Many cold storage owners feel that if there is frosting on the coil the performance of cooling unit is better compared to coils not getting frosted. In fact the positive temperature coolers should never accumulate frost. Frosting means not only loss of cooler efficiency but also excess power consumption as the compressor would be working at lower evaporating pressures.

If the coolers need defrosting then ideal method is hot gas defrost. The hot gas defrost is most effective since the heat is from inside and not external as in other cases. Also it consumes no additional power, quickest and least down time, but system design is complex and needs special expertise. Also it is more expensive compared to other methods. The generally misunderstood aspects in hot gas defrost is engineers feel that higher the temperature of hot gas and more the pressure better is the defrosting. Both these assumptions are wrong. The ideal defrost pressure should be 5 to 6 bar and hot gas temperature not exceeding ambient temperature.

In this presentation effort has been made to cover most of the design aspects which are normally overlooked. The operation and maintenance and use of proper controls plays important role and it could be separate subject for discussions. ■