COLD STORAGE LOAD ESTIMATING

By

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COMMON UNDERSTANDING

- Most of the designers , when requirement is received, open their computers and stat calculating cooling loads with the help of the software. The software is mixed in the sense that some units are in FPS and some are in SI system.
- I strongly suggest that the designer discusses many aspects, which even customer may not be aware and educate him and both the parties come to common understanding which is signed by both the parties, before the load calculations are made. This would avoid future disputes if they arise
- The points to be discussed are given in next slides

Design Basis Review

Location of Installation	**City, Place of installation, distance from main communication like roads, airports & available transportation facilities**
Weather data information	Dry Bulb, Wet Bulb data for the year, altitude of place, since air properties change as per altitude
Adequate utilities availability	Water, it's quality, whether tube well or corporation and availability of adequate electric power.
Waste disposal and affluent treatment facility	How customer is going to address this issue without polluting water and atmosphere
Type of product to be stored	Its characteristics, season-months when product is to be harvested and loaded in cold rooms
Through knowledge of product to be stored	Temperature/Humidity/and expected shelf life

Design Basis Review

Expected duration of storage	**Weather transit, short tem or long term and duration of each type**
Facility Type	Whether multi product or single product and whether same temperature or different temperatures.
If multi product storage	Compatibility with other products for temperature, humidity, shelf life
Quantity of product to be stored per room	Total weight, weight of each package, number of packages, density of product
Storage system	Rack system , or bulk storage, trolly movement, room height, rack height, bar coding, first in ,first out
External and internal dimension of cold room	calculated on the basis of above with enough room for air circulation so that each box or product is fully enveloped with cold air

Design Basis Review

Temperature	Product incoming and expected storage as well as expected product core temperature
Loading /removal rate	Loading per hour and per day as well as removal rate peer hour , per day
Expected temperature pull down rate	Temperature to be achieved in how many hours from incoming temperature to final/storage temperature
Product packaging method	Open type preferred or with perforated boxes. Completely sealed product will take very long time
Insulation	Type of insulation panels, thickness, and type , whether continuous or cam lock
Door Details	Number , size, frequency of opening. Duration, door protection –weather air curtain or plastic curtain
Ante room	Whether provided or not

COMPONENTS CONTRIBUTING HEAT LOAD

1. Transmission Load- Through walls, roof, Floor
2. Product Load
   - Sensible Heat load –Before & After Freezing
   - Latent Heat Load-during Freezing
   - Respiration load

3. Air Change Load- Infiltration & Ventilation
4. Fan Motor Load
5. Lighting Load
6. Occupancy Load
7. Base Load-Trolleys, Fork lifts etc.

THE FACTORS CONTRIBUTING TO HEAT LOAD ARE:

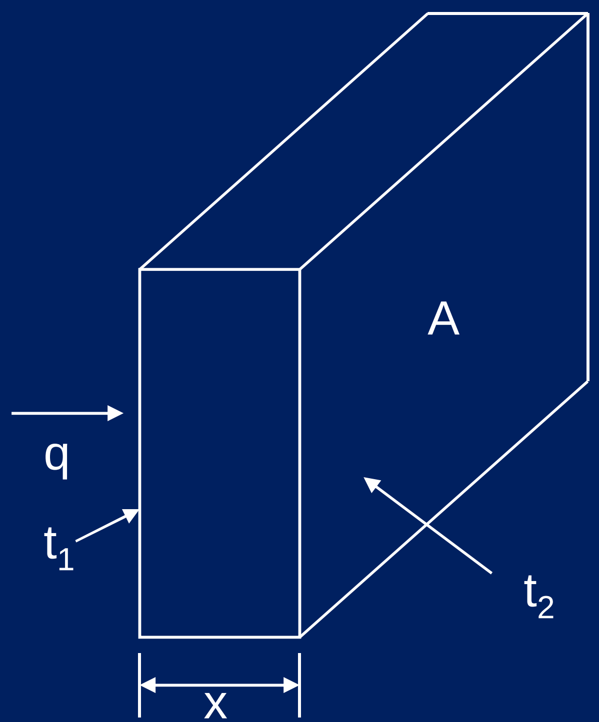
1. Transmission load:

Heat inflow from outside the building surfaces like walls, roof and floor due to higher ambient temperature than the temperature requirements inside the cold rooms.

1. TRANSMISSION LOAD

- Type of Construction
- Type of Insulation & Thickness
- Exposed Surface Area
- Temperature Difference
- Building shape
- Direction of East ,West and longitudinal walls
- Roof protection

TRANSMISSION LOAD



$$q = k/x\ .A\ .\ (t_1 - t_2)$$

q= rate of heat transfer, W (Btu/hr)

k= conductivity of material, W/m.K (Btu/hr.ft Deg F)

A= cross-sectional area of wall, m^2(ft^2)

x= thickness of wall, m (ft)

t_1 & t_2 = temperatures on opposite surfaces of wall, Deg C (F)

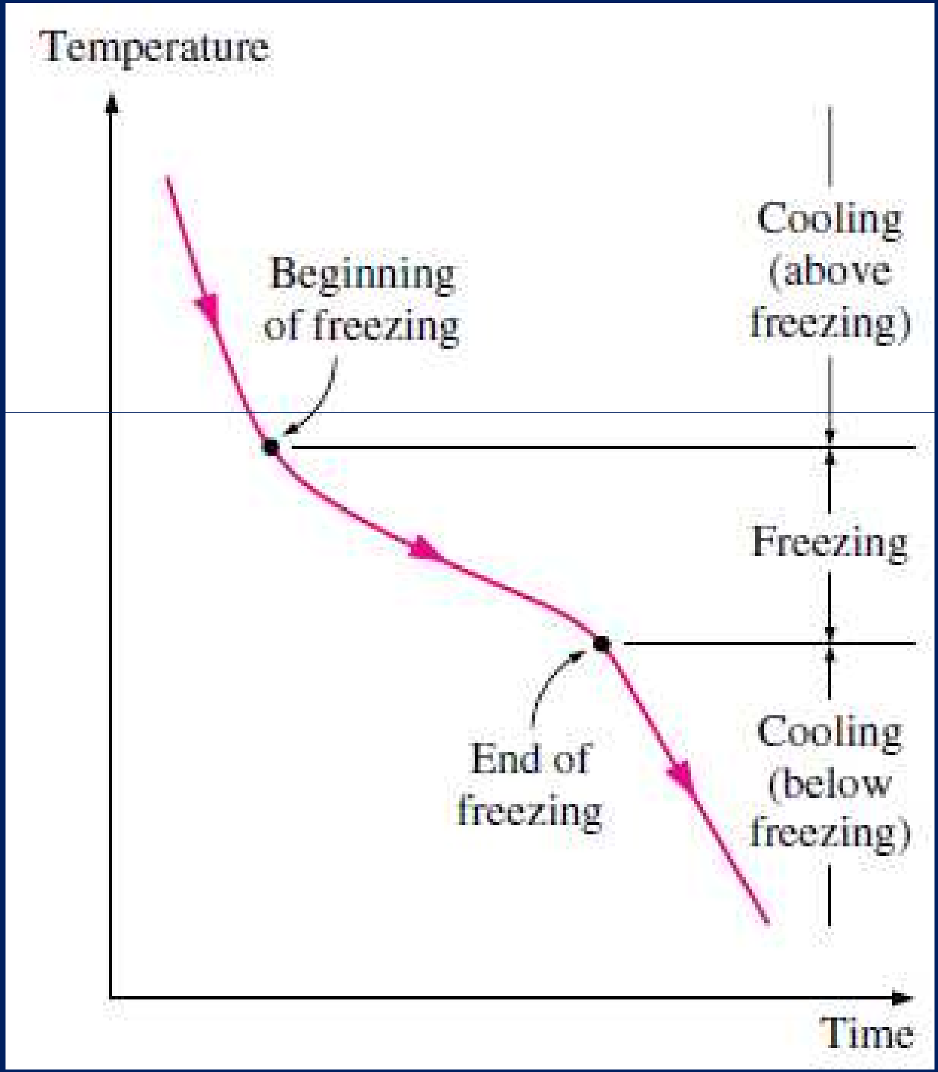
TRANSMISSION LOAD

- $Q = U \times A \times \Delta T$
- Q= Total Heat Transfer-kW
- U= Over all Heat Transfer Coefficient-$W/m^2.K = K/x$
- A= External Area of walls. Roof, Floors in Sq. m.

2. PRODUCT LOAD:

- Product load comprises of Sensible Load above freezing
- Latent load of freezing
- Then again sensible heat load below freezing temperatures.
- Product may be entering at ambient conditions or precooled condition or in frozen temperature condition.

FREEZING CURVE OF FOODS- TAKES LONGER TIME FOR FREEZING



3. RESPITATION LOAD-ONLY FOR FRUITS/VEGETABLES

During growth in fields, fruits and vegetables are supplied with sugar from leaves through photosynthesis and with water and minerals through roots.

Once harvested, this supply is cut off, but plants continue to respire and mature. They have to depend on their own internal resources to generate energy required for metabolism.

Even in refrigerated storage of live products, they generate heat, which is called heat of respiration. They continuously undergo a change in which energy is released in the form of heat,. Respiration load therefore needs be considered while calculating heat load.

Respiration load is highest when products are loaded and gradually diminishes as the product gets cooled.

4. INFILTRATION LOAD (BY DEFAULT):

Ambient or outside air leaking in, having higher temperature and moisture content, whenever the doors of cold rooms are opened for movement of goods or air leaking in through cracks, openings in the insulated walls/ceiling and flooring.

Calculation of this load need many details such as door sizes, number of doors, duration of door opening, air velocity etc. For simplicity, there is also a table published by ASHRE Handbook -Fundamental 1972, where based on room volume approximate air changes are given.

Also, it should be kept in mind that many cold storages have Ante rooms, pre-cooling rooms and hence air leaking inside the cold room may not be entirely ambient air.

AIR CIRCULATION

Please also remember the difference between air changes and air circulation rate.

Air changes is outside air contributing to load calculations

Air circulation rate is how many times the air passes over the cooling coil. The air circulation rate is important to ensure that the temperature variation inside the cold room is minimum and the air pockets are not formed. If air quantity is inadequate and circulation is not uniform, it can lead to **aging** of air. Air circulation rate depends on the quantity of air circulated by the fans

VENTILATION LOAD (BY DESIGN):

Certain vegetables and fruits like potatoes, bananas produce gases like Ethylene, Carbon dioxide etc. .

one need to control the concentration of them by removing them and substituting with fresh air.

This ventilation load is by design. For this purpose, fans are provided this is known as force ventilation whereas infiltration is by default.

There is heat recovery equipment installed which cools outside air entering by air which is expelled out

We are considering only infiltration load for this particular document.

OTHER MISCELLANEOUS LOADS

1. **Equipment load:** Fans-motors of the air coolers, fan ring heaters, defrost heaters if any, Electrical equipment if any like forklifts / electrical hoists or lifts for handling the products or belt motor loads, cranes motor loads etc.

2. **Occupancy load:** People entering the cold room for loading/unloading the goods

3. **Lighting load**: Lighting fixtures inside the cold rooms, if the lights remaining on during storage

4. **Base Load**: Metal trolleys, racks, baskets, trays, heaters in the flooring etc., contributing heat load.

5. **Defrost heat load**: When air coolers are defrosted for low temperature storages, certain heat gets added and needs to be considered in the overall heat load for offsetting the same.

ASSUMPTIONS:

1. Product-Potatoes
2. Location- Uttar Pradesh
3. Outside temperature -+45^{0}C max Db/+30^{0}C Wb (page 38 sr. No. ii &iii)
4. Product loading temperature 20^{0}C-25^{0}C-max (sr. no. vii)
5. Each bag weighing -50 kg**. (**sr.no. viii**)**
6. Total storage Capacity-5000 Metric Ton (sr. no. ix)
7. Loading Density- 3.4 m^3/Metric Ton - NHB Standard-Page 44
8. Each Room storage-1250 Ton- (1250x3.4=4250m^3) (sr. no. x)
9. Chamber Size each -21mLx16mWx13.7mH -Volume 4603 m^3, floor Area=226 m^2 (sr. no. xi)
10. Loading rate- 4% of total capacity/day= 1250x0.4=50 Ton or 50000 kg/day (sr.no. xii)

11. Pull down Time: 15^0C in 24 hrs. (sr. no. xiii)

12. Compressor running hours -20 hrs./day during pull down (sr. no. xiv)

13. Ventilation requirements- 2 to 6 air changes per day to maintain CO2 concentration below 4000PPM-(Page 4- 2-h)

14. Insulation PUF -32 kg/m^3 density, 0.023 W/m.k –K value (page-10) (ASHRAE Refrigeration Hand Book Page 24.1 Table-1) Although NHB standard indicates 32kg/cm^2 density, normal practice is to use minimum 38kg/cm^2 which is standard

15. Thickness of insulation-walls, roof, floor- 100 mm (NHB standard Page -10)

16. Specific heat of potato above freezing-3.433 kJ/kg.k (NHB standard Page-51)

17. Heat Of Respiration 0.018W/kg at 3^0C (ASHRAE Refrigeration hand Book 2014-page 19.22) or 18kW/ton- Also NHB standard - Page 51

18. Safety factor 0f 10% considered (NHB standard Page 39 Point 4) whereas

19. Diversity factor not considered since it is load calculation for one room only.

POSITIVE TEMPERATURE LOAD CALCULATIONS

POTATO COLD STORAGE LOAD CALCULATIONS
5000-TONS STORAGE-(4 ROOMS, EACH 1250TON)

BASIS NHB STANDARD-NHB-CS-TYPE 01-2010

THE NHB STANDARD 01-2010 GIVES SUMMARY OF COOLING LOAD CALCULATION ON PAGE 40 FOR

1. 5-A-Loading & pull down the temperature to 15^0C per chamber
2. 5-B During pull down to 3^0C @ 0.5^0C per day-Fully loaded per chamber
3. 5-C During Holding period at $+3^0$C-with full load per chamber

Page 38 & 39 gives the assumptions for 5000MT Potato Cold storage & suggested typical layout of Chambers

The maximum refrigeration load is during loading and pull down to 15^0C for 1000 Bags/day per chamber of potatoes each bag weighing 50 kg thus totaling to 50 Tons/day per chamber (4% of 1250 Tons) and the cooling load indicated is **85.32 kW (24.37 TR**) per chamber.

The detailed calculations how individual values have been arrived at is not given in the standard.

This document is therefore prepared giving detailed load calculations so that it would then become easier for the consultant/contractor/end user to calculate the cooling load if the conditions are different than indicated in the standard.

The document gives basic equations and formulae and would therefore also help to calculate refrigeration load for any other commodity with different conditions and parameters of room sizes, storage capacity, and insulation type used etc. for positive temperature cold storages.

1-TRANSMISSION LOAD WITH STANDARD BRICK WALL CONSTRUCTION

The current practice is to use PUF panels for construction, however the designer should know if the construction is different, then how to calculate the transmission load.

If the old type of construction comprising of brick wall, insulation and cement parameter is used then we need to calculate overall resistance offered by each element for heat flow and then a reciprocal of it to calculate overall heat transfer coefficient ‘U’ We shall calculate resistance offered by each element and have illustrated same in the table given below.

1	2	3	4	5
Item	**Thickness - inch**	**Resistance- R-ft^2. h.^{0}F/Btu**	**Thickness- m**	**Resistance- R- m^2. K/W**
F_o-outside air	**15mph- velocity**	**1/6=0.166**	**25kmh- velocity**	**1/11 = 0.0909**
Cement plaster	**½"**	**0.5/5 = 0.1**	**20mm**	**0.017**
Brick wall	**18" (100lb/cu.ft)**	**18/5 = 3.6**	**450mm**	**0.45/0.92 = 0.489**
Insulation	**4Inch EPF**	**4/0.18 = 22.22**	**100mm**	**0.1/0.023= 4.347**
Cement Plaster	**½"**	**0.5/5 = 0.1**	**20mm**	**0.017**
F_i-inside air	**Still air**	**1/1.6 = 0.625**		**1/9.5 = 0.105**
Total Resistance		**26.8110**		**5.066**

The most important point to be noted is that the resistance offered by insulating material indicated in **RED**, is far greater compared with any other resistances offered by the thick walls and air films and also by cement plaster.

With modern construction of cold storages, using PUF factory made panels it is therefore adequate to take only resistance offered by insulation panels for the sake of simplicity and neglect other resistances especially where the insulation thickness is 100mm or more.

1. TRANSMISSION LOAD

We shall now consider each factor for this typical NHB presented data on page 40 (only PUF panel resistance is considered)

Temperature pull-down from 45^{0}C to 15^{0}C in 24hrs.

Q= U x A x TD

=0.023/0.1 x 2 x (21x16+21x13.7+16x13.7) x (45-15) - (100m=0.1m)

=0.23 x1685.8x30 =11632.02 W say **11.63 kW**

(NHB standard 12.12 kW)

2. PRODUCT LOAD

= 4% of 1250 Ton (1250x1000x4/100=50,000kg))x sp.ht. x ΔT

= 50,000 kg x 3.433 kJ/kg. K x (25-15)

= 1,716,500 ÷ (24x3600) = **19.87 kW**

Assuming remaining (1,250 – 50 = 1200 Ton) or 1,200,000 kg Potatoes are already in store, & refrigeration load on the last day of loading is considered then respiration load would be

Respiration load =1,200,000 x 0.018 = 21,600W = **21.6 kW**

Total Product load would be 19.87+ 21.6= **41.47 kW say 42 kW**

(NHB standard-43.16kW)

3. INFILTRATION LOAD:

Based on 4 air changes/day (2 to 6 Indicated in NHB standard), outside enthalpy h_2 is 99.173kJ/kg at 45^0C Db &30^0C Wb and inside enthalpy h_1 at 3^0C 90% RH-13.62 kJ/kg, Δh=85.553.

The values have been taken from Psychrometric property tables for moist air.

Amount of ventilation air for

4603 (volume of room m^3) x4 air changes ÷ (24x3.6) = 213 LPS

Using standard formula for total heat load as ==1.2 x l/s x (Δh)

= 1.2x 213 x85.53/1000=21.86 kW with 70% recovery it would be **15.3 kW**- **(NHB standard-16.14kW)**

OTHER LOADS

5. INTERNAL LOAD DUE TO FAN MOTORS- Assuming 4 coolers per room each with 2 fans of 0.75 kW= total motor power is 6 kW. Power contributed to heat load 993W per motor 8x0.933=**7.94 kW**

6. LIGHTING DENSITY -at 10 W /m^2. during loading =226m^2 floor area x10 W/m^2= **2.6 kW**

7. OCCUPANCY LOAD: - Assuming 4 persons working inside cold room during loading each person would be contributing 250 Wx4 = **1 kW**

TOTAL INTERNAL LOAD= 7.94+ 2.6 + 1 =11.54kW

Refrigeration Load summary - per Chamber each of 1250 Ton storage capacity

Sr. No.	Description	Refrigeration Load- kW/24 hrs As Per NHB standard-Page 40	Calculated as Above
1	Transmission Load	12.12	11.63
2	Product Load	43.16	42
3	Internal Load	5.25	3.6
4	Infiltration & Ventilation Air Load	16.14	15.3
5	Equipment Load-Fan motors	8.65	7.94
6	Total Load	85.32 (24.37 TR)	80.47x1.1 Safety Factor-88.517 kW

Considering compressor running time of 20 hrs, Total capacity required would be 89.517x24/20=106.22 **kW** per room. The standard is for 5000 Tons having 4 rooms. Hence total plant capacity required during loading is 106.22x4=424.88 **kW**

Refrigeration System Capacity Recommended in NHB standard at +2 ^{0}C SST and +38^{0}C SCT is 469.7 kW-Page 42 - 6-ii

LOAD CALCULATIONS FOR NEGATIVE TEMPERATURE COLD ROOM AT-20^{0}C AND FOR PROCESS FREEZING AT -40^{0}C

- We shall combine both these designs in one calculation program with the assumption that the end user has installed freezing process equipment to freeze at -40^{0}C,as well as the facility for storing processed frozen product in the same premises at -20^{0}C.

THE PRODUCT HAS TO BE COOLED AS UNDER

1.first from ambient temperature to some lower temperature above freezing point which is sensible heat removal, known as pre-cooling

$Q_1=m.Cp_1\ (t_1-t_2)$

2.Cool product further to lower temperature to reach freezing point. $Q_2=mCp_1(t_2-t_f)$ or from t_1 to $t_{f\ again}$ sensible heat process.

3. Heat removed to freeze product-latent heat process $Q_3=m \times h_{if}$

4.The cool the product from freezing point to storage temperature which is again sensible cooling process $Q_4=mCp_3(t_{if}-t_3)$

Where:

1. Q1, Q2, Q3, Q4 are =Heat removed- kJ
2. q=average cooling load in kW=kJ/second
3. Cp_1 =Specific heat of product above freezing-kJ/kg.K
4. t_1= initial temperature of product above freezing^{0}C
5. t_2= Lower temperature below ambient temperature after pre-cooling but above freezing temperature
6. t_f=Freezing temperature^{0}C
7. h_{if}=latent heat of freezing-kJ/kg
8. Cp_2= Specific heat below freezing-kJ/kg.K
9. t_3= Final temperature of product below freezing^{0}C
10. Cp_3-Specific heat below freezing-kJ/kg.K
11. m=mass of product -kg

n=allocated time in hours for processing

For the purpose of load calculations, we shall consider fish as a product to be frozen at -40^{0}C, and preserved at -20^{0}C temperature in a cold storage.

There are 3 freezing processes which are normally used

1. **IQF/Spiral Freezer**- Individual quick freezing-continuous process- for identical product like shrimps
2. **Blast freezing**-Batch production for mix size & type of fish-Normally 6 hrs. freezing time for each cycle including loading and unloading time.
3. **Plate freezers**- Batch production for fish of small size and uniform variety or fish paste or any other slabs etc.-Normally 2 hours per batch including loading/unloading time

For load calculations, we shall consider blast freezer batch

Assumptions: We shall maintain the same assumptions mentioned for positive temperature for this calculation as regards ambient conditions, room size for cold room etc. except wherever there is a different requirement.

1. Quantity of fish per batch-5 tons
2. Room size of blast freezer room-7.6mLx3.7mWx2.4m high
3. Pre-cooling is done with ice before loading and loading temperature in blast freezer would be say +10^{0}C
4. Normally there is ante room and fish is loaded in trolleys with perforated trays open to air, from anteroom which is maintained below +20^{0}C
5. Quantity to be frozen per batch -5 tons of assorted fish-(5000kg)
6. Specific heat of fish above freezing-3.78kJ/kg.K
7. Freezing point of fish -Minus 2.2^{0}C

8.Latent heat -271kJ/kg

9.Specific heat below freezing-2.14kJ/kg.K

10. Product freezing temperature maintained in refrigeration system-minus 40^{0}C, to circulate air at minus 37 to minus 35^{0}C, with the air cooler in blast freezer room

11. Insulation thickness -200mm for blast freezer room (more since lower temperature of -40^{0}C)

12. Core temperature of product at the end of freezing cycle-minus 18^{0}C

13. Insulation Thickness for cold room -150mm-increased as temperature is lower at -20^{0}C

14. Batch time -6 hrs. (5 hours for freeing and one hour for loading unloading, and defrosting)

Compressor running time -18hrs -3batches per day

LOAD CALCULATIONS FOR FREEZING IN BLAST FREEZER

Transmission load for blast freezer room	0.115x2x(7.6x3.7+7.6x2.4+3.7x 2.4) x40-(-35) ÷1000	0.952kW
Product load- Sensible before freezing	5000x3.78x10- (-2.2)/5x3600	12.81kW
Product freezing load-latent heat load	5000/5x271÷3600	75.27kW
Product load below freezing- sensible load	5000/x2.14x17.8(20- 2.2)/5x3600	10.58kW
Total product load		99.2kW
Fan motor load	3 fan each of 5kW-(Require large quantity of air for quick freezing- 40 to 80 air changes as per ASHRAE)	15.0 kW
Total load		114.13kW
Add 10% safety		125,54kW
Refrigeration plant capacity	with compressor running time 18 hours 107.11x24/18	167.4kW

We now need to calculate load requirement for storing this product at -20^{0}C in a cold room.

For the purpose of cold room calculations, we shall use the same parameters as positive room cold room design except wherever there is deviation due to lower temperature.

1. Normally product is loaded after packaging and arranging on racks and in the process some temperature rise takes place. Let us assume product is loaded at -12^{0}C
2. There would insulation thickness of 150mm since it is low temperature -20^{0}C storage room
3. The air leaking in will be from process hall at say +20^{0}C instead at ambient conditions-Enthalpy to be taken accordingly
4. Air changes -2/day=0.125l/sec
5. Product storage capcity-500Tons
6. Hourly loading-3 batches of production will produce 18 tons/day-18000/24=750kg

LOAD CALCULATIONS FOR -20^{0}C ROOM

Transmission load	.023/0.150=0.1533x1932x40	11.85kW
Product load	750x2.14x(20-12)/3600	3.57kW
Air infiltration	1.204x0.125x(51.81+18)	10.50kW
Other loads -fans trolleys etc. -say		13kW
Total load		38.92kW
Adding 10% safety factor		42.81kW
Refrigeration capacity based on 18hrs running	42.81x24/18	57kW

Thank you

Any Questions ?

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