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Refrigeration and Air conditioning Engineering.
3rd year – refrigeration and Air conditioning Course

Lecture - 21 – COLD STORE LOAD part 1

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CHAPTER SEVEN

Cold store

7.1 Refrigeration load:

The load, which is heat transferred into the refrigerated space segments of total refrigeration load are:

1. .Transmission through its surface.
2. Product load, which is heat removed from and produced by products brought into and kept in the refrigerated space.
3. Internal load, which is heat produced by internal sources, e.g., lights, electric motors, and people working in the space.
4. Infiltration air load, which is heat gain associated with air entering the refrigerated space.
5. Equipment-related load.

The first four segments of load constitute the net heat load for which a refrigeration system is to be provided; the fifth segment consists of all heat gains created by the refrigerating equipment.

Thus, net heat load plus equipment heat load is the total refrigeration load for which a compressor must be selected.

7-1-1 TRANSMISSION LOAD:

Sensible heat gain through walls, floor, and ceiling is calculated at steady state as:

$Q = U.A.\Delta T$

Q: Heat transfer rate through outer surface of wall (W)

A: Outer surface of the wall (m^2)

ΔT: Temperature difference between outside and inside air

U: Overall heat transfer coefficient (W/m^2 K), and can be calculated as follows:

$$U = \frac{1}{\frac{1}{h_i}+\frac{x}{k}+\frac{1}{h_o}}$$

Where:

U: Overall heat transfer coefficient, W/m^2·K.

x: Wall thickness, m.

k: thermal conductivity of wall material, W/m. K

h_i: Inside surface conductance, W/m^2·K.

h_o: Outside surface conductance, W/m^2·K.

A value of 9.3 W/m^2·K. for $\boldsymbol{h_i}$ and $\boldsymbol{h_o}$ is frequently used for still air.

If the outer surface is exposed to 24 km/h wind, $\boldsymbol{h_o}$ is increased to 34 W/m^2·K.

With thick walls and low conductivity, the resistance x/k makes U so small **that $\frac{1}{h_i}$ and $\frac{1}{h_o}$ have little effect and can be omitted from the calculation.**

Walls are usually made of more than one material; therefore, the value x/k represents the composite resistance of the materials. The U-factor for a wall with flat parallel surfaces of materials 1, 2, and 3 is given by the following equation:

$$U = \frac{1}{\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{x_3}{k_3}}$$

The thermal conductivity of several cold store insulations are listed in Table (7-1). These values decrease with age. The metal surfaces of prefabricated or insulated panels have a negligible effect on thermal performance and should not be considered in calculating the U-factor.

Table (7-2) lists minimum insulation thicknesses of expanded polyisocyanurate board recommended by the refrigeration industry.

In most cases the temperature difference (Δt) can be adjusted to compensate for solar effect on the heat load. The values given in Table (7-3) apply over a 24-h period and are added to the ambient temperature when calculating wall heat gain

Latent heat gain due to moisture transmission through walls, floors, and ceilings of modern refrigerated facilities is negligible.

Table (7-1) Thermal conductivity of cold store Insulation:

Insulation	**Thermal Conductivity k, W/(m·K)**
Polyurethane board (R-11 expanded)	0.023 to 0.026
Polyisocyanurate, cellular (R-141b expanded)	0.027
Polystyrene, extruded (R-142b)	0.035
Polystyrene, expanded (R-142b)	0.037
Corkboard[b]	0.043
Foam glass[c]	0.044

a Values are for a mean temperature of 75°F and insulation is aged 180 days.
b Seldom used insulation. Data is only for reference.
c Virtually no effects due to aging.

Table (7-2) Minimum Insulation Thickness

Storage Temperature	**Expanded Polyisocyanurate Thickness (mm)**
10 to 16	50
4 to 10	50
-4 to 4	50
-9 to -4	75
-18 to -9	75
-26 to -18	100
-40 t0 -26	125

Table (7-3) Allowance for Sun Effect

Typical Surface Types	East Wall °C	South Wall °C	West Wall °C	Flat Roof °C
Dark colored surfaces				
Slate roofing Tar roofing Black paint	5	3	5	11
Medium colored surfaces				
Unpainted wood, Brick, Red tile Dark cement Red, gray, or green paint	4	3	4	9
Light colored surfaces				
White stone Light colored cement White paint	3	2	3	5

7-1-2 PRODUCT LOAD:

The primary refrigeration load from products brought into and kept in the refrigerated space are (1) the heat that must be removed to reduce the product temperature to storage temperature .(2) and the heat generated by products in storage, mainly fruits and vegetables.

The quantity of heat to be removed can be calculated as follows:

1- Heat removed to cool from the initial temperature to some lower temperature above freezing:

$Q_1 = m.C_u.(T_1 - T_2)$

Q_1: Heat removed to cool food. (kJ)

m: Mass of food (kg)
C_u: Specific heat of unfrozen food Eq. (6-3) kJ/kg K
T_1: Initial temperature (^oC)
T_2: Lower temperature above initial freezing temp. (^oC)
2- Heat removed to cool from the initial temperature to the freezing point of the product, in kJ:
$Q_2 = m.C_u.\left(T_2 - T_f\right)$
T_f: Initial freezing point (table 6-1) (^oC)
3- Heat removed to freeze the product in kJ
$Q_3 = m.x_{wo}.h_{if}$
x_{wo}: Mass fraction of water in food (table 6-1)
h_{if}: Enthalpy of fusion equals 333.6 kJ/kg.
Heat removed to cool from the freezing point to the final temperature below the freezing point, in kJ.
$Q_4 = m.C_a.\left(T_f - T_3\right)$
C_a: Specific heat of frozen food (Eq. 6-3) (kJ/kg K)
T_3: Final freezing temperature (^oC)

The refrigeration capacity required for products brought into storage is determined from the time allotted for heat removal and assumes that the product is properly exposed to remove the heat in that time. The calculation is:

$$Q = \frac{Q_1+Q_2+Q_3+Q_4}{3600.24.n}$$

n: no. of day

5-Fresh fruits and vegetables respire and release heat during storage.

This heat produced by respiration varies with the product and its temperature; the colder the product, the less the heat of respiration.

Example 1

100 kg of lean beef is to be cooled from 18 to 4°C, then frozen and cooled to −18°C.

Solution:

From table (6-1) the mass fraction of water in lean beef is 0.717

the initial freezing point is (-1.7 ^{o}C). and x_p=0.2124

1- Heat removed to cool from the initial temperature to some lower temperature above freezing:

$$Q_1 = m.C_u.(T_1 - T_2)$$
$$C_u = 4.19 - 2.3x_s - 0.628x_s^3$$
$$x_s = 1 - x_{wo} = 1 - 0.717 = 0.283$$
$$C_u = 4.19 - 2.3x_s - 0.628x_s^3$$
$$C_u = 4.19 - 2.3 \times 0.283 - 0.628 \times 0.283^3 = 3.524 \frac{kJ}{kg.K}$$
$$Q_1 = m.C_u.(T_1 - T_2) = 100 \times 3.524 \times (18 - 4) = 4935\ kJ$$

2-Heat removed to cool from the initial temperature to the freezing point of the product, in kJ:

$$Q_2 = m.C_u.\left(T_2 - T_f\right)$$

$Q_2 = m.C_u.(T_2 - T_f) = 100 \times 3.524 \times (4 - (-1.7)) = 2009\ kJ$

3-Heat removed to freeze the product in kJ

$Q_3 = m.x_{wo}.h_{if}$

$Q_3 = 100 \times 0.717 \times 333.6 = 23919\ kJ$

4- Heat removed to cool from the freezing point to the final temperature below the freezing point, in kJ.

$Q_4 = m.C_a.(T_f - T_3)$

$c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}$

$x_b = 0.4.x_p$

$x_b = 0.4 \times 0.2124 = 0.085$

$c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}$

$c_a = 1.55 + 1.26 \times 0.283 + \frac{(0.717 - 0.085) \times 333.6 \times -1.7}{(-18^2)} = 1.9 \frac{kJ}{kg.K}$

$Q_4 = m.C_a.(T_f - T_3)$

$= 100 \times 1.9 \times (-1.7 - (-18)) = 3018\ kJ$

$Q_t = Q_1 + Q_2 + Q_3 + Q_4$

$Q_t = 4935 + 2009 + 23919 + 3018 = 33881\ kJ$

7.2 INTERNAL LOAD:

7.2.1 Electrical Equipment.

All electrical energy dissipated in the refrigerated space (from lights, motors, heaters, and other equipment) must be included in the internal heat load.

Heat equivalents of electric motors are listed in Table 27.

7.2.2 Fork Lifts. Fork lifts in some facilities can be a large and variable contributor to the load.

While many fork lifts may be in a space at one time, they do not all operate at the same energy level.

For example, the energy used by a fork lift while it is elevating or lowering forks is different than when it is moving.

7.2.3 Processing Equipment. Grinding, mixing, or even cooking equipment may be in the refrigerated areas of food processing plants.

Other heat sources include equipment for packaging, glue melting, or shrink wrapping. Another possible load is the makeup air for equipment that exhausts air from a refrigerated space.

7.2.4 People. People add to the heat load, and this load varies depending on such factors as room temperature, type of work being done, type of clothing worn, and size of the person.

Heat load from a person Qp may be estimated as:

$$Q_p = 272 - 6.T$$

T: Temperature of the refrigerated space in °C

7.3 Infiltration by Direct Flow through Doorways:

In refrigerated spaces equipped with constantly or frequently open doorways or other through-the room passageways, this air flows directly through the doorway.

The load imposed on the cold store can calculated from the following equation:

$$Q_{inf} = 1.2 \times \dot{V}[(T_o - T_{in}) + 2500 \times (g_o - g_i)]$$

T_o: Outdoor temperature (^{o}C)

T_{in}: Cold store temperature (^{o}C)

g_o: Moisture content of outdoor air (kg_w/kg_a)

g_i: Moisture content of indoor air (kg_w/kg_a)

$\dot{V}$: Volume flow rate of air (lit/s)

$$\dot{V} = 3.8\sqrt{h}.\sqrt{\Delta T}$$

h: Door height (m)

ΔT: Difference between outside and inside temperatures (^oC)

Example2:

In cold store uses Expanded Polyisocyanurate for walls, ceilings and floors. Used to store a quantity of butter at-20 ℃ and 90% RH, the butter is cooled firstly from initial temperature of 15^{o}C to initial freezing temperature, then freezes from initial freezing temperature to the final temperature of -20 ℃ . If the stored capacity 480 ton. 10 people working at the store 12 hours a day, the lighting in the store 20 W/m^2 operate continuously. Calculate the cold store load. If the outdoor conditions are dry bulb temperature equals of 40 ℃ and 50 RH. If the time required to cool and freezes the butter is 24 hr. calculate the cooling load of the cold store. Assume freezing point of butter is (- 5.6 ^{o}C). The dimensions of the cold store are 16 m Long, 10 m wide and 6 m height. There is one door of dimensions of 3m ×3m. Assume the maximum wall area facing north.

Solution

From table (6-1) the properties of butter as follows:

	Moisture Content, %	Protein, %	Fat, %	Carbohydrate, %	Fiber, %	Ash, %	Initial Freezing Point,	Specific Heat Above Freezing,	Specific Heat Below Freezing
Butter	17.9	0.85	81.11	0.06	0.0	0.04	—	2.18	—

From table (7-1) the thermal conductivity of Expanded Polyisocyanurate is 0.027 W/m. K,

while from table (7-2) the thickness of Expanded Polyisocyanurate is 100 mm.
The heat transfer coefficient of the wall is:

$$U = \frac{k}{x} = \frac{0.027}{0.1} = 0.27 \; W/m^2K$$

Then freezes from initial freezing temperature to the final temperature of -20 ℃
The addition on the temperature difference can be found from table (7-3) assuming dark color wall. The heat gain through store is as follows

Table (7-3) Allowance for Sun Effect

Typical Surface Types	East Wall ℃	South Wall ℃	West Wall ℃	Flat Roof ℃
Dark colored surfaces				
Slate roofing Tar roofing Black paint	5	3	5	11

	U	A	$\Delta T + correction\ (table - 3)$	Load
Qw/W =	0.27	10×6	× (40-(-20))+5	= 1053
Qw/N =	0.27	16× 6	× (40-(-20))	= 1555
Qw/E =	0.27	10×6	× (40-(-20))+5	= 1053
Qw/S =	0.27	16×6	× (40-(-20))+3	= 1633
Qr =	0.27	10×16	× (40-(-20))+11	= 3068
Total				8362

Product load:

Food Item	Moisture Content, % x_{wo}	Protein, % x_p	Fat, % x_f	Carbohydrate, % x_c	Fiber, % x_{fb}	Ash, % x_a	Initial Freezing Point, °C	Specific Heat Above Freezing, kJ/(kg·K)	Specific Heat Below Freezing kJ/(kg·K)
Butter	17.9	0.85	81.11	0.06	0.0	0.04	—	2.18	—

Load due to cooling butter from initial temperature to initial freezing point

$$Q_1 = m.C_u.(T_1 - T_2)$$

$$C_u = 4.19 - 2.3x_s - 0.628x_s^3$$

$$x_s = 1 - x_{wo} = 1 - 0.179 = 0.821$$

$$C_u = 4.19 - 2.3x_s - 0.628x_s^3$$

$$C_u = 4.19 - 2.3 \times 0.821 - 0.628 \times 0.821^3 = 1.951 \frac{kJ}{kg.K}$$

$$Q_1 = m.C_u.\left(T_1 - T_f\right)$$

$$Q_1 = (480000 \times 1.951 \times \left(15 - (-5.6)\right)$$

$$Q_1 = 19291488k\,J$$

Heat removed to freeze the product in kJ

$$Q_3 = m.x_{wo}.h_{if}$$

$$Q_3 = 480000 \times 0.197 \times 333.6 = 31545216 \ kJ$$

Food Item	Moisture Content, % x_{wo}	Protein, % x_p	Fat, % x_f	Carbohydrate, % x_c	Fiber, % x_{fb}	Ash, % x_a	Initial Freezing Point, °C	Specific Heat Above Freezing, kJ/(kg·K)	Specific Heat Below Freezing kJ/(kg·K)
Butter	17.9	0.85	81.11	0.06	0.0	0.04	—	2.18	—

Heat removed to cool from the freezing point to the final temperature below the freezing point, in kJ.

$$Q_4 = m.C_a.\left(T_f - T_3\right)$$

$$c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}$$

$$x_b = 0.4.x_p$$

$$x_b = 0.4 \times 0.0085 = 0.0034$$

$$c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}$$

$$c_a = 1.55 + 1.26 \times 0.821 + \frac{(0.197 - 0.0034) \times 333.6 \times -5.6}{(-20^2)} = 1.68 \ \frac{kJ}{kg.K}$$

$$Q_4 = m.C_a.\left(T_f - T_3\right) = 480000 \ \times 1.68 \times \left(-5.6 - (-20)\right)$$

$$Q_4 = 12967348 \ kJ$$

$$Q_t = Q_1 + Q_3 + Q_4 = 19291488 + 31545216 \ + 12967348 = 73300704kJ$$

$$Q = \frac{Q_1 + Q_2 + Q_3 + Q_4}{3600.n} = \frac{19291488 + 31545216 \ + 12967348}{3600 \times 24} = \mathbf{738.5} \ \boldsymbol{kW}$$

Heat load from a person Qp

$$Q_p = 272 - \mathbf{6}.T = 10 \times \left(272 - 6 \times (-20)\right) \times \frac{12}{24} = 1960 \ W = 1.96 \text{ kW}$$

Lighting load

Q= 20*(16*10)= 3200 W=3.2 kW

Infiltration by Direct Flow Through Doorways

$$Q_{inf} = 1.2 \times \dot{V}[(T_o - T_{in}) + 2500 \times (g_o - g_i)]$$

$$\dot{V} = 3.8\sqrt{h}.\sqrt{\Delta T} = 3.8 \times \sqrt{3}.\sqrt{40 - (-20)} = 51 \ lit/s$$

From pshychrometric chart

go=0.0229 kgw/kga,

gi=0.00055 kgw/kga

$$Q_{inf} = 1.2 \times \dot{V}[(T_o - T_{in}) + 2500 \times (g_o - g_i)]$$

$$Q_{inf} = 1.2 \times 51 \times [(40+20) + 2500(0.0229 - 0.00055)]$$

$$Q_{inf} = 1.21 \times 51 \times (60+56) = 7100\ W = 7.1 \text{ kW}$$

Total load

$$Q_t = 8.362 + \mathbf{738.5} + 1.960 + 3.200 + 7.100 = 759 \text{ k}W$$

Transmission | Product | Persons | Lighting | Infiltration

$$Q_t = 8.362 + \mathbf{738.5} + 1.960 + 3.200 + 7.100 = 759 \text{ k}W$$

It can be seen that the storage load is

تم حذف 738.5

$$Q_t = 8.362 + \square + 1.960 + 3.200 + 7.100 = \mathbf{20.622\ kW}$$

While the cooling and freezing load = 738.5 kW

Then the percentage of storage load is = 20.622/759= 2.7 %

Thus, it is recommended to store the product in different cold store of total capacity of **21 kW.**