Refrigeration and Air conditioning Engineering.

3rd year – refrigeration and Air conditioning Course

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FROZEN-FOOD PROPERTIES
&
Freezing Time of Food

Lecture -14 -

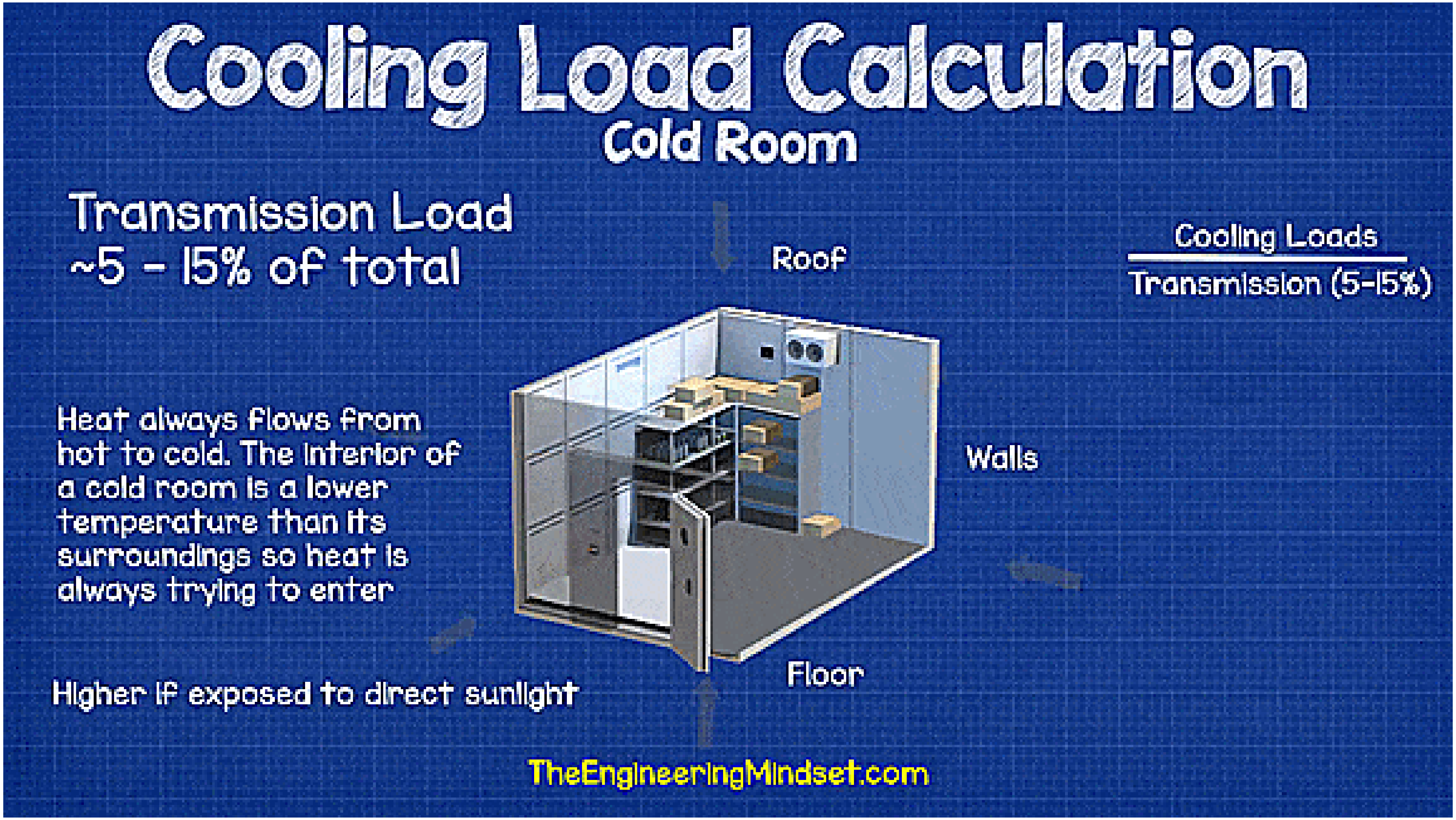
M.Sc. Zahraa F. Hussain

Refrigeration load:

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

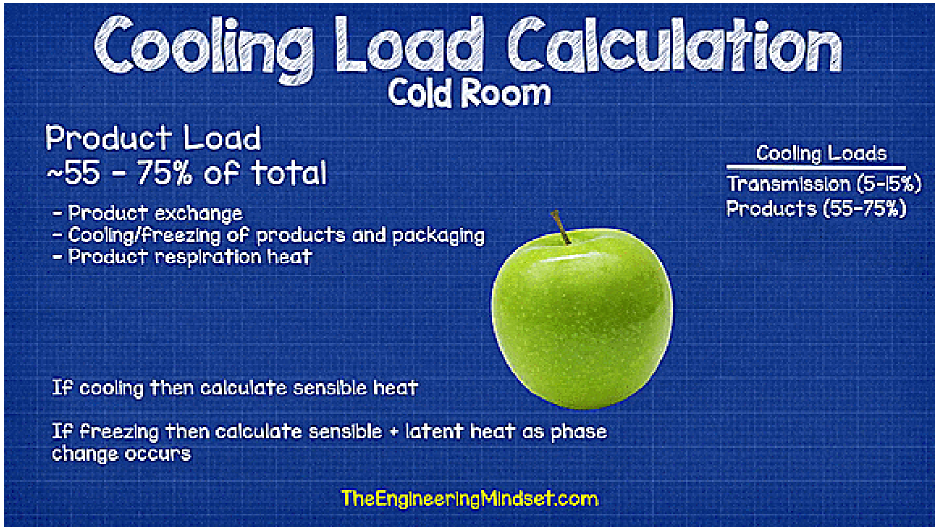
Refrigeration load:

- **Transmission through its surface.**



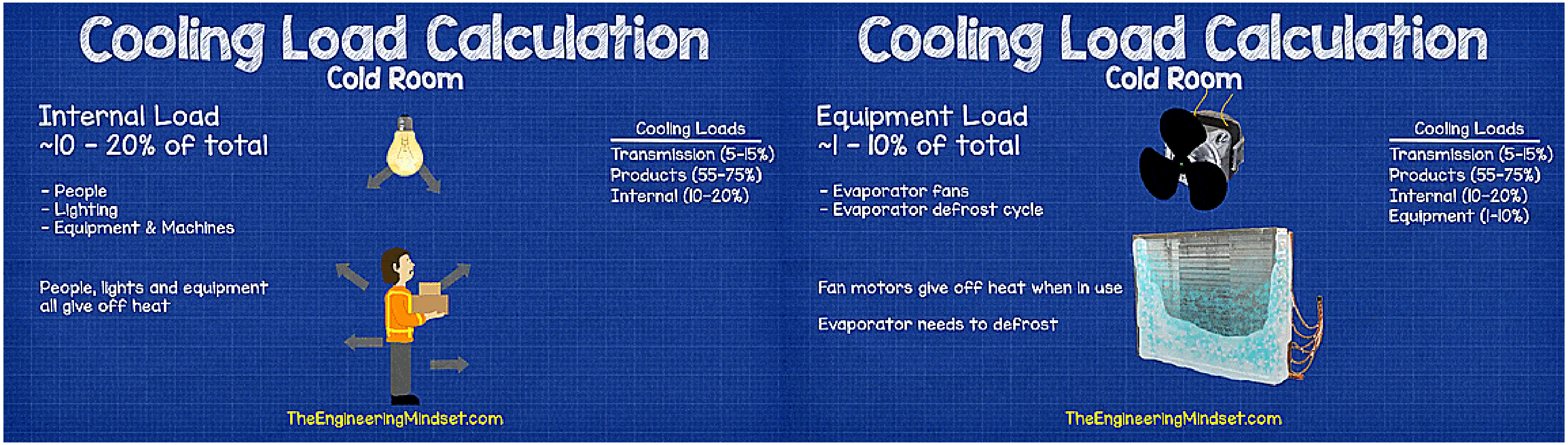
Refrigeration load:

- Product load, which is heat removed from and produced by products brought into and kept in the refrigerated space.

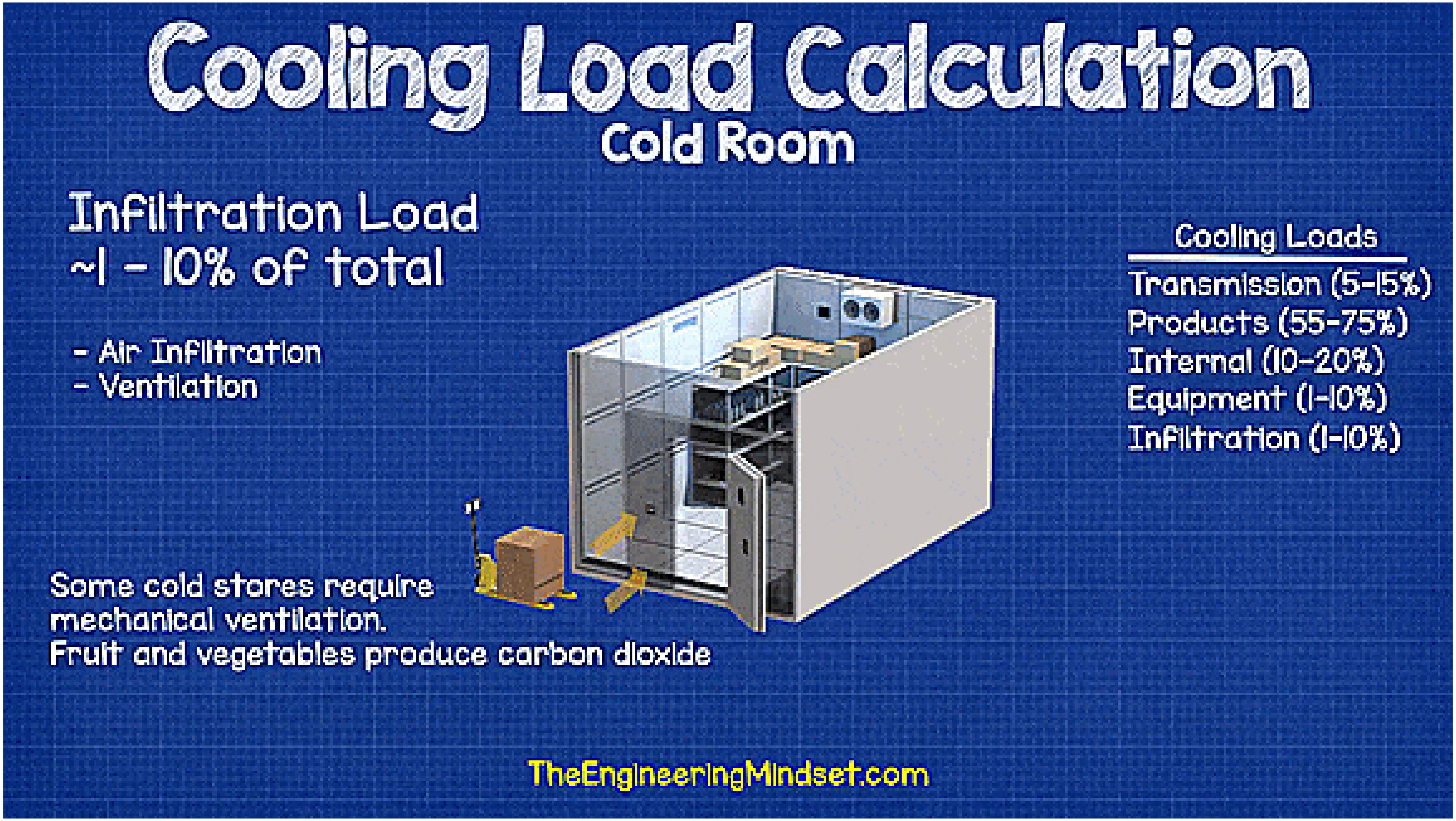


Refrigeration load:

- Internal load, which is heat produced by internal sources, e.g., lights, electric motors, and people working in the space.



- Infiltration air load, which is heat gain associated with air entering the refrigerated space.



Refrigeration load:

- Equipment-related load.
- Cooking
- Backing
- Gluing

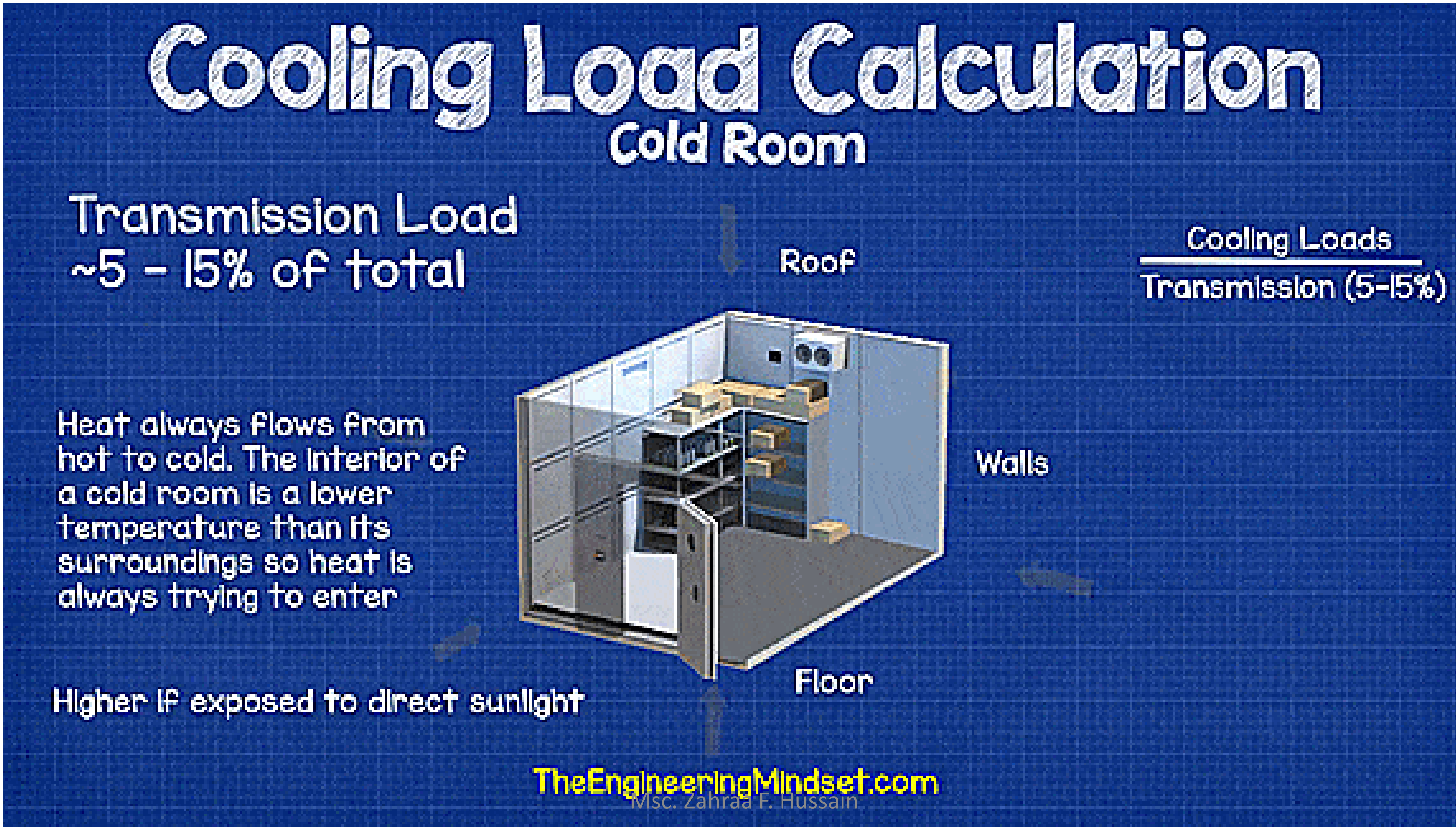
Refrigeration load:

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

- The first five segments of load constitute the net heat load for which a refrigeration system is to be provided;
- the sixth 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



- $U = \frac{1}{\frac{1}{h_i}+\frac{x}{k}+\frac{1}{h_o}}$
- Where:
- U: Overall heat transfer coefficient, $W/m^2 \cdot K$.
- x: Wall thickness, m.
- k: thermal conductivity of wall material, W/m. K
- h_i: Inside surface conductance, $W/m^2 \cdot K$.
- h_o: Outside surface conductance, $W/m^2 \cdot K$.
- A value of 9.3 $W/m^2 \cdot K$. 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 $W/m^2 \cdot K$.

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

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insulated panels have a negligible effect on thermal performance and should not be considered in calculating the U-factor.

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) lists minimum insulation thicknesses of expanded polyisocyanurate board recommended by the refrigeration industry.

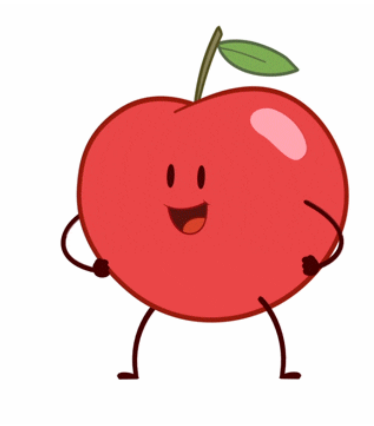
Storage Temperature (°C)	Expanded Polyisocyanurate Thickness (mm)
10 to 16	50
4 to 10	50
-4 to 4	50
-9 to -4	75
-18 to -9	75
-26 to -18	100
-40 t0 -26	125

- 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

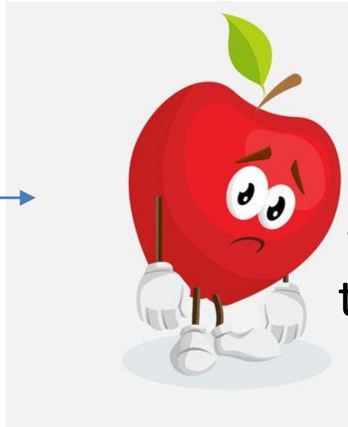
Typical Surface Types	East Wall	South Wall	West Wall	Flat Roof
	°C	°C	°C	°C
Dark colored surfaces				
Slate roofing	5	3	5	11
Tar roofing				
Black paint				
Medium colored surfaces				
Unpainted wood	4	3	4	9
Brick				
Red tile				
Dark cement				
Red, gray, or green paint				
Light colored surfaces	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

7-1-2 **PRODUCT LOAD:**

7-1-2 **LIVING PRODUCT LOAD:**



Removed heat generated by products



heat that must be removed to reduce the product temperature to storage temperature

7-1-2 **DEAD PRODUCT LOAD:**

heat that must be removed to reduce the product temperature to storage temperature

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.

Heat removed to cool

Heat removed to cool from the initial temperature to the freezing point

T_1

T_2

T_f

Heat removed to freeze the product

Heat removed to cool from the freezing point to the final temperatur

T_f

T_f

T_3

PRODUCT LOAD

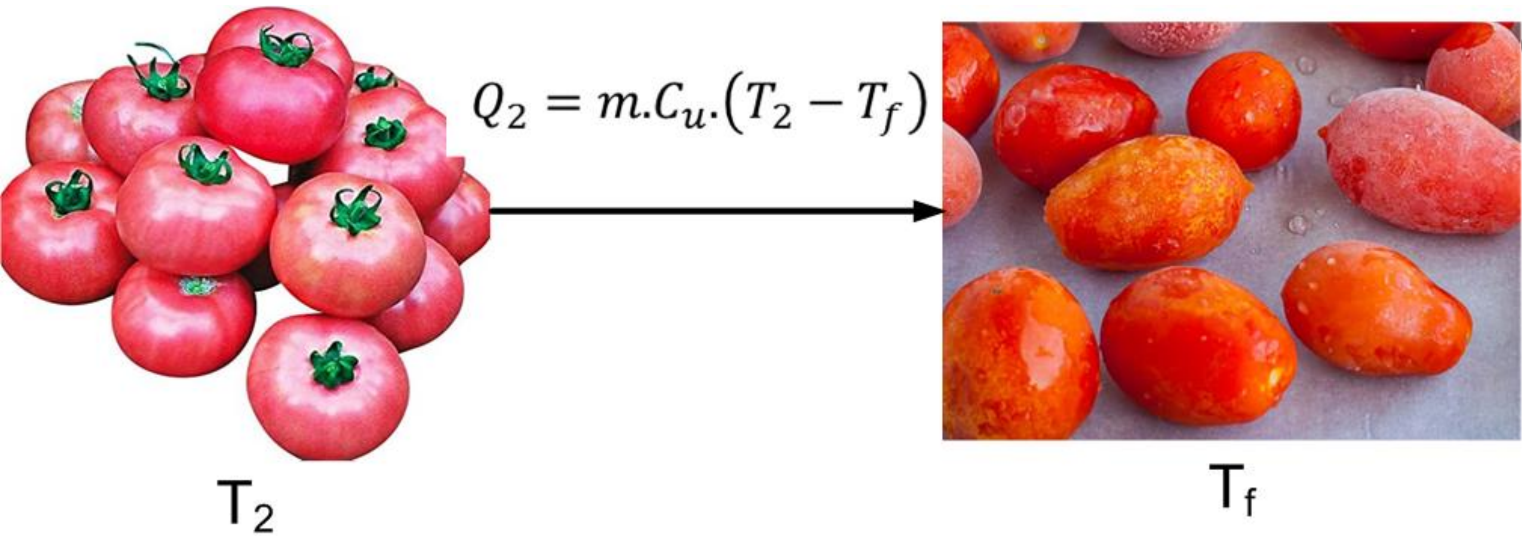
- The quantity of heat to be removed can be calculated as follows:
- 1- Heat removed to cool from the initial temperature to some lower temperature above freezing:

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

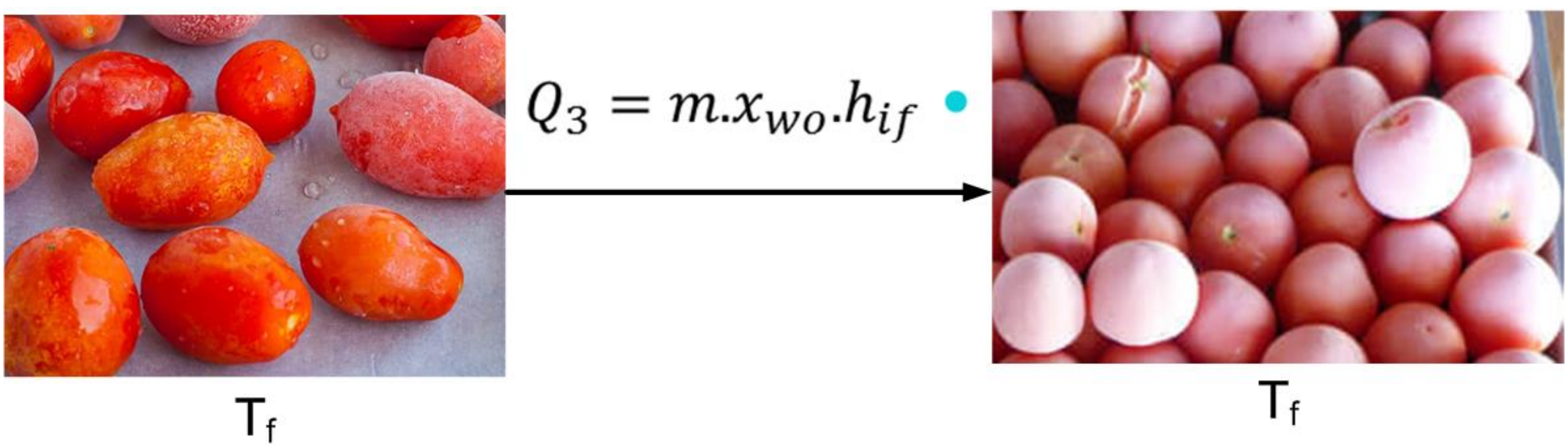
T_1 T_2

- 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

- 2- Heat removed to cool from the initial temperature to the freezing point of the product, in kJ:
- $Q_2 = m.C_u.(T_2 - T_f)$



- 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.



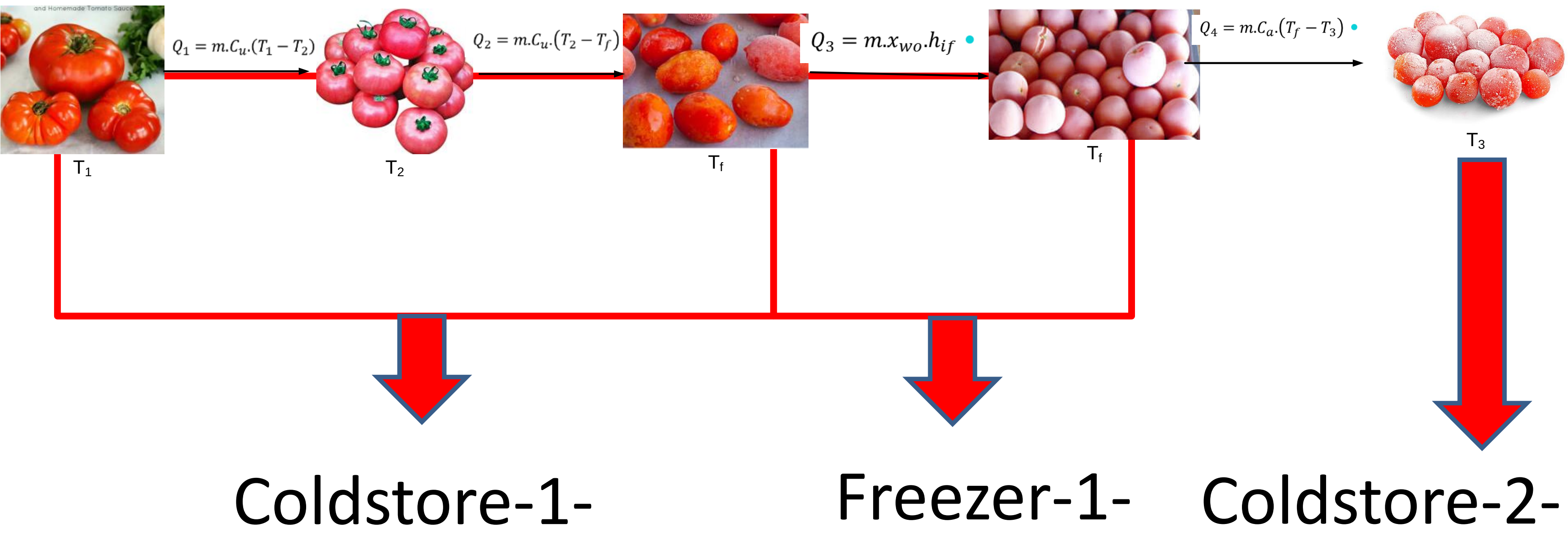
- Heat removed to cool from the freezing point to the final temperature below the freezing point, in kJ.
- $Q_4 = m.C_a.(T_f - T_3)$
- C_a: Specific heat of frozen food (Eq. 6-3) (kJ/kg

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

zing temperature

T_f

T_3


$Q_1 = m.C_u.(T_1 - T_2)$
$Q_2 = m.C_u.(T_2 - T_f)$
$Q_3 = m.x_{wo}.h_{if}$
$Q_4 = m.C_a.(T_f - T_3)$
T_1
T_2
T_f
T_f
T_3
Coldstore-1-
Freezer-1-
Coldstore-2-

- 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.

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)
Liver	69.0	20.00	3.85	5.82	0.0	1.34	−1.7	3.43	1.72
Ribs, Whole (Ribs 6-12)	54.5	16.37	26.98	0.0	0.0	0.77	—	—	—
Round, Full Cut, Lean and Fat	64.8	20.37	12.81	0.0	0.0	0.97	—	3.35	1.68
Round, Full Cut, Lean	70.8	22.03	4.89	0.0	0.0	1.07	—	3.35	1.68
Sirloin, Lean	71.7	21.24	4.40	0.0	0.0	1.08	−1.7	3.08	1.55

- **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

$T_1 = 18^oC$ $T_2 = 4^oC$

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

- 2-Heat removed to cool from the initial

$T_2=4^oC$

$T_f=-1.7^oC$

- 3-Heat removed to freeze the product in kJ
- $Q_3 = m.x_{wo}.h_{if}$
- $Q_3 = 100 \times 0.717 \times 333.6 =$

T_f=-1.7^{o}C

T_f=-1.7^{o}C

- 4- Heat removed to cool from the freezing point ...perature below the freezing point,

- ... $-T_3)$
- ... $6x_s + \frac{(x ...}{...}$
- $x_b = 0.4\ x_p$

T_f=-1.7°C

T_3=-18°C

- $x_b = 0.4 \times 0.2124 = 0.085$
- $c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}$
- c_a

$(0.717 - 0.085) \times 333.6 \times -1.7$

- $Q_4 = m.C_a.\left(T_f - T_3\right) = 100 \times 1.9 \times \left(-1.7 - (-18)\right) = 3018\ kJ$

T_f=-1.7^{o}C

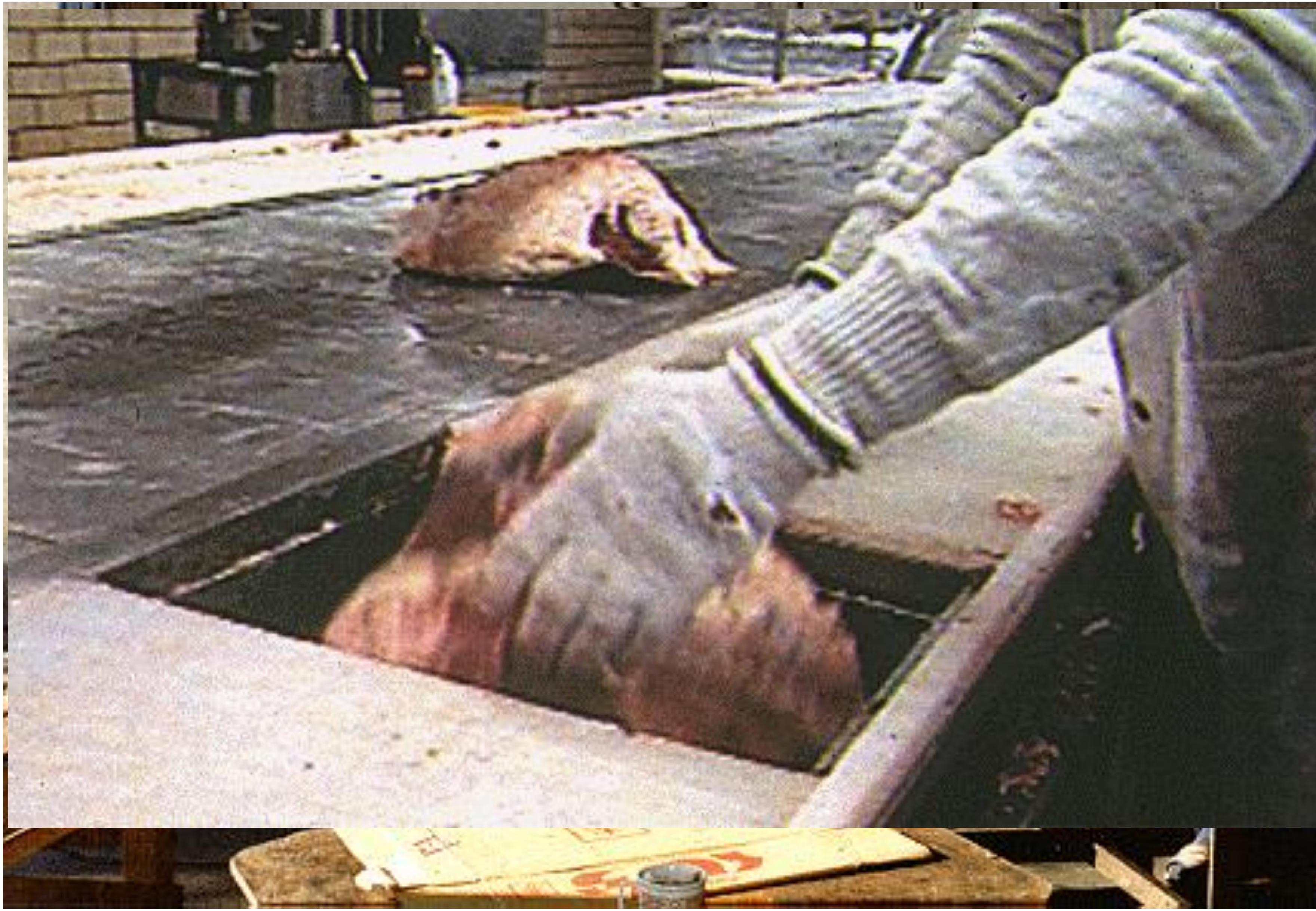
T_3=-18^{o}C

- $Q_t = Q_1 + Q_2 + Q_3 + Q_4$
- $Q_t = 4935 + 2009 + 23919 + 3018$
  $= 33881\ kJ$

Table 27 Heat Gain from Typical Electric Motors

Motor Name-plate or Rated Horse-	power (kW)	Motor Type	Nominal	Full Load Motor Efficiency,	Location of Motor and Driven Equipment with Respect to Conditioned Space or Airstream		
					A	B	C
					Motor in, Driven Equipment in,	Motor out, Driven Equipment in,	Motor in, Driven Equipment out,
			rpm	%	Watt	Watt	Watt
0.05	(0.04)	Shaded pole	1500	35	105	35	70
0.08	(0.06)	Shaded pole	1500	35	170	59	110
0.125	(0.09)	Shaded pole	1500	35	264	94	173
0.16	(0.12)	Shaded pole	1500	35	340	117	223
0.25	(0.19)	Split phase	1750	54	346	188	158
0.33	(0.25)	Split phase	1750	56	439	246	194
0.50	(0.37)	Split phase	1750	60	621	372	249
0.75	0.56	3-Phase	1750	72	776	557	217
1	0.75	3-Phase	1750	75	993	747	249
1.5	1.1	3-Phase	1750	77	1453	1119	334
2	1.5	3-Phase	1750	79	1887	1491	396
3	2.2	3-Phase	1750	81	2763	2238	525
5	3.7	3-Phase	1750	82	4541	3721	817
7.5	5.6	3-Phase	1750	84	6651	5596	1066
10	7.5	3-Phase	1750	85	8760	7178	1315
15	11.2	3-Phase	1750	86	13 009	11 192	1820
20	14.9	3-Phase	1750	87	17 140	14 913	2230
25	18.6	3-Phase	1750	88	21 184	18 635	2545


Tuna Processing After Harvest - Tuna Frozen, Cleaning, Cutting, Processing and Pac...
AMAZING ZONE

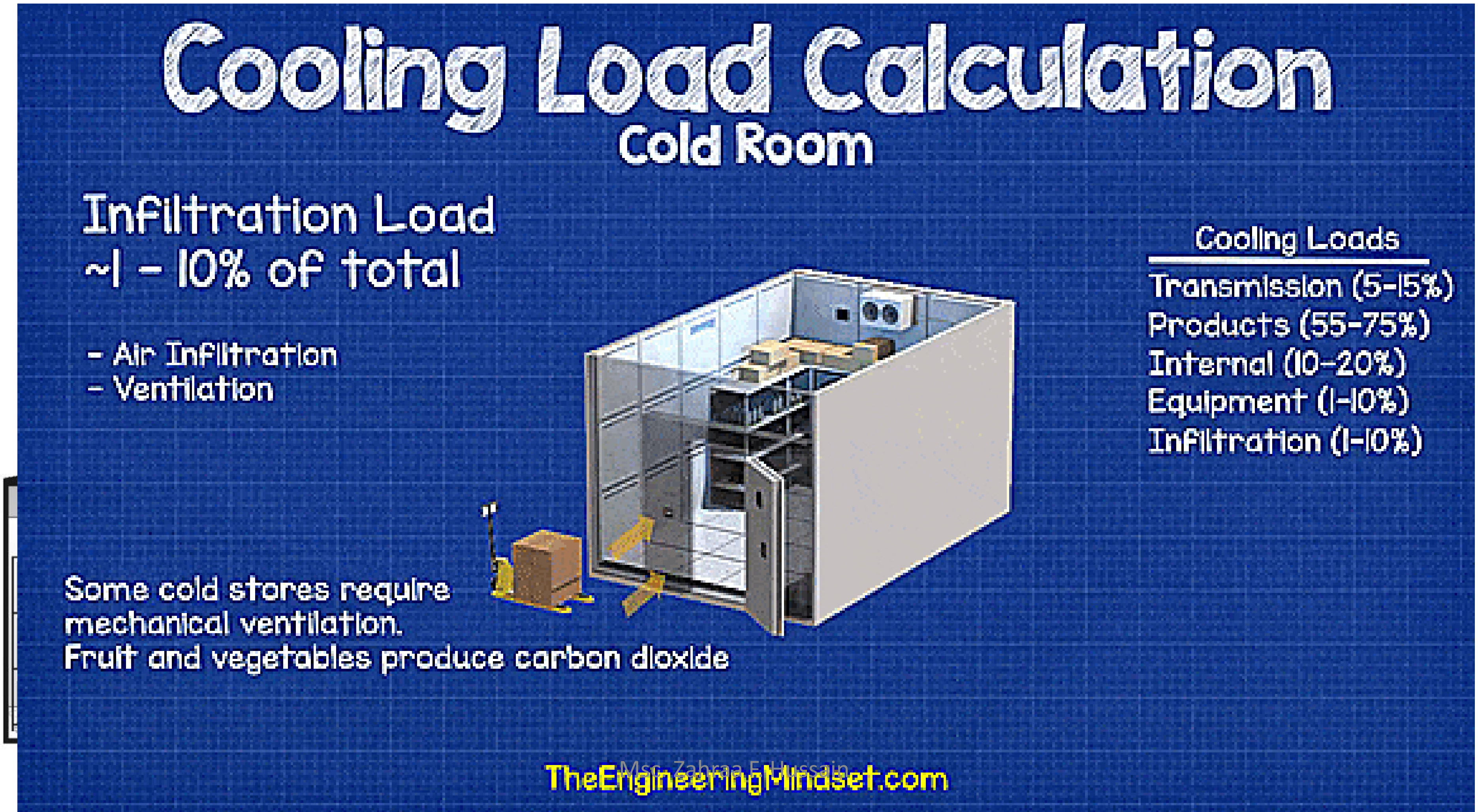


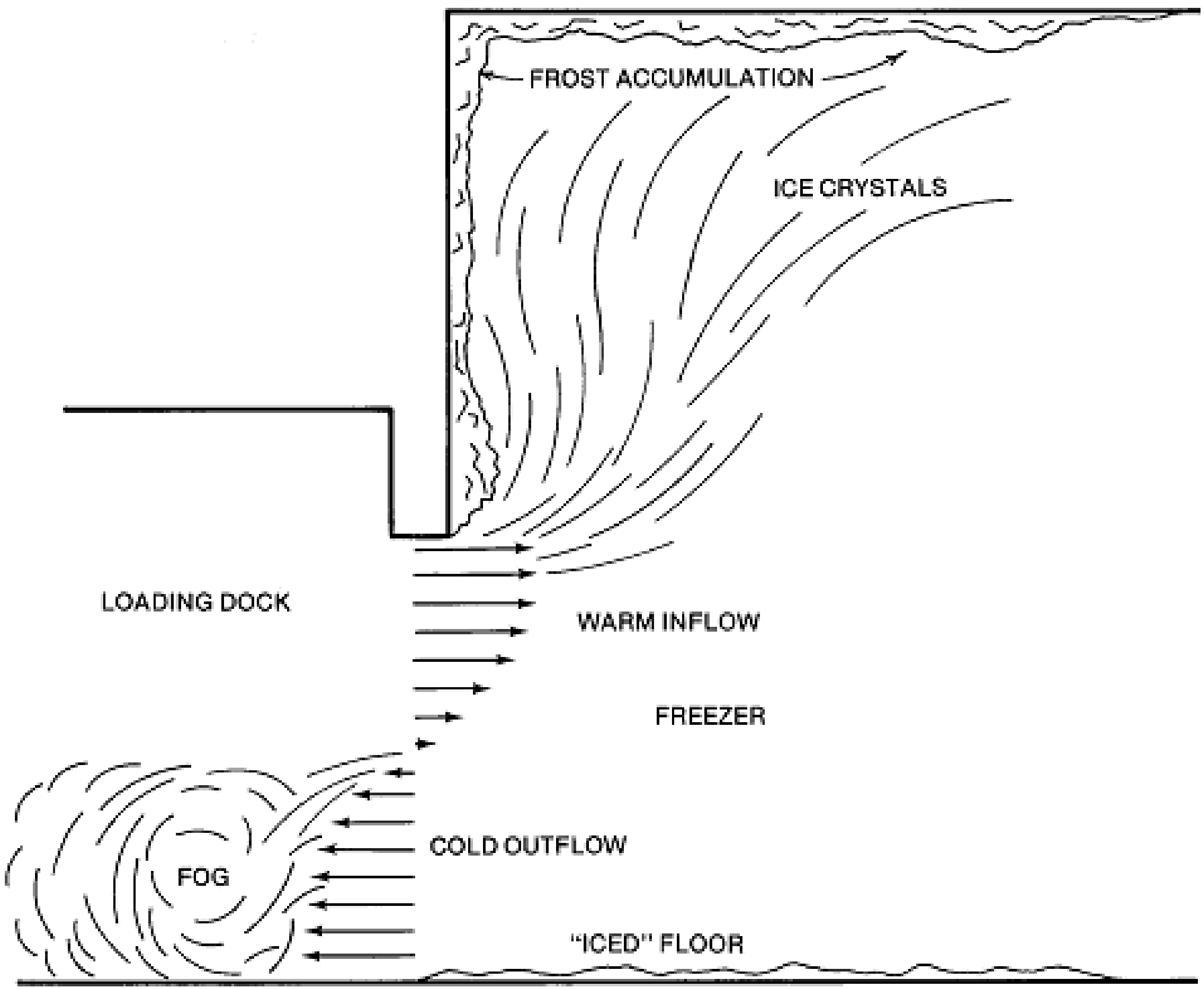
People

- **People.** ad, and this load var tors as room tempera done, type of clothing son.
- Heat loa be estimate
- $Q_p = 27$
- T: Tempe l space

Infiltration by Direct Flow Through Doorways

- **Infiltration by Direct Flow Through Doorways:**




FROST ACCUMULATION
ICE CRYSTALS
LOADING DOCK
WARM INFLOW
FREEZER
COLD OUTFLOW
FOG
"ICED" FLOOR

Infiltration by Direct Flow Through Doorways

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

Example2:

- In cold store uses Expanded Polyisocyanurate for walls, ceilings and floors.
- Used to store a quantity of butter at-20 °C 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 °C .
- 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 °C 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

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

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	—

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

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

- 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 °C

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

- 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 °C	South Wall °C	West Wall °C	Flat Roof °C
Dark colored surfaces				
Slate roofing Tar roofing Black paint	5	3	5	11

		U	A		$\Delta T + correction\ (table - 3)$		Loa d
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
- $Q_1 = m.C_u.(T_1 - T_2)$
- $C_u = 4.19 - 2.3x_s - 0.628x_s^3$
- $x_s = 1 - x_{wo} = 1 - 0.179 = 0.821$
- $C_u = 4.19 - 2.3x_s - 0.628x_s^3$
- $C_u = 4.19 - 2.3 \times 0.821 - 0.628 \times 0.821^3$

- $Q_1 = m.C_u.(T_1 - T_f)$
- $Q_1 = (480000 \times 1.951 \times (15 - (-5.6))$
- $Q_1 = 19291488\ k\ J$
- 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.
- $Q_4 = m.C_a.(T_f - T_3)$
- $c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}$
- $x_b = 0.4.x_p$
- $x_b = 0.4 \times 0.0085 = 0.0034$
- $c_a = 1.55 + 1.26x_s + \frac{(x_{wo} - x_b).L_o.t_f}{t^2}$
- c_a

- $Q_4 = m.C_a.(T_f - T_3) = 480000 \times 1.68 \times (-5.6 - (-20))$
- $Q_4 = 12967348\ kJ$
- $Q_t = Q_1 + Q_3 + Q_4$
  $= 19291488 + 31545216 \ + 12967348$
  $= 73300704 kJ$
- $Q = \frac{Q_1 + Q_2 + Q_3 + Q_4}{3600.n}$
  $= \frac{19291488 + 31545216 \ + 12967348}{3600 \times 24} = \mathbf{738.4kW}$

- Heat load from a person Qp
- $Q_p = 272 - 6.T = 10 \times \left(272 - 6 \times (-20)\right) \times \frac{12}{24} = 1960\ W$=1.96 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 kW
- **Total load**
- $Q_t = 8.362 + \mathbf{738.4} + 1.960 + 3.200 + 7.100 = 759\ \text{k}W$

Transmission	Product	persons	Lighting	Lighting

- $Q_t = 8.362 + \mathbf{738.4} + 1.960 + 3.200 + 7.100 = 759\ \mathrm{k}W$

Transmission	Product	persons	Lighting	Infiltration

- It can be seen that the storage load is
- $8.362 + 1.960 + 3.200 + 7.100 =$ **20.622 kW**
- While the cooling and freezing load = $\mathbf{738.4}$ 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.**


Thank
You!