Calculating Cooling Load

Example: Let's design an exemplary warehouse for storing apples with a cold storage size of 8.0*5.0*4.0 m, where 6 tons of products are placed daily and 30 tons of apples are stored permanently inside.

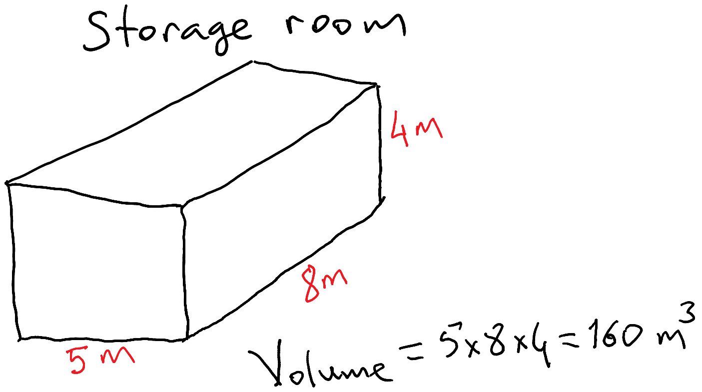
1 - Transmission Heat Loads:

- Ambient air (where the warehouse is located) 30°C with 50% relative humidity, Indoor air (desired air condition inside the warehouse) 1°C at 95% relative humidity.
- The walls, roof, and floors are insulated with 80 mm polyurethane with a U = 0.28W / m^2.K value.
- Since using floor panels in industrial warehouses will not be suitable due to forklift passage, we will use an XPS insulation plate. Thickness 80 mm U = 0.42 W / m^2.K
- The floor temperature is 10°C.

To calculate the transmission load, we will use a formula like this:

$Q = U \times A \times (T_0 - T_i) \times 24/1000$

- Q = kWh / per day heat load
- U = Insulation value of sandwich panel (W / m^2.K)
- A = Surface area of ceiling, wall, and floor (we will calculate this) (m^2)
- T_i = Air temperature inside the room (°C)
- T_0 = Ambient outside temperature (°C)
- 24 = Hours in a day
- 1000 = Watt to kW conversion.



Calculating "A" is very easy:

1. Wall= 8m x 4m = 32 m^2
2. Wall = 8m x 4m = 32 m^2
3. Wall = 5m x 4m = 20 m^2
4. Wall = 5m x 4m = 20 m^2

Roof = 5m x 8m = 40 m^2
Floor = 5m x 8m = 40 m^2

We need to calculate the floor separately from the wall and ceiling, because the temperature difference is different under the floor, so the heat transfer will also be different.
Walls and Ceiling

$Q = U \times A \times (T_0 - T_i) \times 24/1000$
$Q = 0.28W / m^2.K \times 144\ m^2 \times (30 - 1)°C \times 24/1000$
$Q = 28.06$ kWh /day

[A = 144 m^2 = 32 m^2 + 32 m^2 + 20 m^2 + 20 m^2 + 40 m^2]

Floor
$Q = U \times A \times (T_0 - T_i) \times 24 \div 1000$
$Q = 0.42W / m^2.K \times 40\ m^2 \times (10 - 1)°C \times 24/1000$
$Q = 3.62$ kWh / day

Total daily conduction heat gain = 28.06 kWh/day + 3.62 kWh/day = 31.68 kWh/day

2 - Product Heat Loads:

a) Calculate the cooling capacity due to the products placed in the warehouse
For this example, we will store apples. If you are going to carry out processes such as freezing and further cooling in addition to cooling the products, you must also make separate heat gain calculations for them. In this example, we only do cooling.
Every day, 6,000 kg of apples arrive at the warehouse at a temperature of 10°C and a heat capacity of 0.87 kcal/kg.°C.
We can use the following formula for this calculation:

$Q = m \times Cp \times (T_P - T_i) / 860$

- Q = kWh / day
- CP = Specific Heat Capacity of the Products (kJ/kg.°C)
- m = Mass of added products (kg)
- T_P = Product inlet temperature (°C)
- T_i = Temperature inside the cold room (°C)
- 860 = Kcal to kWh conversation rate

$Q = m \times C \times (T_P - T_i) / 860$
Q = 6.000 kg x 0.87 kcal / kg°C x (10 - 1)°C / 860
Q = 54.6 kWh / day

b) Calculating cooling load from product respiration
The next step is to calculate the cooling load from the product respiration. In this example, let's use the average respiratory heat of 1.9 kJ/kg per day for the apple to be stored. But, this rate varies with time and temperature. In our example design, we apply a single value only to simplify the calculation, as this cooling load is not considered critical. In our sample design, 30,000 kg of apples is stored in the warehouse. To calculate this, we will use the following formula:

$Q_{resp} = m \times q / 3600$

- Q_{resp} = kWh / day = cooling load from product respiration
- m = amount of product in the warehouse (kg)
- q = heat of respiration of product (assume 1.9 kJ / kg)
- 3600 = Converts kJ to kWh.

$Q_{resp} = m \times q / 3600$
Q_{resp} = 30.000kg x 1.9kJ/kg / 3600
Q_{resp} = 15.9 kWh / day

That is when we calculate the cooling load from the new product entering the warehouse and the cooling load due to the respiration of the product; a total cooling load of 70.5 kWh/day (54.6+15.9).

If the food product to be stored is a non respiring food, then, q = 0.

3 - Internal Heat Loads:

a) Calculation of cooling load from people

The amount of heat emitted by the working people in the cold storage varies according to the temperature of the warehouse and the volume of the warehouse.
If we take into account that 2 people will work for 4 hours for the apple store we have designed, the formula will be as follows.

$Q = P \times t \times q_p / 1000$

- Q = kWh / day
- P = Number of people working in the warehouse
- t = Length of time spent in the warehouse per person (Hours)
- q_p = Heat losses per person per hour (Watts)
- 1000 = Converts watts to kW only

$Q = P \times t \times q_p / 1000$
Q = 4 hours x 2 person x 271 Watts / 1000
Q = 2.16 kWh/day

b) Calculation of cooling load from lighting (lamps)

In the next step, we will calculate the heat produced by the lighting. The formula we will use for this calculation is;

$Q = L \times t \times q_L / 1000$

- Q = kWh / day,
- L = number of lamps in the cold room
- t = daily usage hour of cold room lighting
- q_L = power rating of the lighting (Lamps)
- 1000 = Watts to Kw

If there are 3 lamps at 120W each, running 4 hours a day, the calculation would be:
$Q = L \times t \times q_L / 1000$
Q = 3 x 4 hours x 120W / 1000
Q = 1.44 kWh/day
Total internal load: We get a total of 3.6 kWh/day for the heat load from humans (2.16 kWh / day) and the lighting heat load (1.44kWh / day).

c) Calculation of cooling load from fan motors

Now, let’s calculate the heat load from the fan motors of the evaporators.

$Q = F \times t \times q_f / 1000$

- Q = kWh/day
- F = Number of fans
- t = Fan running time per day (hours)
- q_f = Fan motors nominal power (Watts)
- 1000 = Watts to kW.

This cold room evaporator uses 3 fans of 300 W each and we assume they will run 16 hours a day.

$Q = F \times t \times q_f / 1000$
Q = 3 x 16 hours x 300 W / 1000
Q = 14.4 kWh / day

4 - Infiltration Heat Loads:

At this stage, the heat load from air infiltration needs to be calculated. If we use the below formula:

$Q = V \times E \times C \times (T_0 - T_i) / 3600$

- Q = kWh / day
- C = Number of volume changes per day
- V = Cold storage volume
- E = Energy per cubic meter in degrees Celsius
- T_0 = Outdoor air temperature
- T_i = Cold room temperature
- 3600 = kJ to kWh.

Assuming that the door will create 5 volume air changes per day due to the product entering and leaving the warehouse, the volume is calculated as 160 m^3, each cubic meter of new air is 2 kJ /°C, the outside air is 30°C and the air inside the warehouse is 1°C.

$Q = C \times V \times E \times (T_0 - T_i) / 3600$
$Q = 5 \times 160\ m^3 \times 2kJ /°C \times (30 – 1)°C / 3600$
Q = 12.88 kWh / day

5 - Refrigeration Equipment Heat Loads:

a) Cooling load from fan motors defrost

We will now calculate the heat load from defrosting the evaporator (heat load resulting from the evaporator's ice thaw). To calculate this load, we will use the following formula:

Q = P x t x DC x eff

- Q = kWh / day,
- P = Heating element power (kW)
- t = Defrost operation time (Hours)
- DC = How many times per day the defrost cycle occurs
- eff = what % of the heat will be transferred into the ambient

In this example, 1.5 kW resistances are used in our cold room. It works for 20 minutes, 3 times a day, and 30% of all the energy it consumes is transferred to the cold room.

Q = 1.5kW x 0.33 hours x 3 x 0.3
Q = 0.45kWh/day
The cooling load from defrost motors is 0.45 kWh/day.

Total Cooling Load

To calculate the total cooling load, we will simply add up all the calculated values.

Transmission load:	31.68 kWh / day
Product loading:	70.5 kWh / day
Internal load:	3.6 kWh / day
Equipment load:	14.4 kWh / day
Infiltration load:	12.88 kWh / day

Refrigeration equipment heat load: 0.45 kWh/day

Total = 133.51 kWh / day heat must be removed from storage room

Safety Factor

To take into account the errors and variations in the design, we must also apply a safety factor to the calculation. Although it varies according to the project, it is possible to tolerate it by adding a deviation between 5% and 25%.

Let’s use a factor of safety of 10% in this example. Therefore, when we multiply the cooling load with a safety factor of 1.1 (133.51x1.1=146.86), we get a total cooling load of 146.86 kWh/day.

Cooling Capacity Calculation

The last thing we need to do is calculate the cooling capacity required to remove this heat gain load from the environment. For this, the calculated total cooling load is divided by 16, since the device is calculated to operate for 16 hours a day.

This means that the capacity that our cooling unit will need should be 146.86 /16 = 9.17 kW
= 9.17 kJ/s.

Total Refrigeration Required

1 Ton of refrigeration absorbs 3.5 kJ /s heat energy.

Total refrigeration required = Total heat removed / 3.5 (A very rough approximation)

= 9.17/3.5 = 2.62 tons of refrigerant is require to remove 9.17 kJ/s the heat energy from the cold storage room (in order to keep the apple in the storage room at 1°C).