REPUBLIC POLYTECHNIC

E355 : Cold Chain Management

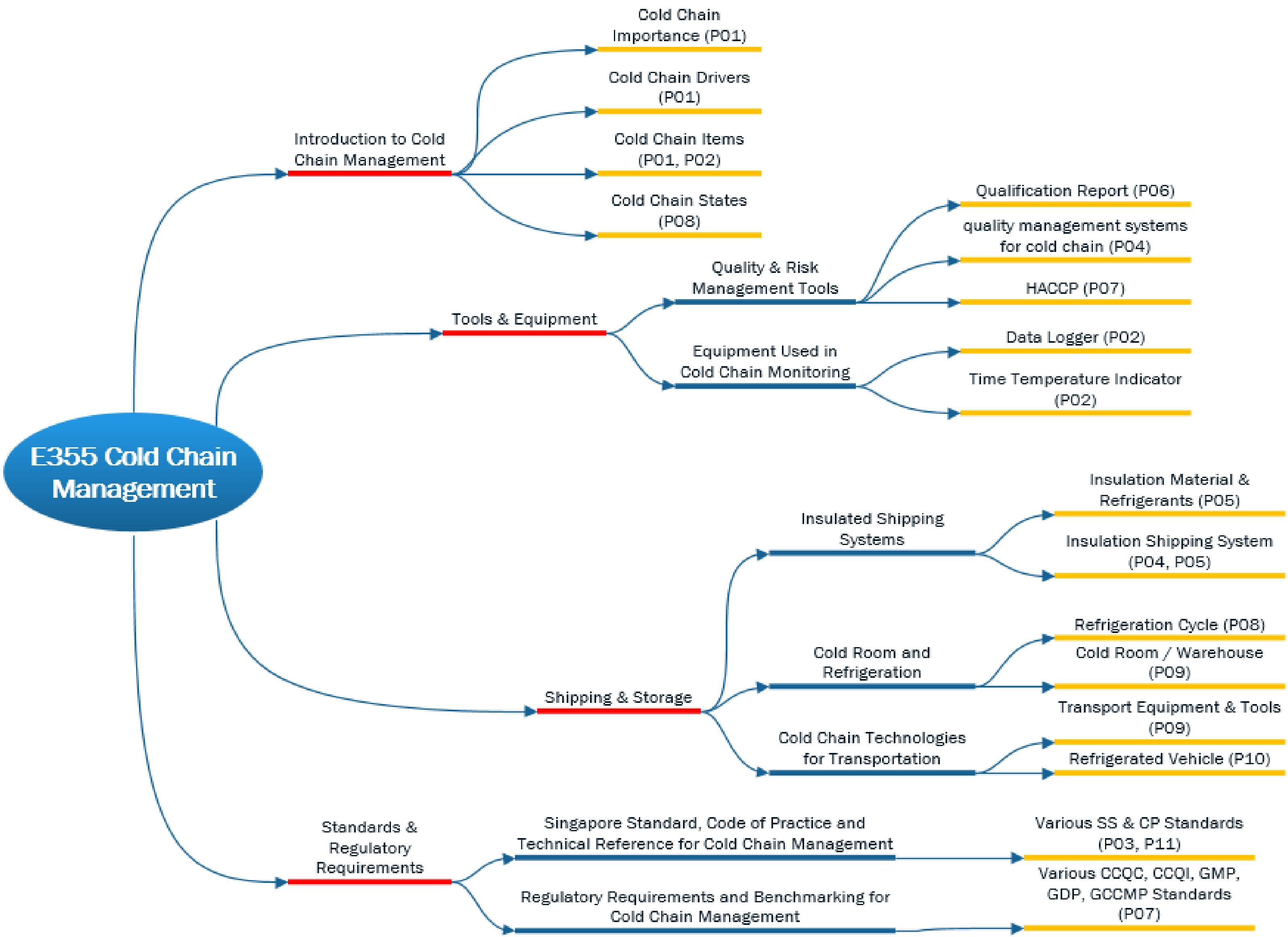
Problem 08

New Cold Chain Hub

- Explain The Principles of Refrigeration Cycle
- Describe The Functions of Main Components in a Cooling System
- Identify The Role of a Refrigerant in a Cooling System
- Design of Cold Room

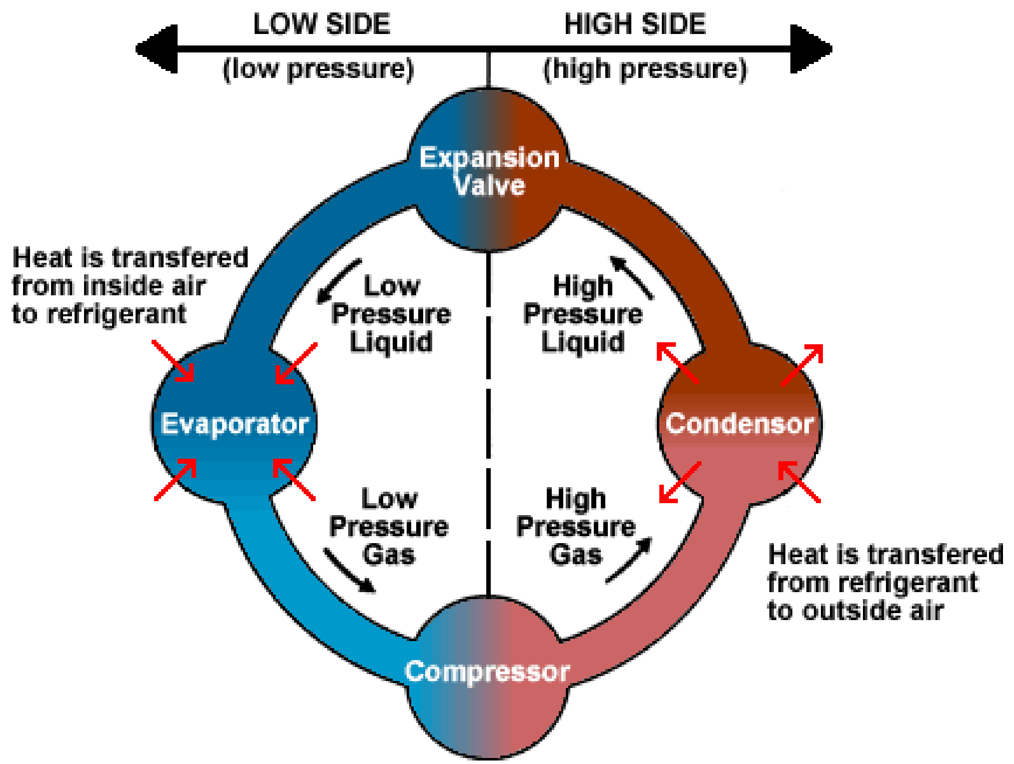
SCHOOL OF ENGINEERING

E355 Cold Chain Management - Topic Tree



What is a Refrigeration Cycle

- A process of using a refrigerant which boils at a low temperature to move heat from one place to another
- Its purpose is to take heat from the inside of the refrigerator and transfer it to the outside
- The working principle is the same for domestic refrigerators and industrial refrigeration systems



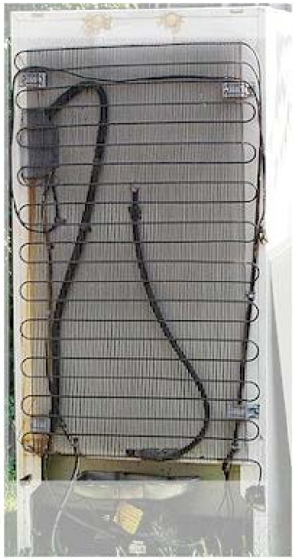
- One can use the following analogy. Imagine you have a sponge. If you squeeze it, then bring it into your room to expand, it soaks up the heat in your room. Then you bring it outside and squeeze it again, and it will disperse the heat into the outside air.

Compressor

- 2 main functions
  - To pump the refrigerant vapour from the evaporator so that the desired temperature and pressure can be maintained
  - To increase the pressure of the refrigerant vapour through the process of compression, and simultaneously increase the temperature of the refrigerant vapour
- With the change in pressure, the vapour is superheated as it flows through the system
- The performance can be specified in either energy efficiency or Compressor power consumption [kW]

Condenser

- A form of heat exchanger that uses air or water as a cooling medium
- The superheated refrigerant vapour condenses into water at this stage when it dissipates its heat to the cooling medium in the loop
- At this point, the refrigerant is in the liquid state and at a high pressure and high temperature, though it has lost some of its heat

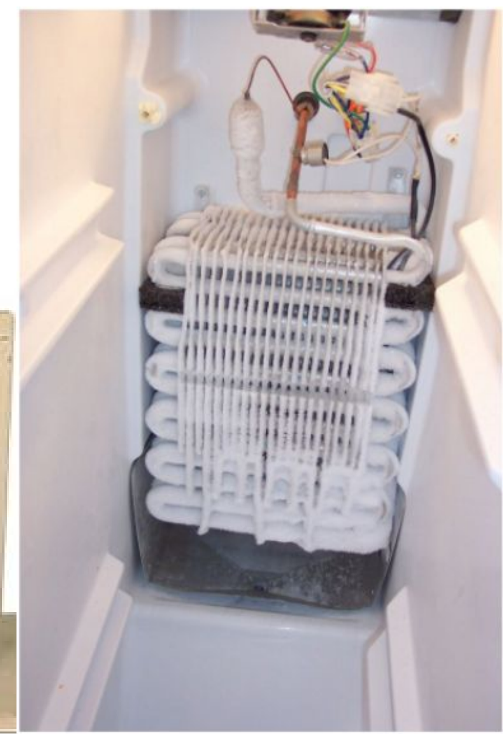


Expansion Valve

- Also known as throttling devices, they are used to reduce the refrigerant condensing pressure to the evaporating pressure
- When the liquid refrigerant passes through the valve, it is ‘flashed’ through to become a lower pressure, cooled liquid

Evaporator

- It is used as the point of heat capture and provides the cooling effect required for any particular application
- When liquid refrigerant enters the evaporator at low pressure caused by the expansion valve and the suction created by the compressor, the refrigerant expands and changes back to a vapour
- While changing its phase, large amount of heat is absorbed from the surrounding to allow the refrigerant to boil and vaporize
- The refrigerant then continues the cycle back at the compressor



Other Components of a Refrigerator

- Thermostat – it is used to control the refrigeration cycle by starting the compressor when the temperature in the refrigerator rises above the set temperature and stopping it when the temperature drops below the minimum

- Cabinet – it is an insulated box to limit the amount of heat transfer going through between the air in and outside of the refrigerator

Refrigerants

- It is a compound used in a heat cycle that undergoes phase change between liquid and gas.
- Traditionally, ammonia was being used but it was toxic, and was replaced by CFCs, but which was found to damage the ozone layer
- Thus, nowadays newer compounds such as HFCs are the most common refrigerants, as they are effective, non-toxic, and do not damage the ozone layer.
- Common refrigerants are R134a, R410a

Refrigerants used in Fridge vs Aircon

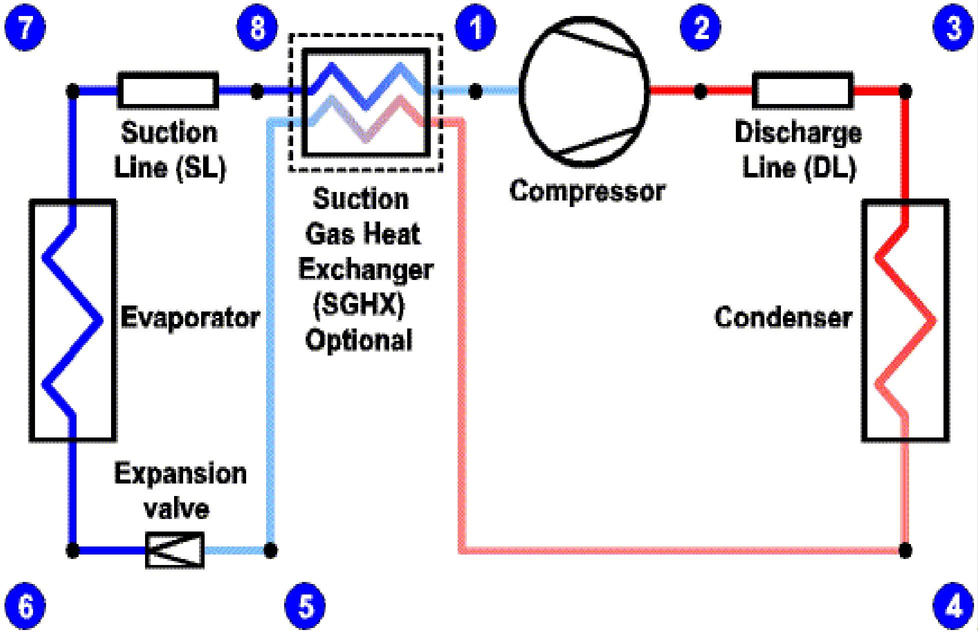
- Common refrigerants:

Refrigerant	Commonly used	**Ozone Depletion Potential**
R-410A	For residential and light commercial air-conditioning	Zero
R-134A	Used in large commercial chillers	Zero
R-600A	Greenest refrigerants in the market for refrigerators	Zero

Performance of Refrigeration Cycle

- Compressor is the mechanical unit that keeps the refrigerant circulating by increasing the fluid's pressure and thermal potential energies
- The choice of refrigerant should be:
  - Low specific heat, as the lower it is, the less heat it will pick up for a given change in temperature during the flow
  - High heat of vaporization, so that it absorbs more heat as it evaporates, increasing the refrigerating effect per kg of fluid
  - Low specific volume, in order to minimize the work required per kg of fluid

State Points of Refrigeration Cycle



State pt	Temperature (°C)	Pressure (kPa)	State of refrigerant
1	-4	426.7	Vapour
2	53.2	1682.1	Vapour
3	53.2	1608	Vapour
4	32.6	1608	Liquid
5	32.6	1608	Liquid
6	-10.4	434.1	Liquid
7	-5	434.1	Vapour
8	-4	426.7	Vapour

Defrosting of Domestic Chillers / Freezers

- Frost forms when water vapour hits the cold coils. The water vapour condenses, turns to liquid and immediately freezes. Defrosting prevents frost formation and maintains the efficiency of the cooling system.
- In a “frost-free” refrigerator, the timer turns the heating coil (wrapped among freezer coils) on periodically to melt off any ice that might have accumulated on the freezer evaporator coils
- Manual defrosting can be performed on a freezers without the “frost-free” function. Freezers should be defrosted when the layer of ice on the cooling coil gets in the way of normal operation, which may cause an increase in temperature in the compartment

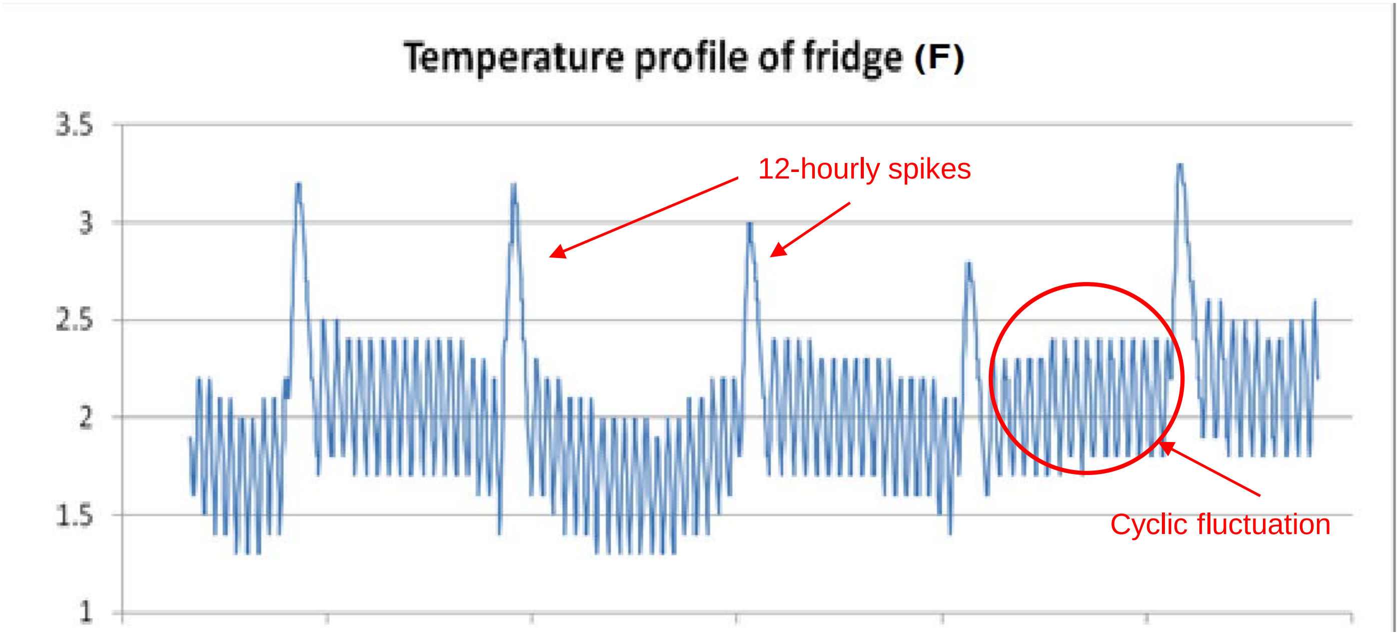
Fridge with/without defrosting function

Fridge without defrosting capabilities

Fridge with defrosting capabilities

Analysing the Temperature Profile of Fridge

- The temperature profile was taken from a “frost-free” refrigerator which has automatic defrosting cycles causing the increase in temperature every 12 hours.
- The thermostat switches the compressor on and off to regulate the temperature in the refrigerator, causing the cyclic fluctuation of temperature in the refrigerator.



Cold Store Design

When designing a cold store, consider heat transfer from

- Heat infiltration through walls, floors, and ceiling

  (Insulation material for walls)
- Heat input by open doors, gaps in walls

  (Infiltration of air)
- Heat transfer to/ from the product

  (Cooling of goods)
- Heat input by fans, lights, open doors, people, room fittings and structures etc.

  (Auxiliary loads)
- Other Factors for consideration

  (Temperature Control, Vapor barriers, Defrosting, Sanitation and Maintenance, Layout Planning Location)

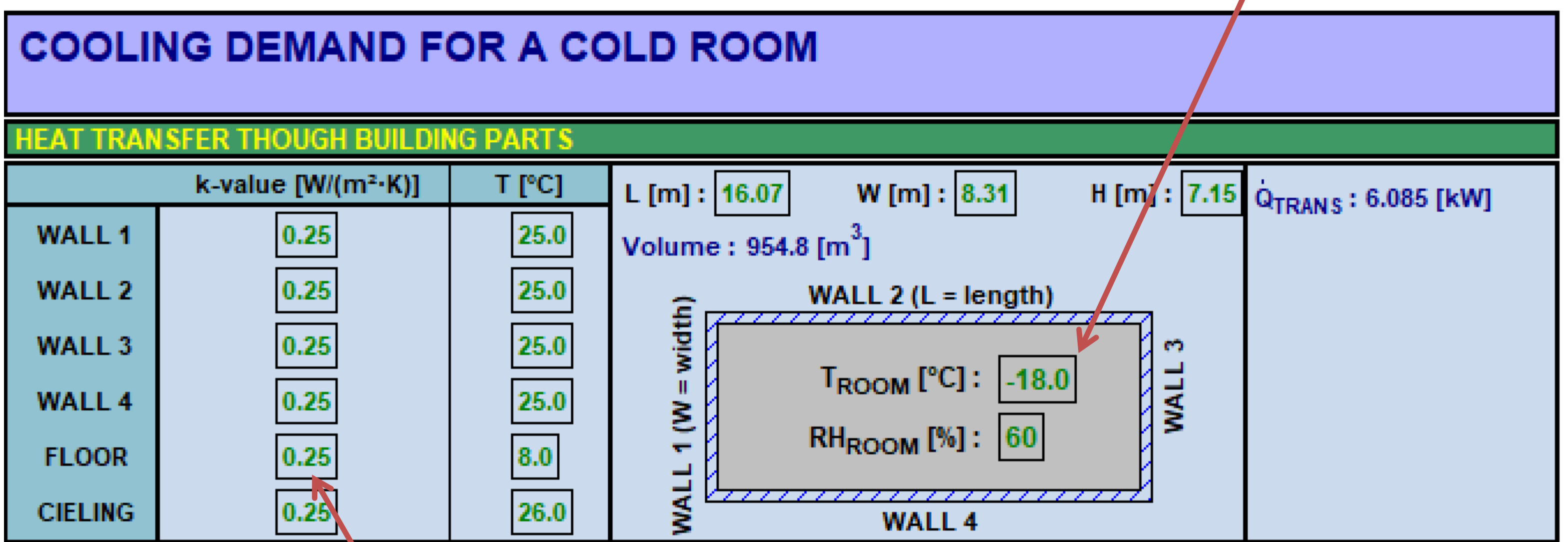
Insulation

- Choice of Insulation accounts for a large proportion of total construction cost
- Besides a suitable thermal conductivity coefficient, the insulation material should also be odour-free, anti-rot, vermin and fire-resistant and impermeable to water vapour
- Common insulation materials include polystyrene and polyurethane
- Small refrigerated rooms are typically constructed of prefabricated walls. Larger rooms are typically constructed individually.
- As a guideline for the thermal conductivity of prefabricated walls, the following can be used.

Thickness [mm]	k-value [W/(m²·K)]	Recommended temperature band
50	0.34	Chilled room
75	0.27	Above 0 °C
100	0.17	Above -29 °C
125	0.14	Above -45 °C
150	0.11	Above -57 °C

Heat Transfer through Building Parts

- Heat transfer is calculated for all 4 walls, roof and ceiling individually
- In a room with temperatures below 0°C, heating pipes should be installed to prevent the ground from freezing
- Based on the size of the room and the thermal conductivity, the rate of energy required to keep the room at -18°C is calculated



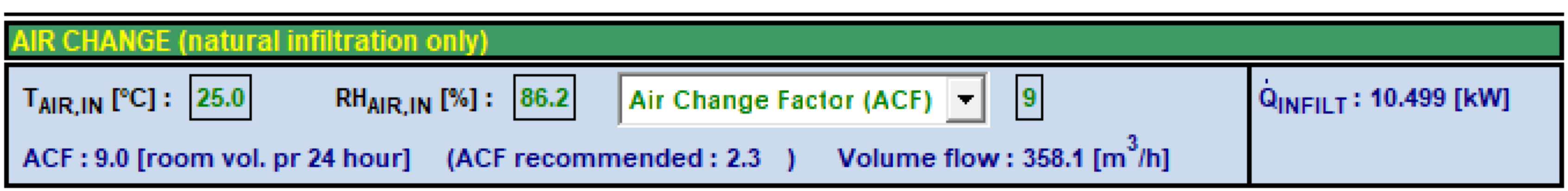
At - 18°C, we can estimate k-value to be between 0.17 and 0.27. (See previous slide)

Infiltration of Air

- Due to opening of doors and leaks in the building parts, warm and humid air flows into the room, and this air has to be cooled and maybe also dehumidified
- The flow of air infiltrating the room can be specified either directly by the flow in [m^3/h] or indirectly by the **Air Change Factor** (ACF) specifying the flow of air as number of times the total room volume is changed per 24 hours
- ACF can be estimated by

$$\frac{70}{\sqrt{Volume}}$$

- ACF varies greatly with the size of the room, number of door openings, protection of door openings, traffic through doors, cold and warm air temperatures and humidity



Cooling of Goods

- The cooling down of goods generates an additional heat load on the refrigeration system
- The calculation of this load is based on the temperature of the goods when they enter the room and the quantity of goods
- The load is calculated as a mean value of the heat load for the first hour of cooling. The average cooling load seen over the entire cool down period is also calculated
- If we bring in of 619 kg of Fish and 936 kg of Diary Product, each at surface temperature of -14ºC, the maximum rate of energy is calculated at 0.612 kW and the average rate is 0.325 kW

COOLING AND FREEZING OF GOODS

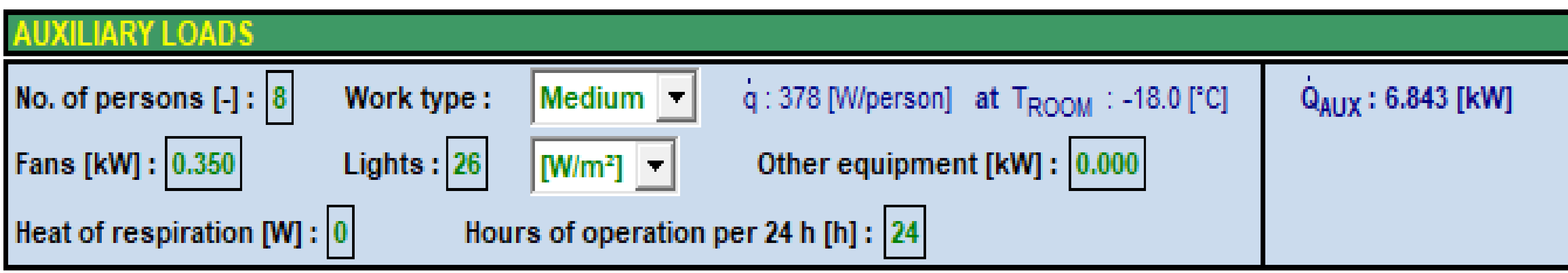
	Quantity [kg]	T_{IN} [°C]	τ_{COOL} [h]	Type	$\dot{Q}_{MAX}$ [kW]	$\dot{Q}_{AVG}$ [kW]	$\dot{Q}_{MAX}$: 0.612 [kW] $\dot{Q}_{AVG}$: 0.325 [kW]
1	619	-14.0	10	Fish	0.220	0.117	
2	936	-14.0	10	Diary products	0.392	0.208	

Auxiliary Loads

- A part of the heat load in a refrigerated room is caused by persons working in the room or from heat developing equipment in the room. These loads can be specified individually
  - Persons – heat load from persons based on the maximal number of persons that are in the room at the same time, and carrying out the type of work
  - Lights – heat from lighting equipment
  - Fans – electrical power consumption for evaporator fans is converted to heat
  - Other equipment – if other power consuming equipment is used in the room, heat developed corresponds to the power consumption

Auxiliary Loads

- Heat of respiration – fruits and vegetables produce heat due to internal chemical processes, depending on the quantity, type and their temperature
- If the heat of respiration is significant compared to the total cooling demand, it is necessary to perform a more detailed calculation. Otherwise, a mean value is acceptable, or it can be negligible
- Hours of operation – To allow for adequate defrosting of evaporators, the number hours of operation per 24 hours can be specified



Total Cooling Demand

COOLING DEMAND FOR A COLD ROOM

HEAT TRANSFER THOUGH BUILDING PARTS

	k-value [W/(m²·K)]	T [°C]
WALL 1	0.25	25.0
WALL 2	0.25	25.0
WALL 3	0.25	25.0
WALL 4	0.25	25.0
FLOOR	0.25	8.0
CIELING	0.25	26.0

L [m] : 16.07 W [m] : 8.31 H [m] : 7.15

Volume : 954.8 [m^3]

WALL 2 (L = length)

WALL 1 (W = width)

WALL 3

T_{ROOM} [°C] : -18.0

RH_{ROOM} [%] : 60

WALL 4

$\dot{Q}_{TRANS}$: 6.085 [kW]

AIR CHANGE (natural infiltration only)

$T_{AIR,IN}$ [°C] : 25.0 $RH_{AIR,IN}$ [%] : 86.2 Air Change Factor (ACF) 9

ACF : 9.0 [room vol. pr 24 hour] (ACF recommended : 2.3) Volume flow : 358.1 [m^3/h]

$\dot{Q}_{INFILT}$: 10.499 [kW]

COOLING AND FREEZING OF GOODS

	Quantity [kg]	T_{IN} [°C]	τ_{COOL} [h]	Type	$\dot{Q}_{MAX}$ [kW]	$\dot{Q}_{AVG}$ [kW]
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$\dot{Q}_{MAX}$: 0.612 [kW]

$\dot{Q}_{AVG}$: 0.325 [kW]

AUXILIARY LOADS

No. of persons [-] : 8 Work type : Medium $\dot{q}$: 378 [W/person] at T_{ROOM} : -18.0 [°C]

Fans [kW] : 0.350 Lights : 26 [W/m²] Other equipment [kW] : 0.000

Heat of respiration [W] : 0 Hours of operation per 24 h [h] : 24

$\dot{Q}_{AUX}$: 6.843 [kW]

Maximum cooling demand : 24.039 [kW] at SHR : 77 [%]

Average cooling demand : 23.752 [kW] at SHR : 77 [%]

Total Cooling Demand

- The total cooling demand is the sum of all the individual heat loads described (Maximum cooling demand = $Q_{TRANS} + Q_{INFLT} + Q_{MAX} + Q_{AUX}$)
- Sensible Heat Ratio (SHR) - Dehumidification of air containing water vapor will result in an extra cooling load (latent heat load) on the evaporator compared to the cooling load from changing the temperature of the air (sensible heat load)
- The ratio between the sensible heat load and the total heat load is called "Sensible Heat Ratio" or SHR
- A SHR value of 100% corresponds to a cooling load on the evaporator only from cooling of the air (sensible load). A SHR value of 80% indicates that 80% of the load on the evaporator origins from cooling the air (sensible heat load) and 20% origins from dehumidification of the air (latent heat load)

Cold Store Temperature Monitoring

- Position of logger should give an indication of the warmest air temperature
- With adequate air distribution, the temperature reading of the air return approximates to the mean temperature of the food
- If there is poor air distribution, sensors may be located at
  - Maximum height of the food load, furthest away from the cooling unit
  - Approximately 2/3 the height of the chamber, away from the door and the direct path of the cooling unit
  - 2m above floor level, directly opposite the cooler unit

Cold Store Temperature Monitoring

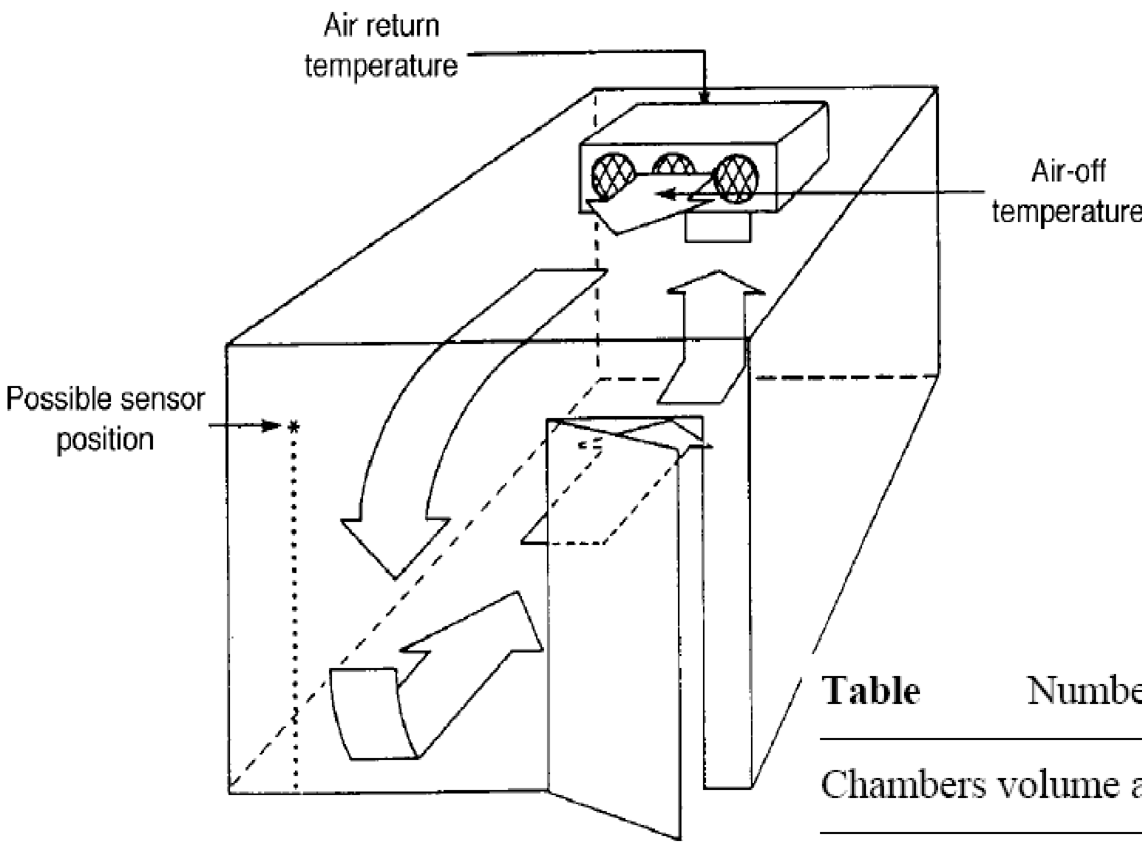

Table Number of sensors recommended in chill stores

Chambers volume above (m^3)	Number of sensors
500	2
5 000	3
20 000	4
50 000	5
85 000	6

Today’s Problem

- To understand the mechanism that allows the cold room to achieve its cooling effect, we need to know how the refrigeration cycle behaves.
- The main components are compressor, condenser, expansion valve, evaporator and the fluid used is the refrigerant, and each has its own function and properties that will affect the cycle.
- There are several factors for consideration in designing a cold room, of which the total cooling demand is of utmost importance as it will affect the overall costs including insulation material and refrigeration.
- The type of goods to store, the volume, the temperature, activity and equipment will affect the temperature and demand of the cold room.

Learning Objectives

- Explain the principles behind the refrigeration cycle
- Identify and describe the functions of the main components inside a cooling system
- Define the role of a refrigerant in a cooling system
- Analyze the possible heat transfer into a cold room
- Explain the considerations for design of cold room
- Explain the need for defrosting freezers / chillers and how defrosting is performed