U-3ARC TRAINING WEBINAR #22

HEAT BALANCE OF A COLD ROOM

Hammadi FERJANI

June 24, 2023

Summary

General
Introduction
Determination of the time base
Calculation of the various balance sheet items
Sum of contributions from all items
Calculation of cooling capacity

General

Food spoilage process

In some regions of the world, half of the food available is lost between the period of production and that of consumption.

The most important destructive agents:

- ❑ Rodents, insects, microorganisms (fungi and bacteria)
- ❑ Humans through improper handling (due to ignorance or negligence)

Place the products in places favoring various alterations

Cold storage is a technique for preserving foodstuffs or foodstuffs allowing their subsequent consumption.

General

Food spoilage process

Two main food groups according to their origin

Products of vegetable origin:

- ❑ Live products before and even during the storage period

Animal products:

- ❑ Products killed prior to their use

- ✓ Perishables have a diversity of physical properties and chemical compositions
- ✓ All contain water, carbohydrates, proteins, mineral salts and vitamins
- ✓ Water is the major constituent

Main factor of product alterability

General

Food spoilage process

Agents responsible for food spoilage

Enzymes:

Water-soluble protein biocatalysts produced by living cells that control the biochemical reactions of degradation of the quality of food products

Microorganisms:

Bacteria and/or fungi which are present on the surface or in the cavities (or folds) of the constituent organs of plants and animals

Other microorganisms can be brought by the manipulations undergone by the products

Microorganisms can spoil food by growing on them and breaking down their constituent substances

General

Incompatibilities due to odors and ethylene

The volatile compounds responsible for the aroma of certain products can be fixed by other neighboring products and give them an undesirable odor or taste.

Example:

Avoid storing:

- Apples with potato
  - Citrus with other products.

  The smell of apples and citrus is easily fixed by butter, meat and eggs

  Apples take on an unpleasant color and smell when stored with potato

- *"Living" Plant Organs Are Capable of Ethylene Production at Different Levels*
- *Ethylene is an odorless gas and even in small quantities shortens the life of oranges that synthesize it or those in their vicinity by accelerating their senescence or ripening for fruits*

General

Incompatibilités dues aux odeurs et à l'éthylène

	Banane	Beure	Bœuf	Chou	Fromage	Langouste	Lard	Mouton	Œufs	Orange	pêche	Pomme	Pomme de terre	Porc	Prune	Raisin
Banane	-	O	O	N	O	O	O	O	O	N	N	N	N	O	N	O
Beure	O	-	O	N	LR	R	LR	O	O	R	LR	N	N	O	O	O
Bœuf	O	O	-	N	LR	LR	LR	O	O	N	O	R	LR	O	O	O
Chou	N	N	N	-	N	N	N	N	N	N	LR	LR	LR	N	LR	LR
Fromage	O	LR	LR	N	-	N	O	LR	N	N	LR	N	LR	LR	LR	LR
Langouste	O	R	LR	N	N	-	LR	LR	LR	N	LR	N	N	LR	LR	O
Lard	O	LR	LR	N	O	LR	-	O	O	N	O	N	O	O	O	O
Mouton	O	O	O	N	LR	LR	O	-	O	N	O	N	LR	O	O	O
Œufs	O	O	O	N	N	LR	O	O	-	N	LR	N	N	O	LR	O
Orange	N	N	N	N	N	N	N	N	N	-	O	O	O	N	O	O
Pêche	N	LR	O	LR	LR	LR	O	O	LR	O	-	O	O	O	O	O
Pomme	N	N	R	LR	N	N	N	N	N	O	O	-	LR	N	O	O
Pomme de terre	N	N	LR	LR	LR	N	O	LR	N	O	O	LR	-	LR	O	O
Porc	O	O	O	N	LR	LR	O	O	O	N	O	N	LR	-	O	O
Prune	N	O	O	LR	LR	LR	O	O	LR	O	O	O	O	O	-	O
Raisin	O	O	O	LR	LR	O	O	O	O	O	O	O	O	O	O	-

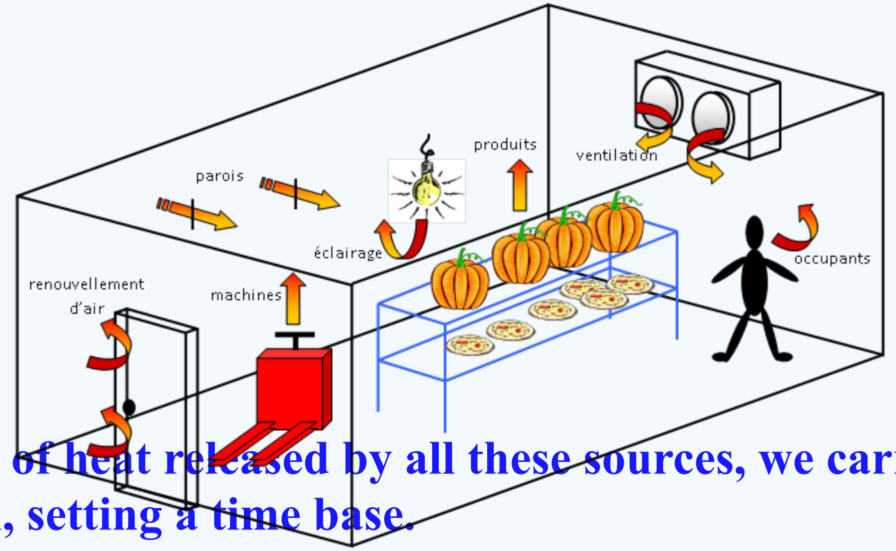
O	Can be together without risk of mutual contamination
LR	Slight risk of mutual contamination
R	Risk of mutual contamination
N	Cannot be stored together: very likely mutual contamination

Thermal balance

Introduction

The sizing of an installation begins with the calculation of the cooling capacity required. This power represents the energy that must be removed from the atmosphere in a given time to maintain the room at the desired temperature. This energy comes from several sources which are:

- ❑ **The walls**
- ❑ **Products**
- ❑ **Ventilation**
- ❑ **Air renewal**
- ❑ **Machines**
- ❑ **Lighting**
- ❑ **The occupants**



In order to estimate the quantities of heat released by all these sources, we carry out a detailed heat balance item by item, setting a time base.

Thermal balance

Determination of the time base

- **Cold rooms for the conservation of fresh or frozen products, the calculations are made for a 24-hour day, i.e. 24 x 3600 = 84,400 seconds.**
- **Applications whose use is cyclical (for example: cooling tunnel, dryer, cold room for rapid freezing, oven, etc.), the base time of the calculation will correspond to the cycle time.**

Example :

Rapid cooling tunnel whose daily use is done in 4 cycles of 3 hours. We will carry out the assessment over one cycle (3 hours), i.e. a time base of: 3 x 3600 = 10800 seconds.

Thermal balance

Calculation of the various balance sheet items

Position 1: conduction through the walls

The amount of heat brought by conduction through the walls is given by:

$$Q_{walls} = K.S.\Delta\theta.t$$

With

Q walls: heat provided by conduction in Joules [J]

K: overall wall exchange coefficient [$W.m^{-2}.°C^{-1}$]

S: total wall area [m^2]

Δθ: temperature difference between the outside temperature and the inside temperature [°C]

t: basic calculation time [s]

Thermal balance

Calculation of the various balance sheet items

Example :

Consider that our apple preservation chamber has the following dimensions:

Length 20 m

Width 10m

Height 6m

- Total surface of the walls of: 2x(20x6+10x6)+20x10 = **560 m2**
- The heat exchange coefficient K is obtained from calculations heat transfers that would require a full webinar.
  (Polyurethane foam panels K = **0.22 W/m2.K).**
- The temperature outside the room is 40°C
- The temperature to be maintained inside is 2°C.
  This gives a Δθ of 38°C

Q walls = 0.22 x 560 x 38 x 84400

= 395,127,040 J

= 395 150 kJ

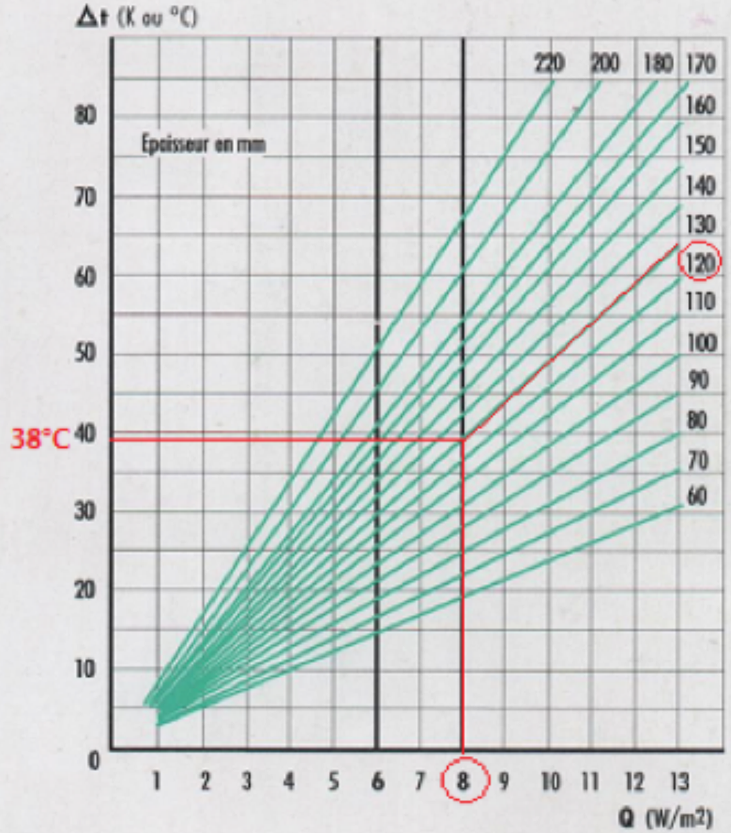
Thermal balance

Calculation of the various balance sheet items

CARACTÉRISTIQUES THERMIQUES

La connaissance de la différence de température entre l'intérieur et l'extérieur de l'enceinte (ΔT) ainsi que le choix des déperditions thermiques admissibles (Q) permettent de déterminer l'épaisseur optimum du panneau en utilisant l'abaque des déperditions.

Q = déperditions thermiques - Valeur préconisée par le DTU 45-1 8W/m² en positif, 6W/m² en négatif.



Epaisseur en mm	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220
(W/m².°C)	0,43	0,37	0,32	0,29	0,25	-	0,22	-	0,19	-	0,16	-	0,15	-	0,13	-	-

Thermal balance

Calculation of the various balance sheet items

Item 2: heat input by the products

The term “products” includes the foodstuffs to be cooled as well as their packaging. When it comes to fresh produce or plants (fruits and vegetables), the heat of respiration must also be added. The latter is due to the humidity that emerges from these products when the temperature drops (only in positive temperature).

Commodities:

Positive cold:

For foodstuffs undergoing a drop in temperature without reaching 0°C, the following formula applies:

$$Q\ commodities = m.cp.(\theta i-\theta f)$$

With :

Q foodstuffs: heat input by foodstuffs [kJ]

m: mass of products entered per day or per cycle [kg]

cp: mass heat capacity of the products before freezing [kJ/kg]

θi: initial product temperature (before cooling) [°C]

θf: final product temperature = temperature in the chamber [°C]

Thermal balance

Calculation of the various balance sheet items

Freezing:

If the food undergoes freezing during cooling, the formula becomes more complex:

$$Q\ commodities = m.cp1.(\theta i-\theta c) + m.lf + m.cp2.(\theta c-\theta f)$$

With :

Q foodstuffs: heat input by foodstuffs [kJ]

m: mass of products entered per day or per cycle [kg]

cp1: Specific heat of products before freezing [kJ/kg]

cp2: Specific heat of products after freezing [kJ/kg]

lf: Latent heat of freezing of products [kJ/kg]

θi: Initial product temperature (before cooling) [°C]

θc: Product freezing temperature (0°C) [°C]

θf: Final product temperature (temperature in the chamber) [°C]

Thermal balance

Calculation of the various balance sheet items

Breathing:

For fresh produce and vegetables at positive temperature, the heat of respiration is expressed as follows:

$$Q_{resp} = m.l_{resp}.10^{-3}$$

With :

Qresp: heat input due to respiration [kJ]

m: mass of products entered per day or per cycle [kg]

lresp: latent heat of respiration [kJ/tonne]

Thermal balance

Calculation of the various balance sheet items

PRODUITS		PROPRIETES THERMIQUES					CONSERVATION DE PRODUITS FRAIS			CONGÉLATION ET CONSERVATION DES PRODUITS CONGELÉS			
		Point de congèl	Chaleur spécifique en kJ/kg *C		Chaleur latente de congélation en	Chaleur de respiration	Tempér.de conserv.	Humidité relative	Durée de conserv.	Temp pour congèl.	Temp pour conserv	Humidité relative	Durée de conserv
		°C	Avant congèl.	Après congèl.	kJ/kg	KJ/kg 24h	°C	%		°C	°C	%	
	Cerises	-2,2	3,64	1,89	284,92	1,47 à 2,1	O à -1	85 à 90	1 à 4 sem.	-55	-18		1 année
	Dattes sèches	-15,5	1,51	1,09	67,04		O à -2	70	4 à 8 mois		-18		1 année
	Fraises	-1,1	3,85	2,01	301,68	2,51 à 3,77	0	85 à 90	1 à 5 jours	-55	-18		1 année
	Citrons	-2,2	3,85	1,93	297,49	1,26 à 3,35	+9 à +10	85 à 90	6 à 8 sem.				
FRUITS	Mandarines	-2,2	3,98	2,14	293,3	1 à 1,5	+4 à +7	85 à 90	3 à 6 sem.				
	Pommes	-2	3,6	1,89	280,73	0,42 à 1,68	-1 à +3	85 à 90	2 à 5 mois				
	Melons	-1,4	4,06	2,05	322,63	2,1 à 4,19	+ 4 à + 10	85 à 90	1 à 4em.				
	Poires	-1,9	3,56	1,89	280,73	0,75 à 0,92	O à -1	85 à 90	1 à 6 mois				
	Pêches	-1,5	3,77	1,89	293,3	0,92 à 1,47	-l à +l	85 à 90	1 à 4 sem.	-55	-18		1 année
	Pamplemousses	-2	3,77	1,89	293,3	0,84 à 1,47	O à +10	85 à 90	4 à 6 sem.				
	Prunes	-2,2	3,69	1,89	289,11	0,42 à 0,75	0	85 à 90	3 à 4 sem.	-55	-18		1 année

Thermal balance

Calculation of the various balance sheet items

Packaging:

$$Qemb = m.cp.(\theta i - \theta f)$$

With :

Qemb: heat input by packaging [kJ]

m: mass of packaging [kg]

cp: specific thermal capacity of packaging [kJ/kg]

θi: initial packaging temperature [°C]

θf: final packaging temperature [°C]

Thermal balance

Calculation of the various balance sheet items

Total products :

The product item can be summarized as follows:

Qproducts = Qcommodities + Qresp + Qemb

Example :

Data: Mass of apples to introduce: m apples = 30 tonnes

Chamber capacity: 300 tons

Specific heat of apples: cp apples = 3.6 kJ/kg.K

Heat of respiration of apples at 2°C: C resp = 1.3 kJ/kg

at 20°C: Cresp = 53 KJ/tonne

Mass of wooden crates: m crates = 20 kg

Specific heat of wood: cp wood = 2.75 kJ/kg.K

It is considered that the products return to 20°C to be cooled to 2°C ($\Delta\theta$=18°C)

Q products = Q foodstuffs + Q resp + Q packaging

Q products = (30000 x 3.6 x 18) + [(30000 x 1.3) + (270 x 53)] + (20 x 2.75 x 18)

Q products = 1,998,300 kJ

Thermal balance

Calculation of the various balance sheet items

Item 3: heat input by ventilation

The evaporators installed in the enclosure to be refrigerated are generally equipped with fans. The thermal losses of the electric motors constitute a heat input to be taken into account in the balance:

$$Q_{ventil} = P_{abs} \cdot t$$

With :
Q ventil: heat input by ventilation [kJ]
Pabs: power absorbed by fan motors [kW]
t: fan operating time [s]

The running time of the fans varies depending on the application:

General case : *the running time of the fans is identical to the running time of the compressors.*

Case of a room with a significant height: *the fans remain permanently powered to avoid stratification of the air temperature. The operating time of the fans is then 24 hours (86400 seconds).*

Case of a tunnel: *the ventilation is on throughout the cycle: the operating time to be taken into account is then the cycle time.*

Thermal balance

Calculation of the various balance sheet items

Fan power input is calculated as follows:

$$P_{abs} = \frac{Q_V . \Delta P}{\eta}$$

With :

Qv: fan volume flow [m3/s]

ΔP: pressure supplied by the fan [Pa]

- 200 to 400 Pa for a cold room
- up to 600 Pa for a tunnel

η: overall efficiency of the fan (between 0.5 and 0.6)

The flow rate Qv of the fan is obtained from another formula:

$$Q_V = \frac{\tau_B . V_{CF}}{3600}$$

With :

τB : mixing rate in volumes per hour

- 15 to 30 vol/h for cold storage rooms at negative temperature
- 20 to 40 vol/h for cold storage rooms at positive temperature
- 300 to 900 vol/h for tunnels
- VCF: volume of cold room or tunnel [m3]

For tunnels, this flow can also be obtained by setting an air speed, while knowing the air passage section: Qv = v . S

with: v: air velocity [m/s]

S: air passage section [m2]

Thermal balance

Calculation of the various balance sheet items

Example :

- The cold storage room is at positive temperature
- 30 vol/h brewing rate
- Chamber volume of 1200 m3

The flow is:

$$Q_v = \frac{30 \times 1200}{3600} = 10 m^3/s$$

- Selected fan pressure differential of 300 Pa
- Fan efficiency is 0.6.

The power of the fan will then be:

$$P_{abs} = \frac{10 \times 300}{0,6} = 5000 W$$

On a 24-hour day, the compressors are considered to operate for 18 hours (depending on the regulation).

The operating time of the fans is then identical, which makes it possible to calculate the load due to ventilation:

Q ventil = 5 x 18 x 3600 = 324 000 kJ

Thermal balance

Calculation of the various balance sheet items

Item 4: heat input due to air renewal

The renewal of air corresponds to the openings of the doors of the cold room, which constitute an additional heat contribution.

$$QRA = m\ air\ .\ (he - hi)$$

With :
QRA: heat gain due to air renewal [kJ]
m air: mass of fresh air entering the chamber [kg]
he: outside air enthalpy [kJ/kg]
hi: indoor air enthalpy [kJ/kg]

Thermal balance

Calculation of the various balance sheet items

It is necessary to know how to estimate the mass of incoming air. For this, we use the notion of air renewal rate (vol/h), or number of air renewals per 24h (vol/d).

$$m_{air} = \frac{V_{air}}{v''_i} = \frac{nr.V_{CF}}{v''_i}$$

With :

Vair: volume of incoming air [m3]

v''i: specific volume of indoor air [m3/kg]

VCF: cold room volume [m3]

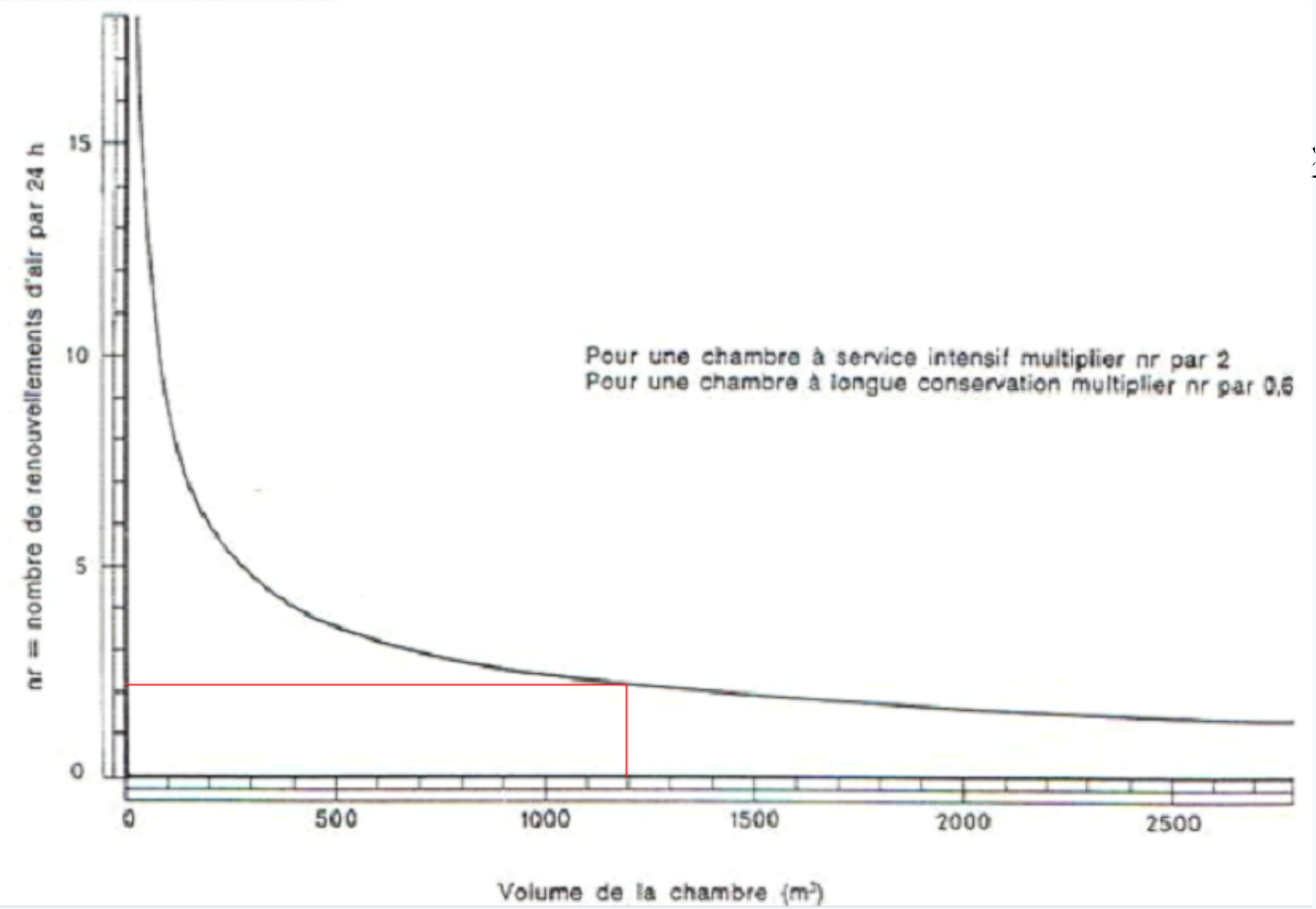
nr: number of air changes [vol/d]

This number of air changes corresponds to the number of times the volume of the chamber is renewed in one day, i.e. 24 hours.

A curve makes it possible to estimate this number according to the volume of the chamber:

Thermal balance

Calculation of the various balance sheet items



:F

Thermal balance

Calculation of the various balance sheet items

Example :

The apple preservation chamber is to be considered as a long preservation chamber (multiply nr by 0.6). Knowing its volume of 1200 m3,
we get nr = 2.2 x 0.6 = 1.32.
The humidity maintained in the room is 90%.
The specific volume of air at 2°C and 90% is 0.783 m3/kg(as),
which gives an air mass of:

$$m_{air} = \frac{1{,}32 \times 1200}{0{,}787} = 2012{,}7 \text{ kg}$$

Consider that the outside air is at 40 °C / 50%.
he = 100.69 kJ/kg(as)
hi = 11.84 kJ/kg(as)

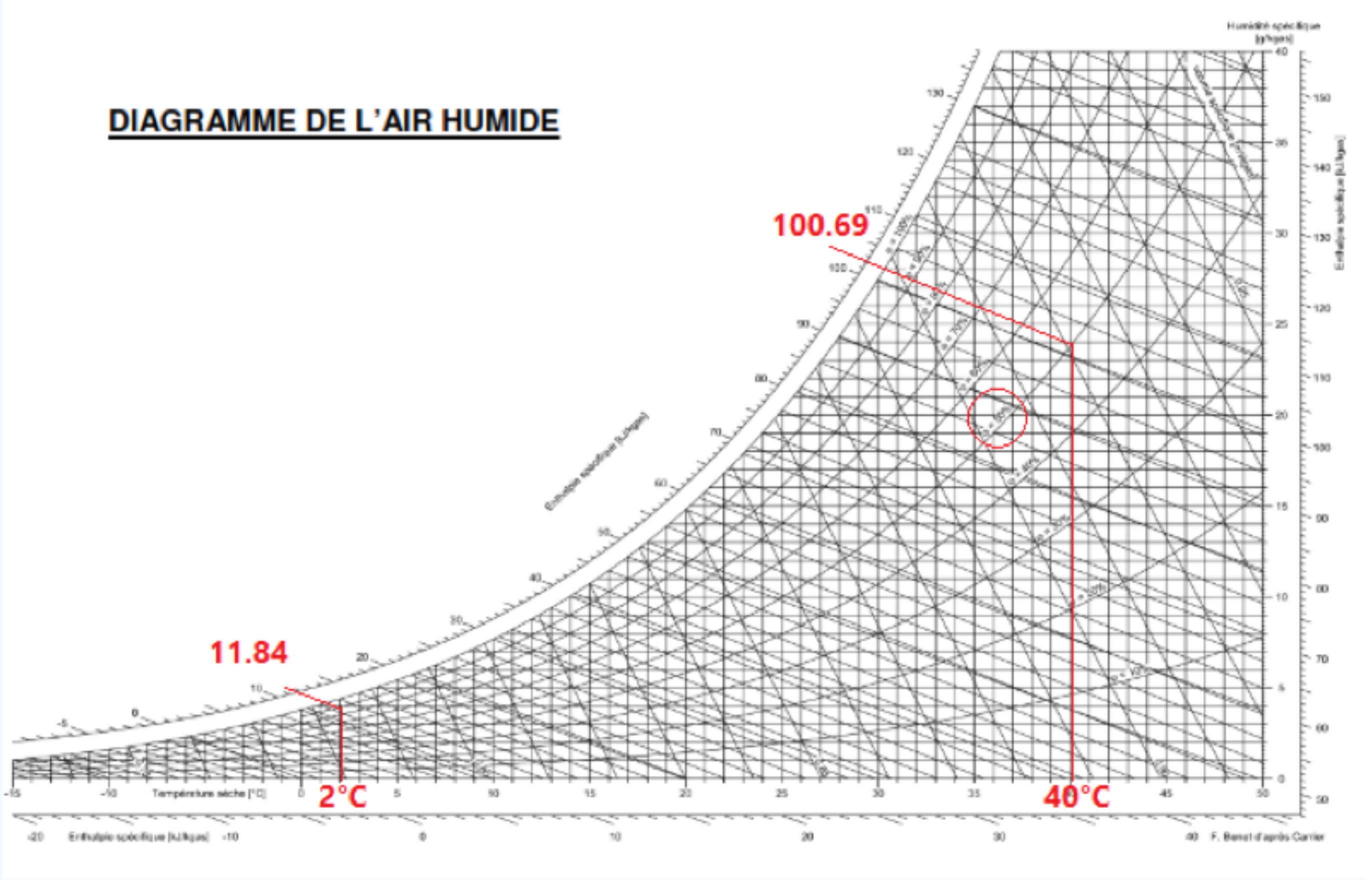
QRA = 2012,7 x (100,69 – 11,84) = 178 828 kJ

Thermal balance

Calculation of the various balance sheet items

Example :

The humidity maintained in the room is 90%.
The specific volume of air at 2°C and 90% is 0.783 m3/kg(as),
Consider that the outside air is at 40°C / 50%.
he = 100.69 kJ/kg(as)
hi = 11.84 kJ/kg(as)



Thermal balance

Calculation of the various balance sheet items

Item 5: heat input by machines

Qmach = N . P . t

With :
Q mach: heat input by machines [kJ]
N: number of machines
P: thermal power released by the devices [kW]
t: operating time [s]

Example:

Forklift power = 4.4 KW
Stay in the room 2 hours

Q mach = 4,4 x (2 x 3600) = 31 680 KJ

Thermal balance

Calculation of the various balance sheet items

Item 6: heat input by lighting

Q ecl = P écl . t

With :
Q ecl: heat input by the lighting [kJ]
P ecl: thermal power released by the lighting [kW]
t: calculation time [s]

The power of the lighting is around 5 to 20 W/m2. This value must be multiplied by the floor area and divided by 1000 to obtain the power in kW.

Example:

Room area = 200 m2
Lighting power is estimated at 10 W/m2
Stay in the room 2 hours

Q ecl = 200 x 10 x (2 x 3600) = 14 400 000 J
= 14 400 KJ

Thermal balance

Calculation of the various balance sheet items

Item 7: heat input by the occupants

$$Qpers = N \cdot P/pers \cdot t$$

With :

Qpers: heat input by the occupants [kJ]

N: number of people

P/pers = power per person [kW]

t: occupation time [s]

Température de la chambre (°C)	Puissance dégagée par personne (W)
10	210
5	240
0	270
-5	300
-10	330
-15	360
-20	390
-25	420

Example:

Number of people = 2 people

Power per person = 0.258 KW

Stay in the room 2 hours

$$Q\ ecl = 2 \times 0{,}258 \times (2 \times 3600) = 3\ 715\ KJ$$

Thermal balance

Sum of contributions from all positions

Once all the items have been calculated, the quantities of heat must be added together to obtain the total balance, in kJ.

Items 5, 6 and 7 are often negligible in relation to the other items, and difficult to calculate. In general, we will take a percentage of the previous contributions to estimate the quantity of heat released by these three stations from 5 to 10% of total Q

$$Q_{total} = \sum Q$$

Qtotal = Qwalls + Qproducts + Qventil + QRA + Qmach + Qecl + Qpers

Thermal balance

Sum of contributions from all items

Example :

Qwalls + Qproducts + Qventil + QRA + Qmach + Qproducts + Qpers

= 1,998,300 + 324,000 + 178,828 + 31,680 + 14,400 + 3,715

the overall sum of the contributions:

$$Q_{total} = 2\ 550\ 923\ \text{kJ}$$

Thermal balance

Calculation of cooling capacity

The final phase of the calculation of the balance consists in dividing the total quantity of energy by the operating time of the compressors to obtain the cooling capacity to be installed.

$$\Phi_0 = \frac{Q_{total}}{t_{CP}}$$

Attention ! tcp is the running time of the compressors which is used to calculate the power of the equipment. Not to be confused with the base time of the calculation which is used to assess the heat input over the entire refrigeration or storage period.

Thermal balance

Calculation of cooling capacity

Indeed, the compressors do not work for the entire duration of use.
If it is a cold room, they will be considered to operate between 16 and 20 hours a day (depending on how often the doors are opened).

On the other hand, for a tunnel, the compressors operate for the entire duration of the cycle. In this case, tcp = base time of the calculation

Example :

In the case of a cold storage room, it will be considered that the compressors operate on average 18 hours a day.
The balance is then obtained as follows: **2,550,923 / 18 x 3600 = 39.366 KJ/s**
Always round up:

$$\Phi 0 = 40 \text{ kW}$$

شكرا

Merci

Thanks

Gracias

Obrigado