ENERGY ISSUES: AN INSIGHT

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Introduction

Energy savings are important for many reasons:

- They reduce the energy bill;
- They preserve the resources of the planet;
- They contribute to comply with the objectives of the Kyoto Protocol and more generally to implement sustainable development.

The paper gives an insight on several facets of energy consumption taking examples in the fields of cold stores and fruit-packing stations.

1. Cold stores

It is important to have some figures in mind:
The refrigerating capacity of a low-temperature cold store is approximately 20 W/m^3. Hence a 10 000 m^3 cold store will have a 200 kW refrigerating capacity. If we consider that the refrigerating plant is functioning 2500 h out of 8760 h per year, the annual consumption is 50 kWh/y/m^3.
In addition, if we consider an average mass of products of 200 kg per m^3, the energy consumption will be 250 kWh/tonne/m^3.
Just to put these figures in perspective, in France, for instance, there are approximately 20 millions m^3 of cold stores and cold rooms (including supermarkets, abattoirs, fruit packing stations). The total annual energy consumption of these cold stores will be 5000 MWh, which is about 1% of the French electricity production (491 TWh in 2003).

2. Fruit packing stations

The table 1 gives average capital costs, product costs and energy costs for a fruit packing station:

Table 1 Average costs for a fruit-packing station of 2000 m^3

Designation		Unitary price	Cost (€)
Capital costs	2000 m^3	100 €/m^3	200 000 €
Product costs	2000 m^3 – 200 kg/ m^3	1 €/kg	400 000 €
Energy costs	2000 m^3 – 50 kWh/ m^3	0.06 €/kWh	6000 €

This table gives rise to 2 commentaries:

1. The value of the product which is stored is generally higher than the cost of the building itself. Therefore, the practitionner will first take care of the quality of the product, because if there is a decrease in the quality, it will have a considerable impact on the commercialisation and a decrease in the selling price, which will generally be much higher than the cost of energy.
2. The level of energy expenses may look very small. However if you compare it to the profit of the plant it is of the same order of magnitude. You may therefore immediately increase the profit if you reduce the energy expenses.

3. Thermal balance of a cold room

Even if the thermal balance is something which is well understood by practitionners, it is worth while to give a few comments :

Table 2 displays the thermal balance of a traditional cold store in preservation mode (Azzouz, 1993).

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Table 2 Thermal balance of a 13 000 m^3 cold store

N°	Items	%
1	Walls	64.0
2	Ventilation	16.0
3	Opening of doors	12.0
4	Lighting	3.0
5	Products	2.6
6	Vehicles	2.0
7	Occupants	0.4
	TOTAL	100.0

In preservation mode the 3 most important items in the thermal balance are:

- Walls (64 %)
- Ventilation (16 %)
- Opening of doors (12 %)

This example demonstrates:

- That the insulation should be excellent when the cold store is built, and should keep good qualities over years. Materials with a low conductivity and a low ageing should be selected.
- The insulation should be protected against shocks. When the coating is open, humidity enters and the coefficient of conductivity c considerably increases. The coefficient c has a value of 0.011 W/m.K for the HFC- 245fa, 0.024 W/m.K for the air, 0.585 W/m.K for water (25 times the conductivity of the air) and 2.32 W/m.K for ice (100 times the conductivity of the air).
- It is worthwhile to use from time to time infrared thermography in order to check the quality of the insulation.
- Ventilation is costly. It is profitable to run ventilators according to the demand and not continuously. Variable speeds fans and the possibility to run only part of a series of ventilators should be designed from the beginning.
- Opening of doors is also costly in energy. Table 3 gives an insight on the considerable ingress of warm air and the escape of cold air through a unique door which is open 1 hour per day (Azzouz, 1993). In addition the great quantity of water vapour which enters will be transformed into frost.

Table 3 Calculation of entries of heat and water vapour through a door

Designation	Values
Cold store volume	13 000 m^3
Size of the door	3 x 2.8 m
Total opening duration per day	1 h/day
Interior	θ = -25°C ; RH = 90%
Exterior	θ = + 20°C ; RH = 80%
Heat ingress	727 000 kJ/day (200 kWh)
Water vapour ingress	108 kg/day

In conclusion, fast-opening doors should be used and doors should be closed when they are not used.

4. Examples of energy costs versus temperature

A practitionner of a cold store should know the amount of the extra costs if the products are preserved at a lower temperature than the regulatory temperature. The preservation of foodstuffs at temperatures lower than the regulatory temperatures may anticipate an increase of temperature in the cold chain after storage and contributes to the global quality of the product. However, this issue is much controversial.

The box below gives figures of extra costs of products stored at – 22°C instead of – 18°C

Extra costs per tonne to store products at – 22°C instead of – 18°C

- 5 % additional energy for each degree C lower
- 250 kWh/tonne/year at – 18°C
- The preservation at – 22°C will request 20% additional energy i.e. 50 kWh/t
- If 0.06 €/kWh
- The additional cost is 3 €/tonne/year
- Or 0.6 €/tonne if the product is stored 2 months

Another issue is how much shall a practitionner pay the energy necessary to decrease the temperature of a product from 1°C. The box below gives an example.

Cost to cool 1 tonne of frozen foods from – 17°C to –18°C

- Heat to extract: $Q = mc\Delta\theta$
- Q = 1000 kg x 2 kJ/kg.K x 1 K = 2000 kJ
- COP = 1 at – 17°C
- COSP = 0.5 at – 17°C
- Energy required = 4000 kJ i.e. 1.2 kWh/tonne (4000/3600)
- Energy cost = 0.072 €/tonne if 1 kWh = 0.06 €

With such figures in mind, practitionners may decide whether they could store the cargo at a lower temperature in a quality perspective. They may also request an additional fee to the clients.

5. Frost is expensive in terms of energy consumption

The figure 1 clearly illustrates that frost formation and defrosting are costly in energy, since energy is required :

1. to make frost;
2. to defrost;
3. to recool the ambient after defrosting;
4. to compensate for lower performances namely:
    - a decrease in the air flow rate because the exchanger tends to be obstructed;
    - a decrease in the thermal exchange (when the exchanger is completed frosted there is no more thermal exchange).

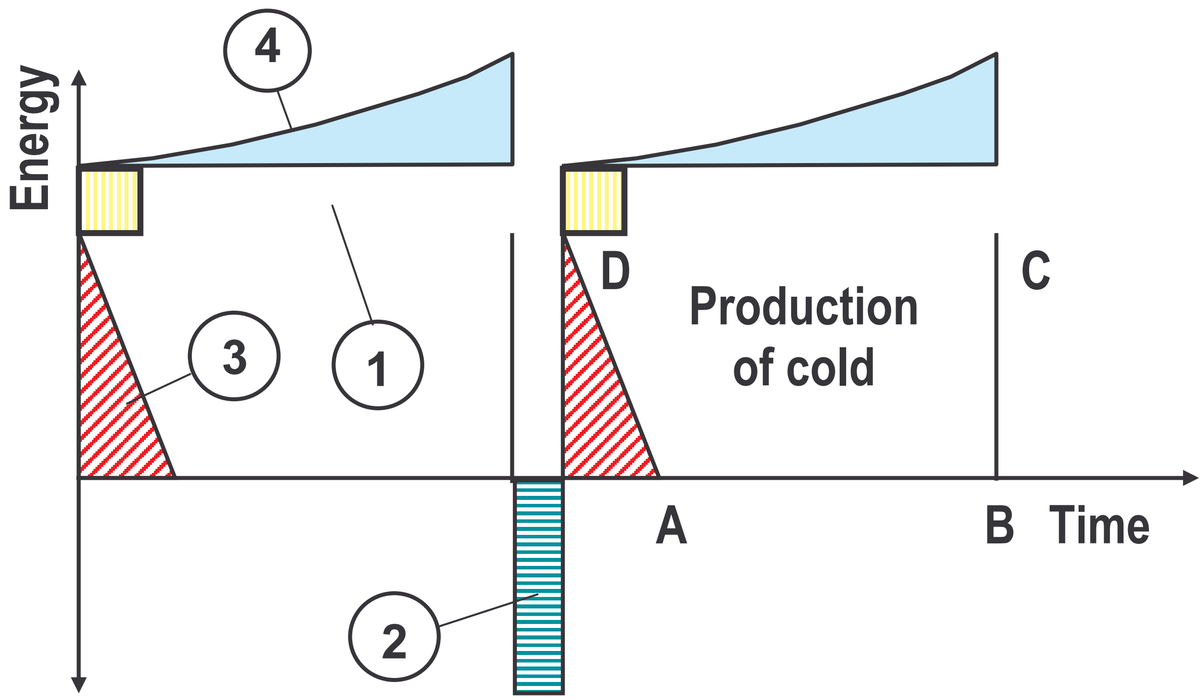

Figure 1 The energy necessary for the production of cold is represented by the trapeze ABCD. The energy consumed, taking into consideration frost formation and defrosting is represented by the trapeze ABCD + the surfaces 1, 2, 3 and 4.

6. Air is heavy

Two examples will demonstrate that air has a certain weight, which is probably higher than generally considered:

1. The Eiffel tower

The weight of the Eiffel tower made of iron is 7000 tonnes.
The weight of the air inside a box which could contain the Eiffel tower is also 7000 tonnes.

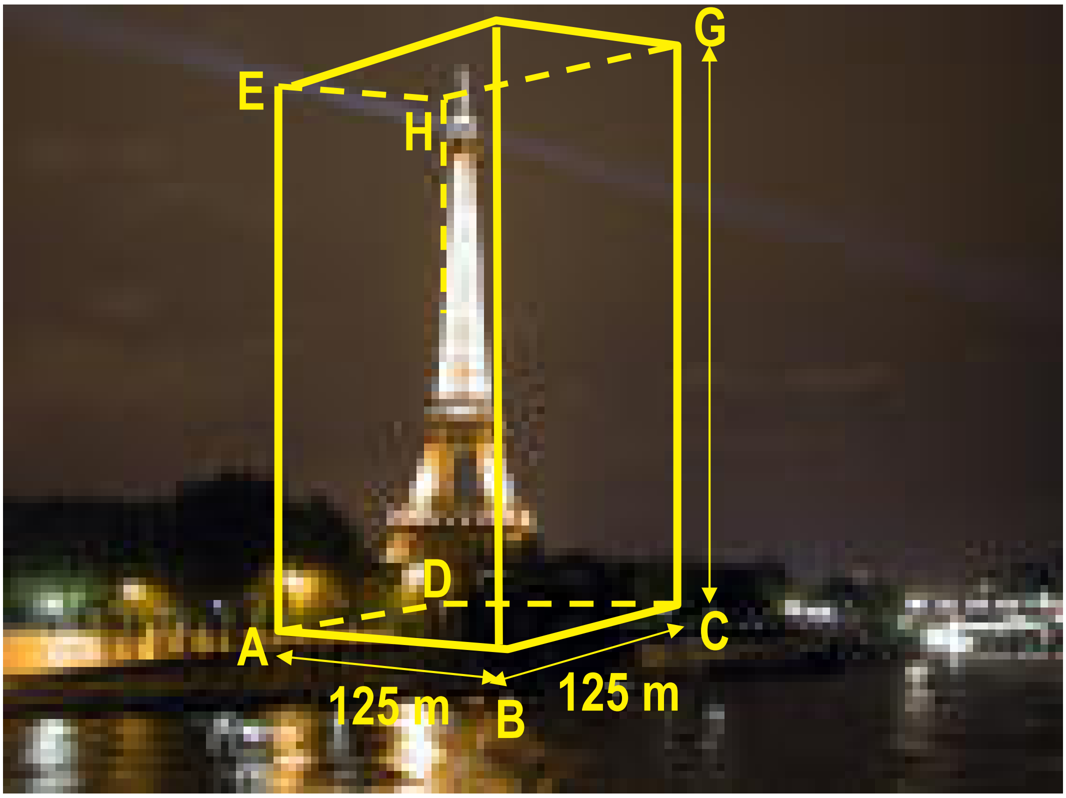

Figure 2 The weight of the air comprised in ABCDEFGH matches the weight of the Eiffel tower itself

2.Plant of prerefrigeration of vegetables

The cooling process of 24 tonnes of cauliflowers (the charge of a semi-trailer) from + 20°C to + 1°C involves:

- air circulation on the basis of 2 kg of air/h/kg of cauliflowers over 12 hours;
- i.e. approximately 600 tonnes of air;
- i.e. 25 times the mass of cauliflowers being cooled;
- to recirculate about 1000 times the same air through the cargo of cauliflowers;
- in addition all the energy used to run the fans is turned up into heat and enters the thermal balance.

Air is an attractive medium because it is very convenient, it has no cost, it is clean and flexible; however we should take into consideration the energy necessary to transport the tonnes of air to be circulated.

7. Lift between low and high pressure

The more the lift between low and high pressure is, the more energy is consumed as indicated in the table 4.

Table 4 Additional energy consumption for each degree of lower evaporation temperature or higher condensation temperature

-1°C at evaporation side (from – 30°C to – 40°C)	+5% energy per °C
-1°C at evaporation side (from -5°C to - 15°C)	+3% energy per °C
+1°C at condensation side (from +25°C to +35°C)	+2% energy per °C

For example if the evaporation takes place at – 40°C instead of – 35°C and if, in addition, the condensation takes place at +35°C instead of +30°C the energy consumption will be increased by approximately 40% according to the calculation below

$$(1.05)^5 \times (1.02)^5 = 1.408$$

As an example the energy consumption of supermarkets should be greatly reduced if a floating condensation system is applied. It means that the temperature of condensation should be linked to the ambient temperature. If the ambient temperature is lower, the temperature of condensation should be decreased instead of maintaining a constant lift and a high condensation temperature for the good-functioning of the thermostatic valve, for instance.

8. Good practices

Taking into account the considerations detailed above some guidelines could be listed for the main components of the refrigerating circuit:

8.1. Compressor

The COP increases if the lift LP-HP decreases.

The COP increases if the suction temperature decreases.

Consider that energy efficiency decreases when the plant is run on partial charge (IIR, 2002):

- a 1-stage compressor plant with screw compressors should not be regulated below 90% capacity;
- a 1-stage compressor plant with reciprocating compressors should not be regulated below 50% capacity.

Use frequency converter for capacity regulation.

8.2. Evaporator

Size the evaporator for a small ΔT, say between 5 and 10°C.
You reduce the size of the compressor when the ΔT is smaller.
Use variable-speed fans.
Size for low-pressure drop in the system (1°C pressure drop in the evaporator).
Defrost when necessary.
Give your preference to hot gases instead of electrical defrost.

8.3. Condenser

Oversize the condenser.
Preferably use evaporative condenser instead of air condenser because the heat is rejected at wet-bulb temperature (16°C instead of 25°C for air at 25°C and RH = 60%, for instance).
Regularly clean evaporative condensers.
Use air purgers because the air inside the circuit increases the condensation temperature (if the air inside an ammonia circuit is responsible of 1 additional bar, it is equivalent to 3 additional °C at 30°C).
Place the condenser in a "cool" spot (avoid warm air returning to the condenser).
Clean heat transmission surfaces.
Report all the events and measurements in a logbook because detection of abnormal operating conditions makes it possible to identify the origin, to reduce consumption (energy, refrigerant) and to avoid damage.

Conclusion

The Kyoto Protocol entered into force on February 16, 2005. Italy will have to reduce the emissions of greenhouse gases during the period 2008-2012 by 6.5% in comparison with the emissions of 1990. In refrigeration and air-conditioning domains, the direct emissions of halocarbon gases should be drastically reduced thanks to a very good containment and the indirect emissions due to energy consumption should also be reduced as far as possible thanks to the pieces of advice and guidelines presented beforehand.

References

1. Azzouz A., Goussé J., Duminil M., 1993, Experimental determination of cold loss caused by opening industrial cold-room doors, Int. Journal of Refrigeration.
2. IIR, 2002, Energy Guidelines for Refrigeration Systems in Cold Stores and Freezers, thematic files Commission d1, www.iifiir.org