SOLAR COOLING

Why Solar Cooling

- Dramatic increase of air conditioning since the early 80ies
- Cost of energy
- Issues related to environmental pollution
  - Due to energy production
  - Due to the use of CFC's and HCFC's
- Matches demand with source availability
- Crucial for improving life standards in developing countries

Thermal Comfort

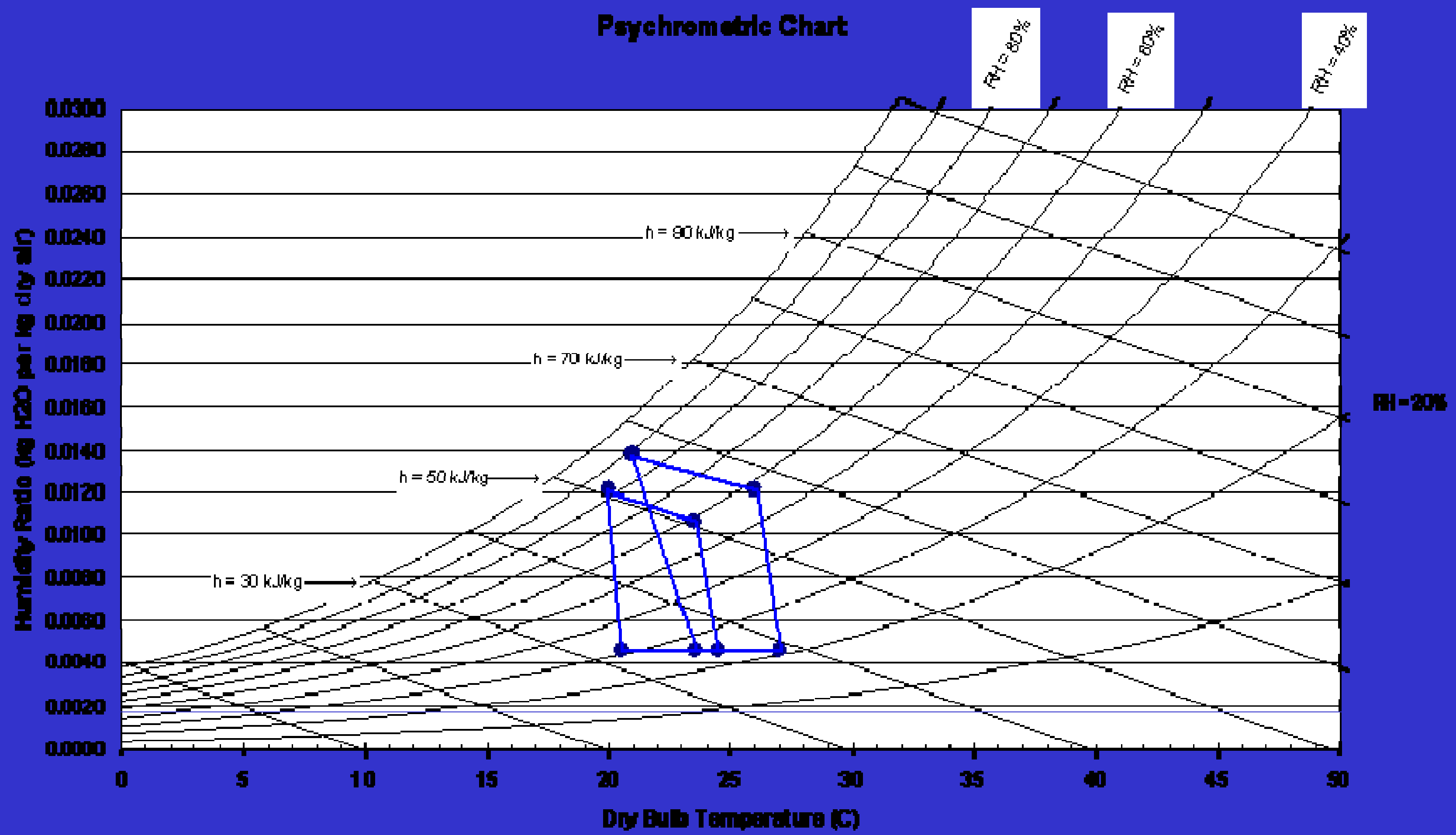
"Is that condition of mind that expresses satisfaction with the thermal environment"

Depends on may parameters:

- Meteorological
- Physiological / psychological
- Clothing
- etc

Conclusion: Concept **<u>not easily</u>** quantifiable!

Thermal Comfort – ASHRAE Approach



Underlying Physics

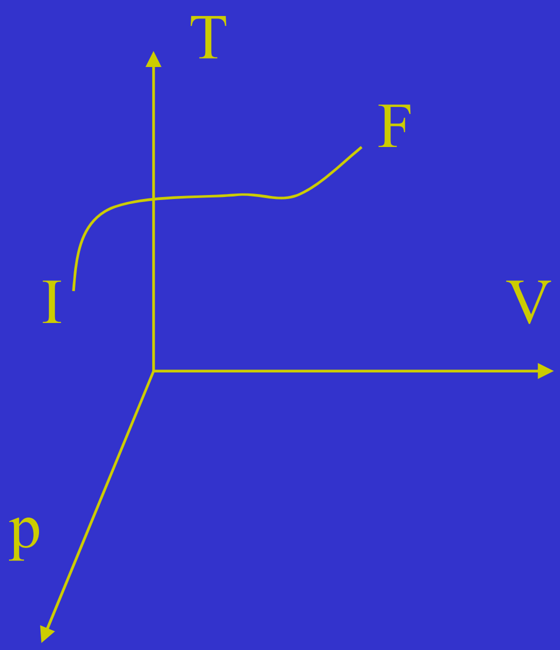
Thermodynamics

1st Law: The change of internal energy (U) of a system is equal to the heat absorbed (Q), plus the external work (W) done on the system

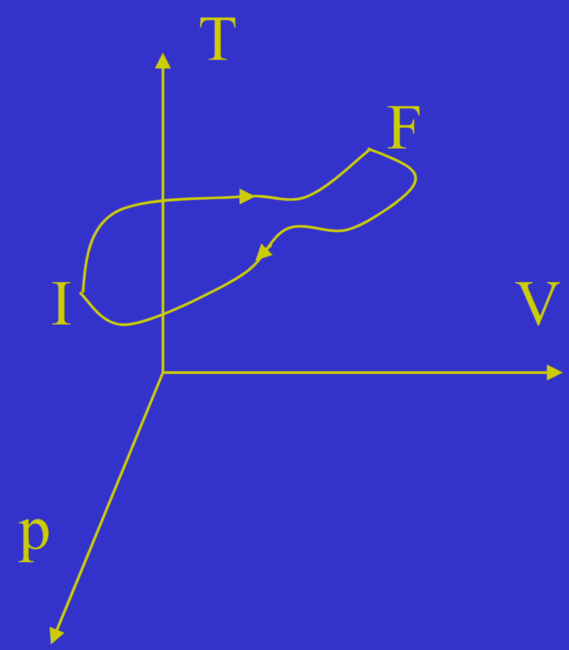
W, Q related to the changes the system experiences when going from an initial to a final state

Thermodynamic Cycle

Simple Transformation



Cyclical Transformation or Cycle



Entropy

The concept of entropy was originally introduced in 1865 by Rudolf Clausius. He defined the *change in entropy* of a thermodynamic system, during a reversible process in which an amount of heat ΔQ is applied at constant absolute temperature T, as

$$\Delta S = \Delta Q / T$$

Clausius gave the quantity S the name "entropy", from the Greek word *τροπή*, "transformation". Since this definition involves only differences in entropy, the entropy itself is only defined up to an arbitrary additive constant

Thermodynamics - 2nd Law

The most probable processes that can occur in an isolated system are those in which entropy increases or remains constant

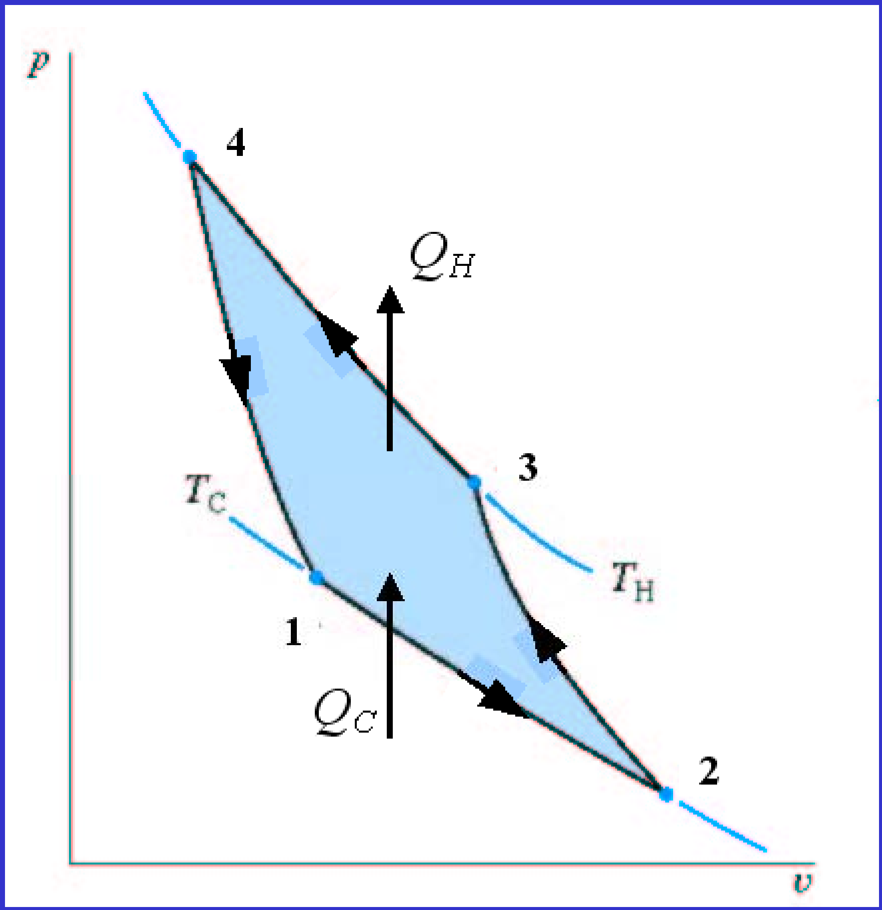
In other words:

> In an isolated system there is a well-defined trend of occurrence of process and this is determined by the direction in which entropy increases.

In other words:

> Heat flows naturally from a system of higher temperature to a system of lower temperature.

Ideal Carnot Refrigeration Cycle



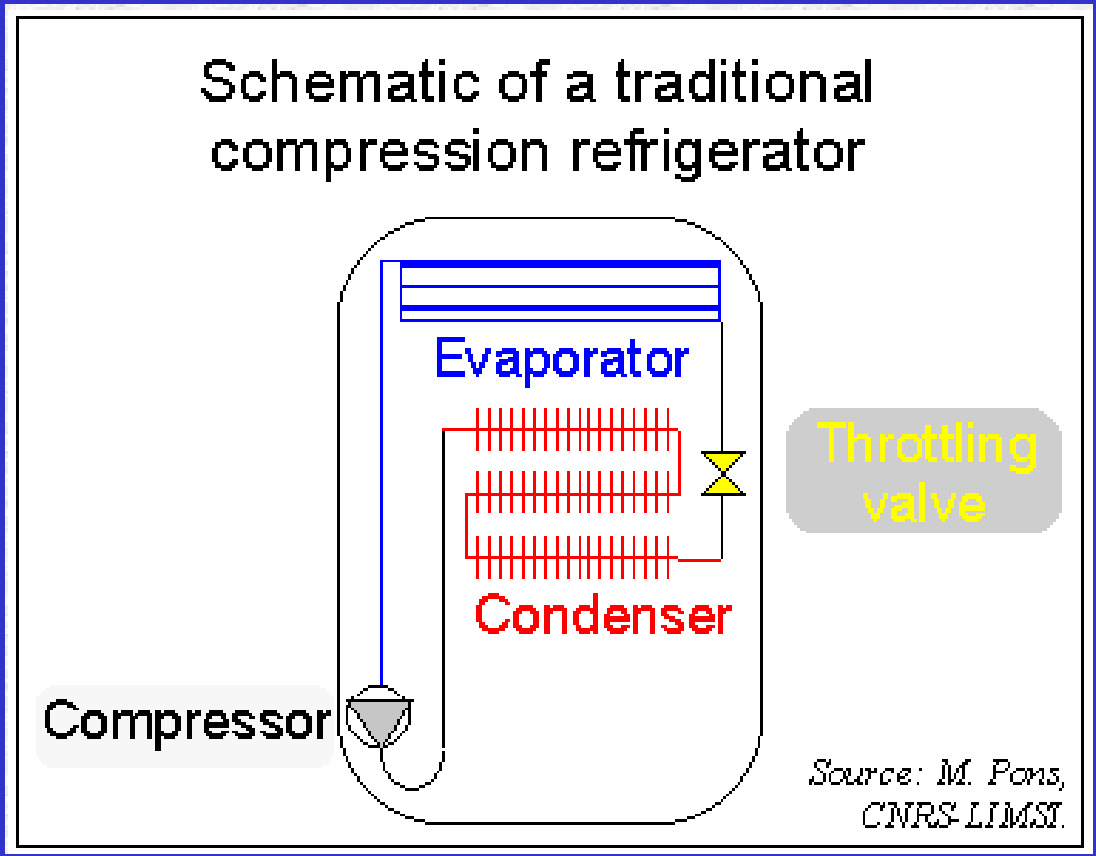
1→2 Isothermal expansion
2→3 Adiabatic compression
3→4 Isothermal compression
4→1 Adiabatic expansion

$$W_{cycle} = \int_1^2 Pdv + \int_2^3 Pdv + \int_3^4 Pdv + \int_4^1 Pdv$$
$$= \text{shaded area (net work } in\text{)}$$

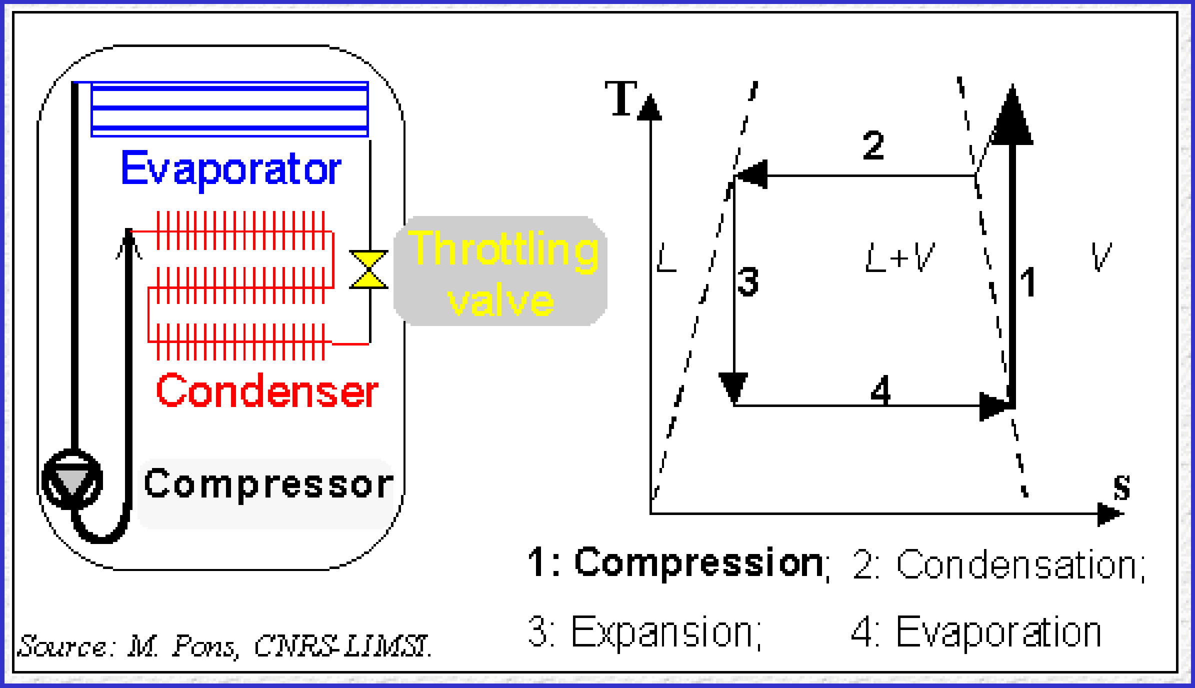
Coefficient of Performance (COP)

$$COP = \frac{\text{Useful cooling energy}}{\text{Net energy supplied by external sources}}$$

Conventional cooling cycle

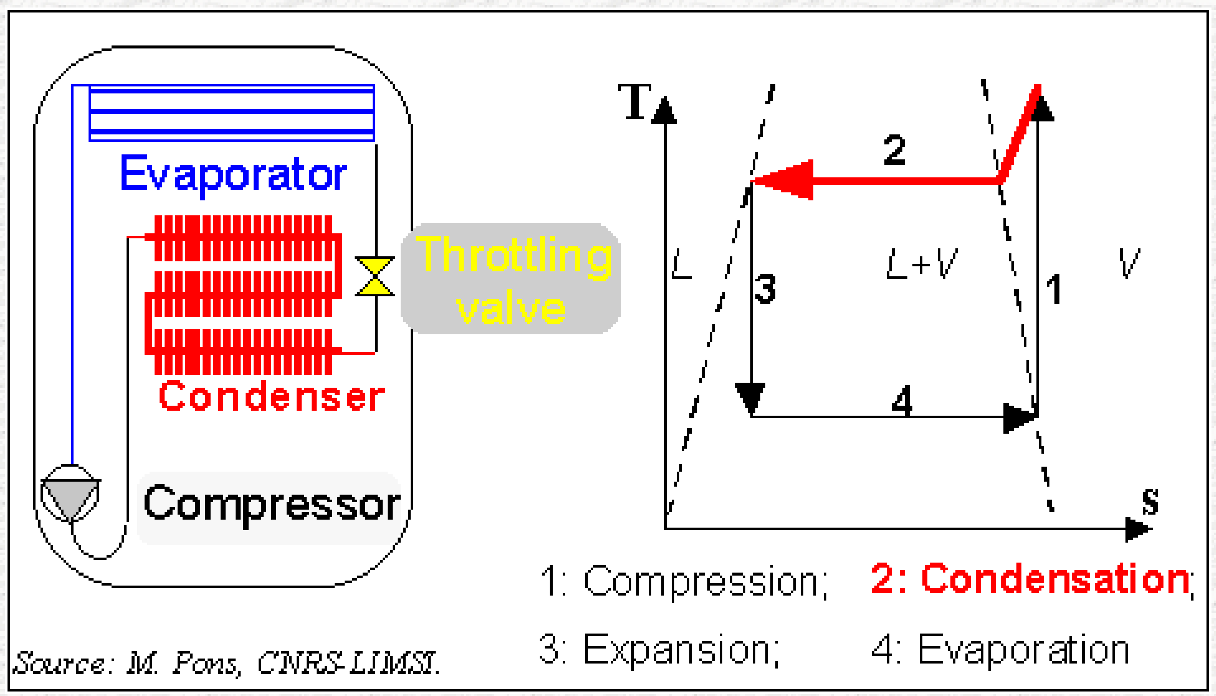


Compression



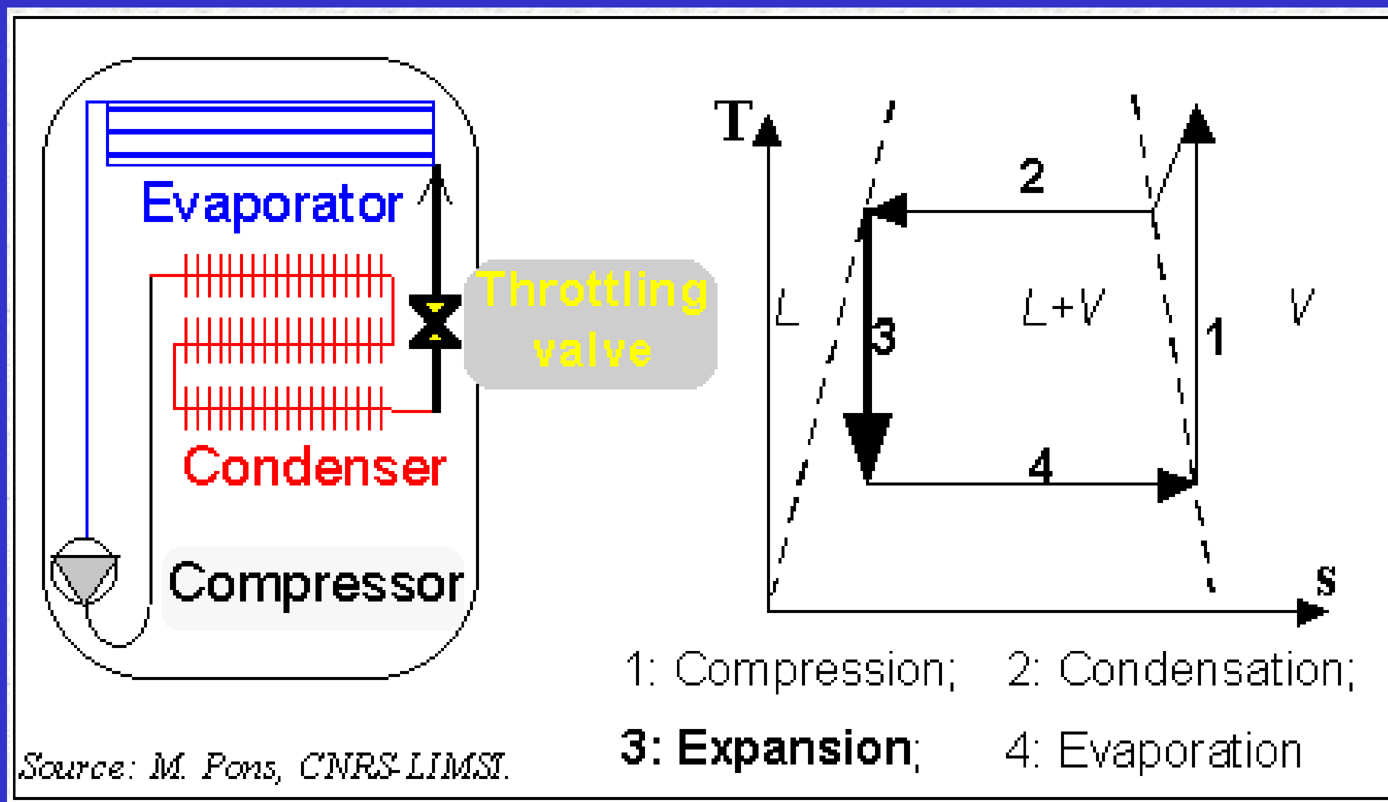
Vapor is compressed and its temperature increases

Condensation



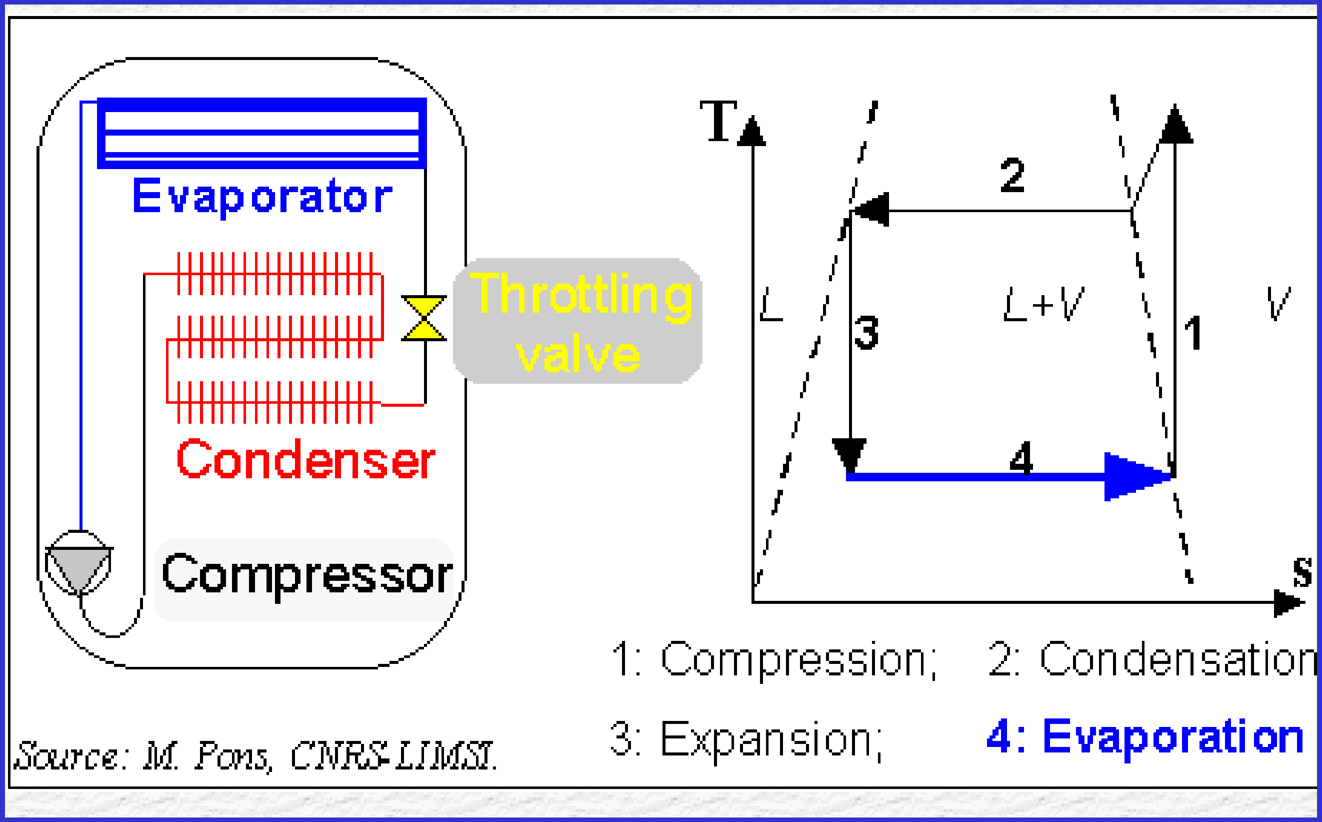
The fluid at "high pressure" is cooled by ambient air and therefore condensed

Expansion



The liquid refrigerant is depressurized and its temperature decreases

Evaporation



The liquid refrigerant at "low pressure" receives heat at low temperature and evaporates

Thermal Solar Cooling Techniques

Absorption Cooling

Energy is transferred through phase-change processes

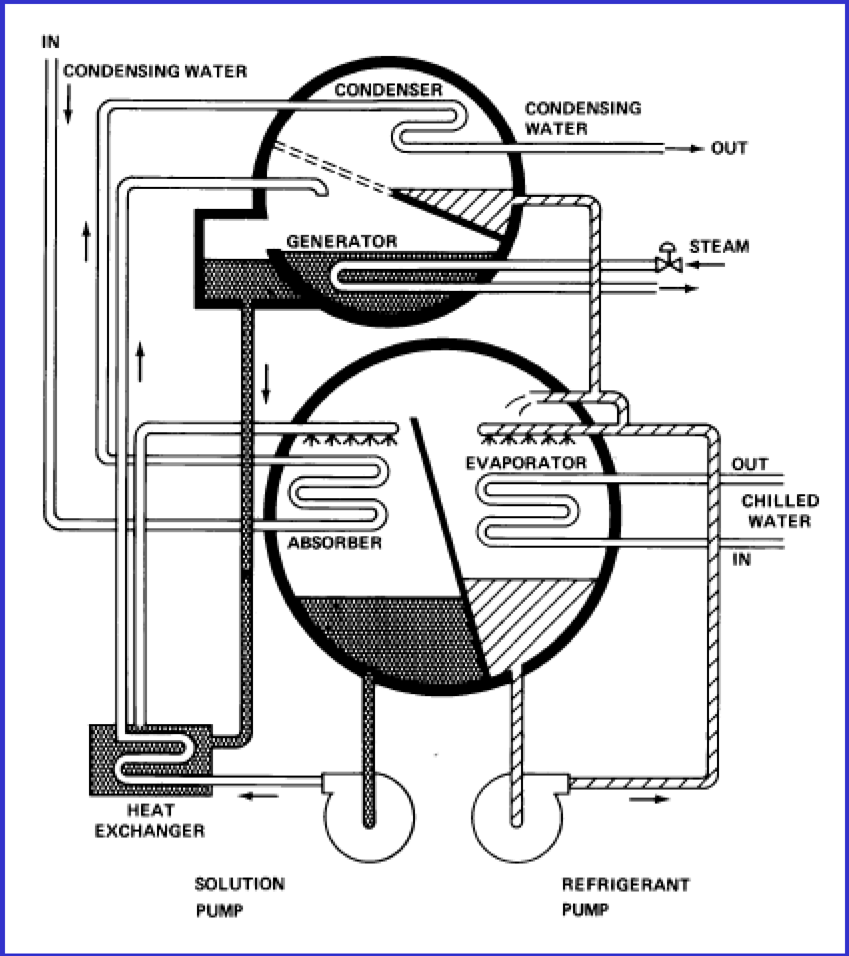
Adsorption Cooling

Energy is transferred through phase-change processes

Desiccant Cooling

Energy is transferred through latent heat processes

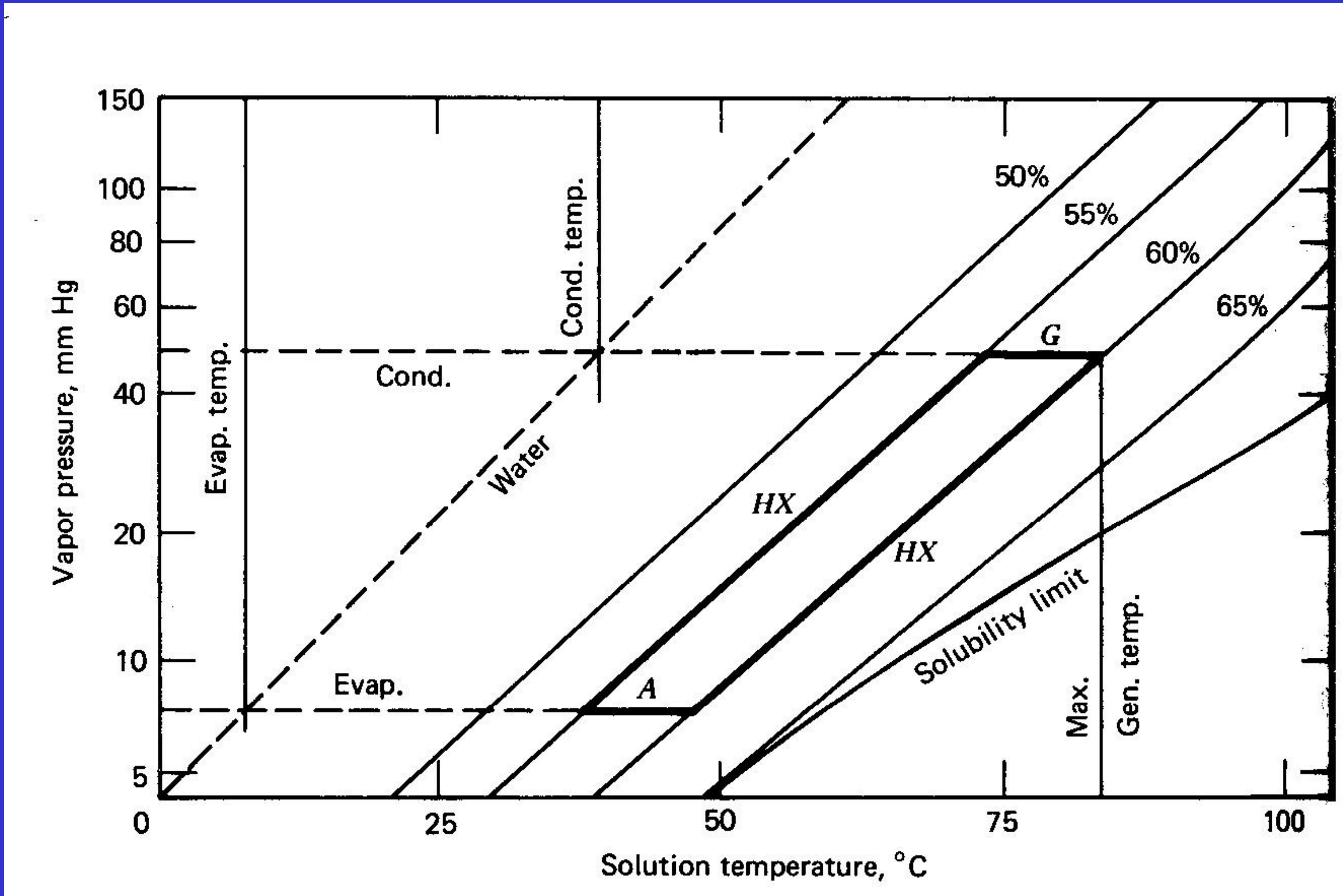
Absorption Cooling



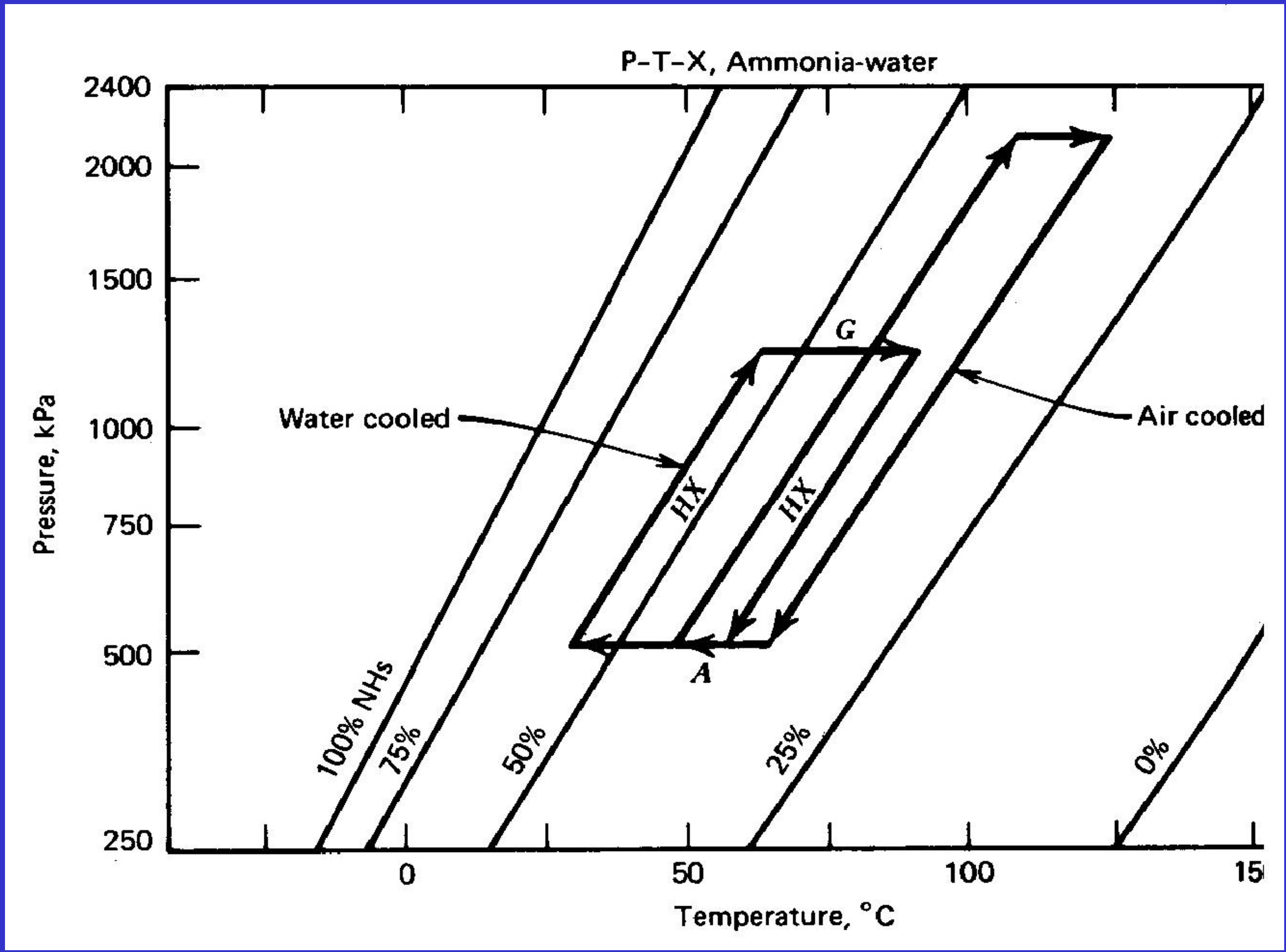
Substances used

Absorbent	Refrigerant
LiBr	H_2O
H_2O	NH_3

Properties of LiBr – H_2O

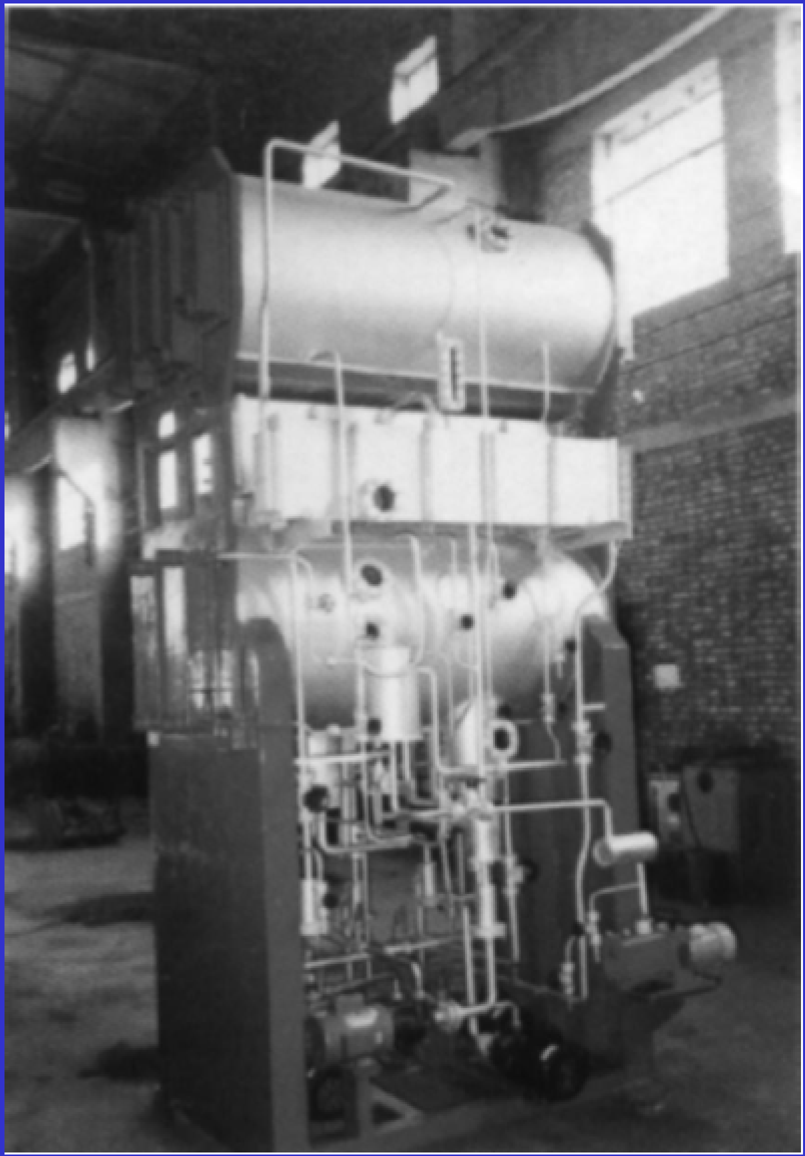


Properties of $H_2O - NH_3$



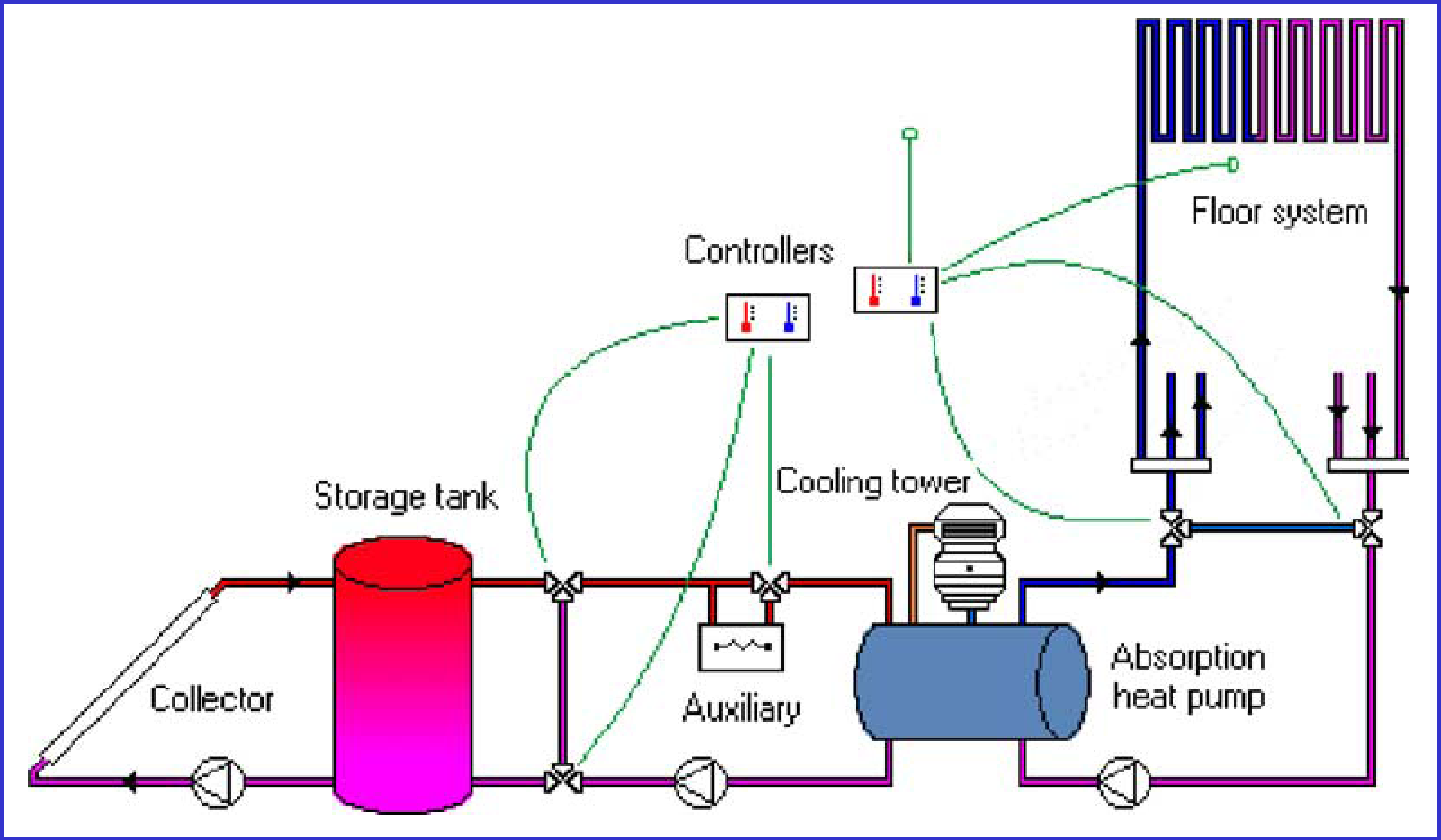
Real application – Solar collectors

Absorption machine



Single effect Yazaki machine (10 ton LiBr

System combined to sub-floor exchanger



Adsorption cooling

Adsorption is the use of solids for removing substances from gases and liquids

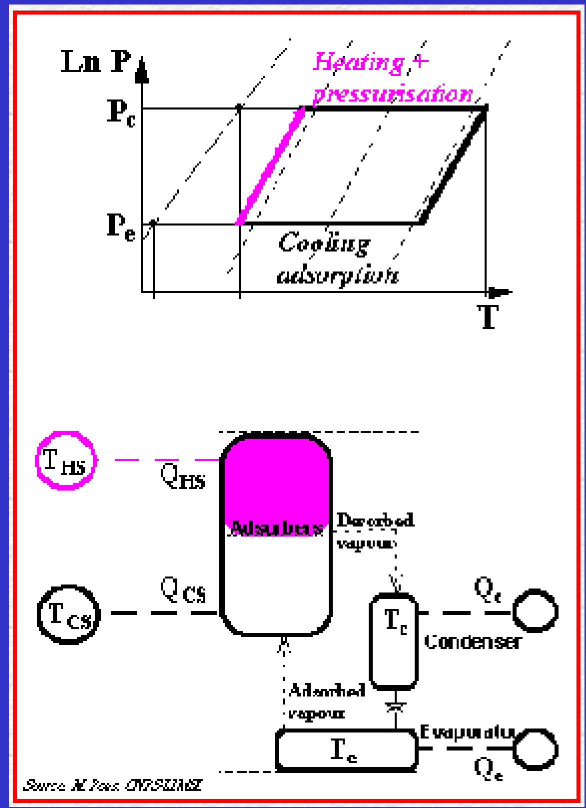
The phenomenon is based on the preferential partitioning of substances from the gaseous or liquid phase onto the surface of a solid substrate.

The process is ***reversible***

Adsorption Phase 1

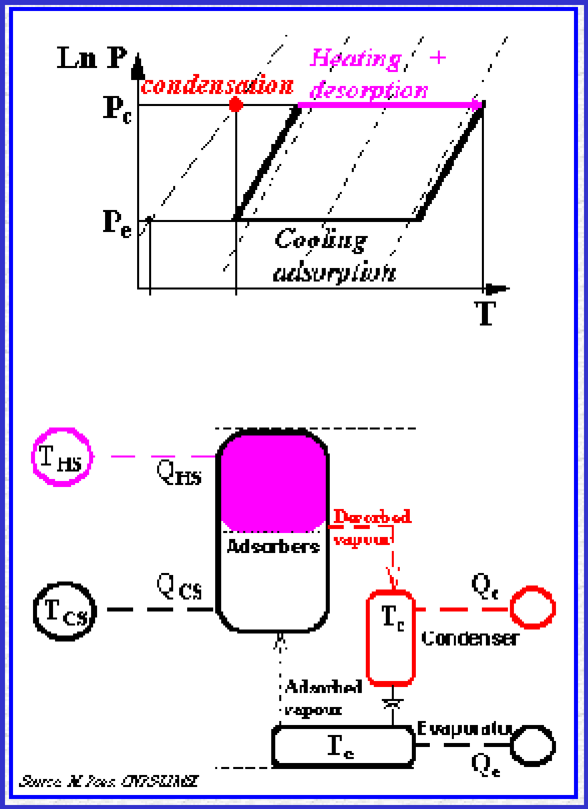
Heating and pressurization

The adsorbent temperature increases, which induces a pressure increase, from the evaporation pressure up to the condensation pressure.
This period is equivalent to the "compression" phase in compression cycles.



Adsorption Phase 2

Heating and desorption + condendsation



During this period, the adsorber continues receiving heat while being connected to the condenser, which now superimposes its pressure.

The adsorbent temperature continues increasing, which induces desorption of vapour. This desorbed vapour is liquified in the condenser.

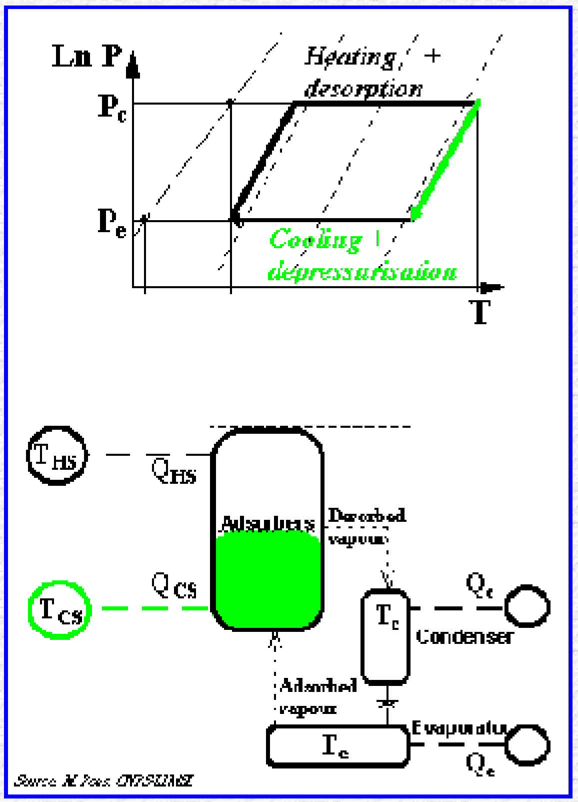
The condensation heat is released to the second heat sink at intermediate temperature.

This period is equivalent to the "condensation" in compression cycles.

Adsorption Phase 3

Cooling and depressurization

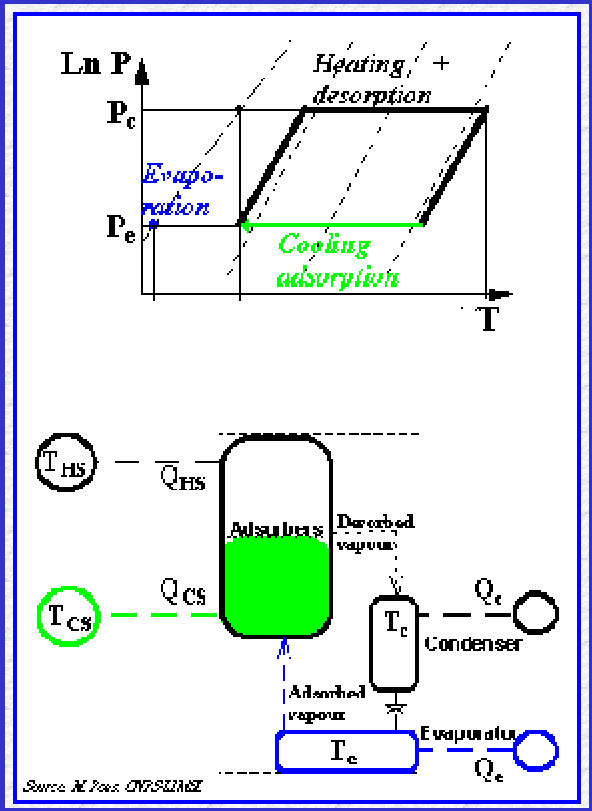
During this period, the adsorber releases heat while being closed.
The adsorbent temperature decreases, which induces the pressure decrease from the condensation pressure down to the evaporation pressure.
This period is equivalent to the "expansion" in compression cycles.



Adsorption Phase 4

Cooling and adsorption + evaporation

During this period, the adsorber continues releasing heat while being connected to the evaporator, which now superimposes its pressure.
The adsorbent temperature continues decreasing, which induces adsorption of vapor. This adsorbed vapour is evaporated in the evaporator.
The evaporation heat is supplied by the heat source at low temperature.
This period is equivalent to the "evaporation" in compression cycles.



Adsorption Cooling - Summary

The cycle is intermittent because production of cooling energy is not continuous: it occurs only during part of the cycle
When there are two adsorbers in the unit, they can be operated separately and production of cooling energy can be quasi-continuous.

When all the energy required for heating the adsorber(s) is supplied by the heat source, the cycle is termed *single effect*.

Typically, for domestic refrigeration conditions, the COP of single effect adsorption cycles is of about 0.3-0.4.

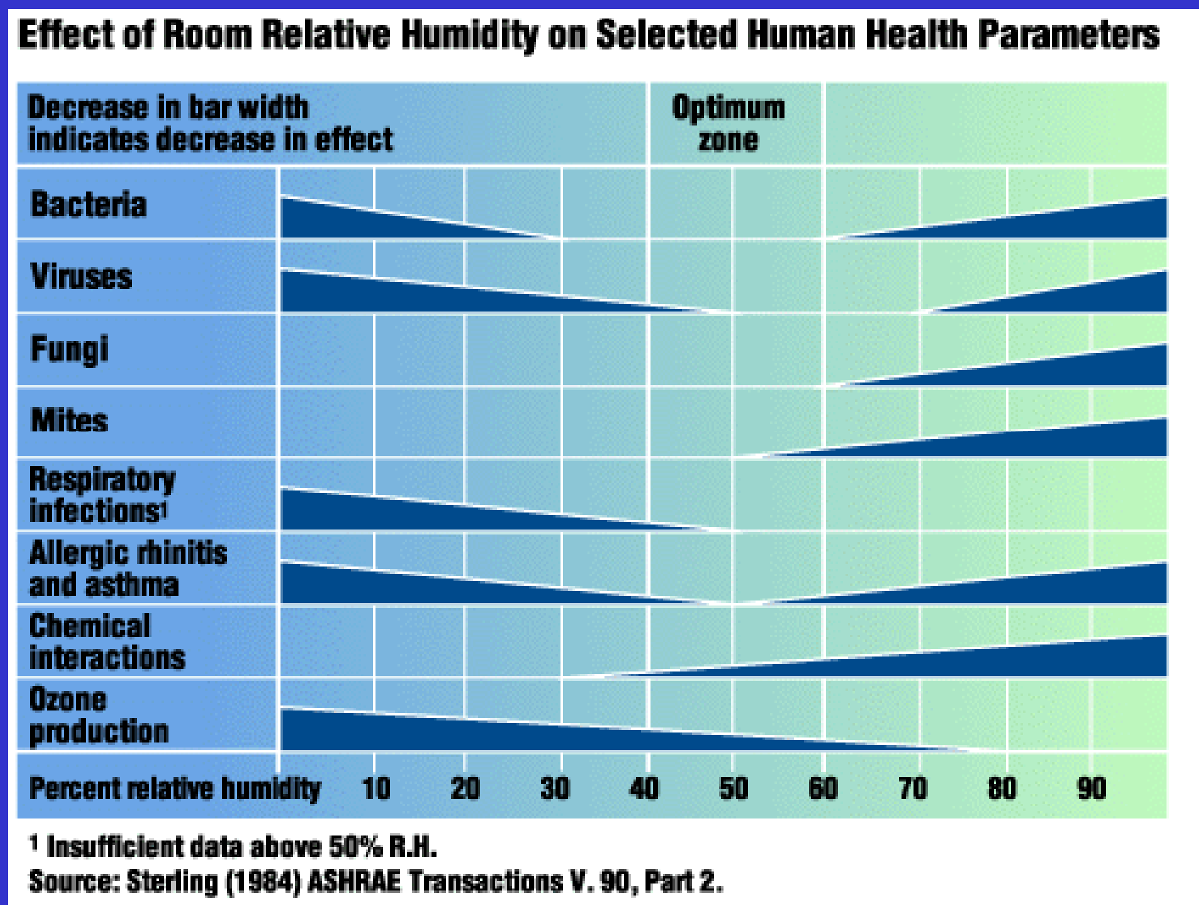
When there are two adsorbers or more, other types of cycles can be designed.

In *double effect cycles* or in *cycles with heat regeneration*, some heat is internally recovered between the adsorbers, and that improves the COP.

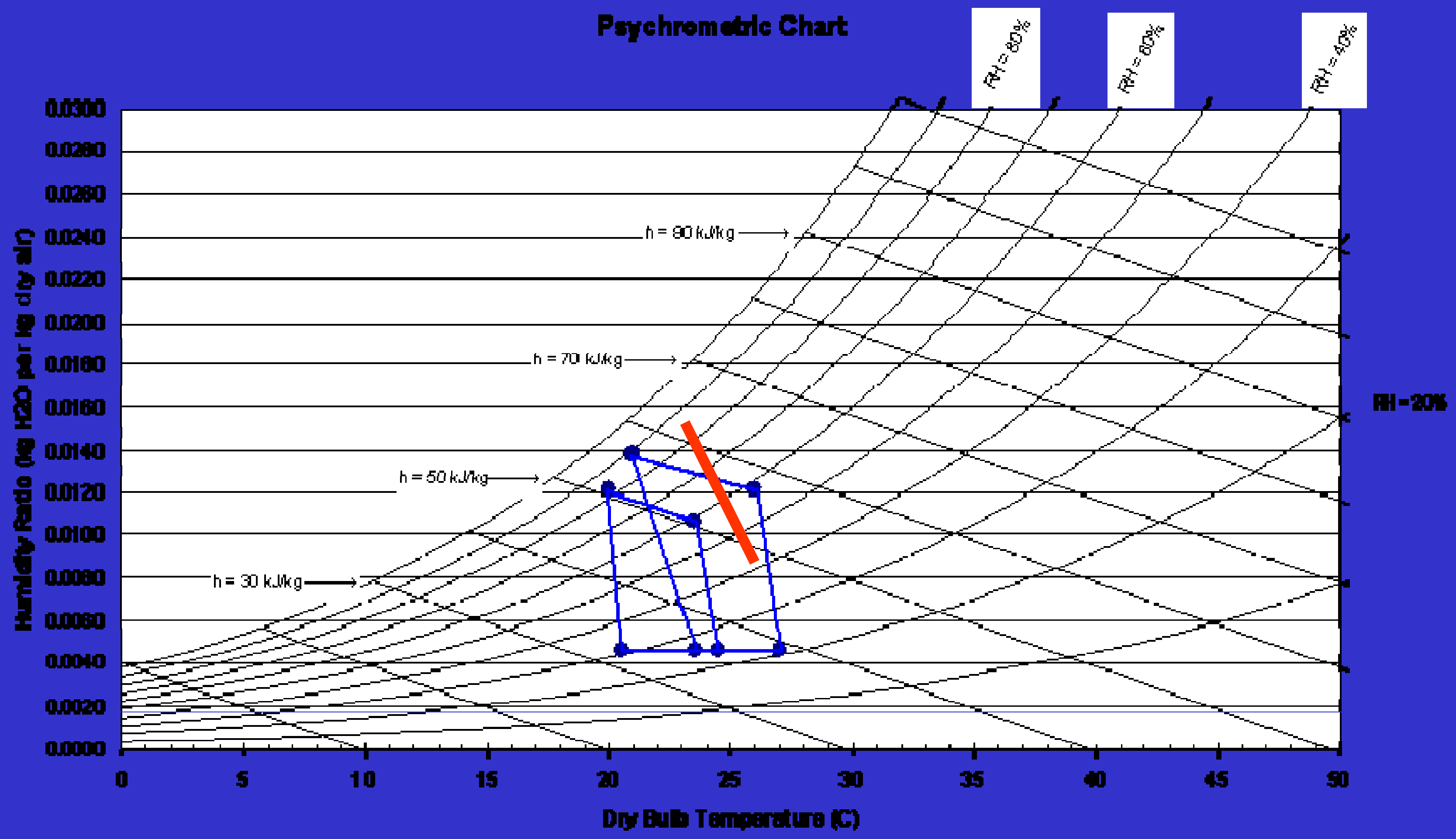
Adsorption cooling - Examples

Desiccant refrigeration

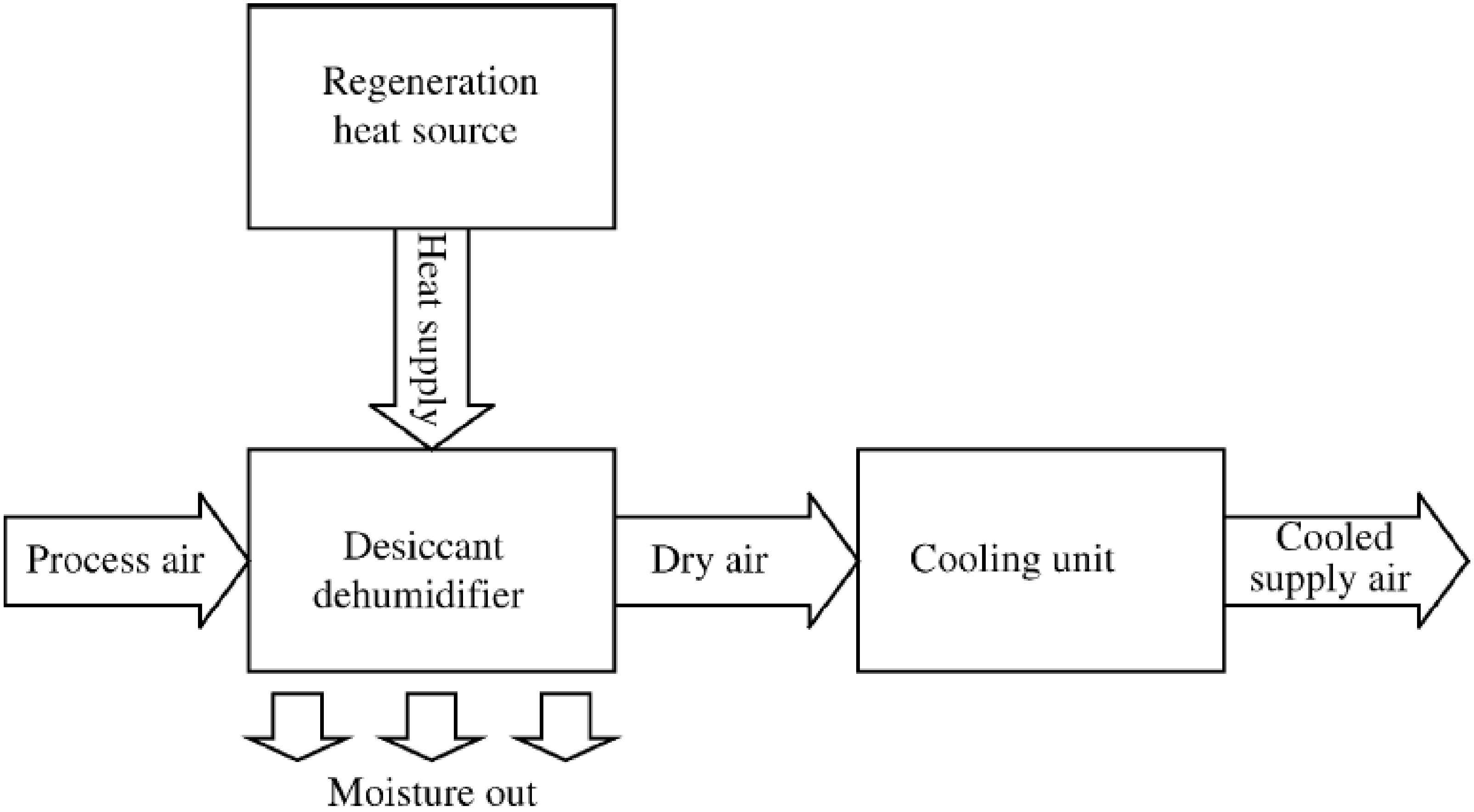
Addresses the issue of thermal comfort by modifying the water vapor content in a space.



Desiccant refrigeration principle



Desiccant refrigeration flow-chart

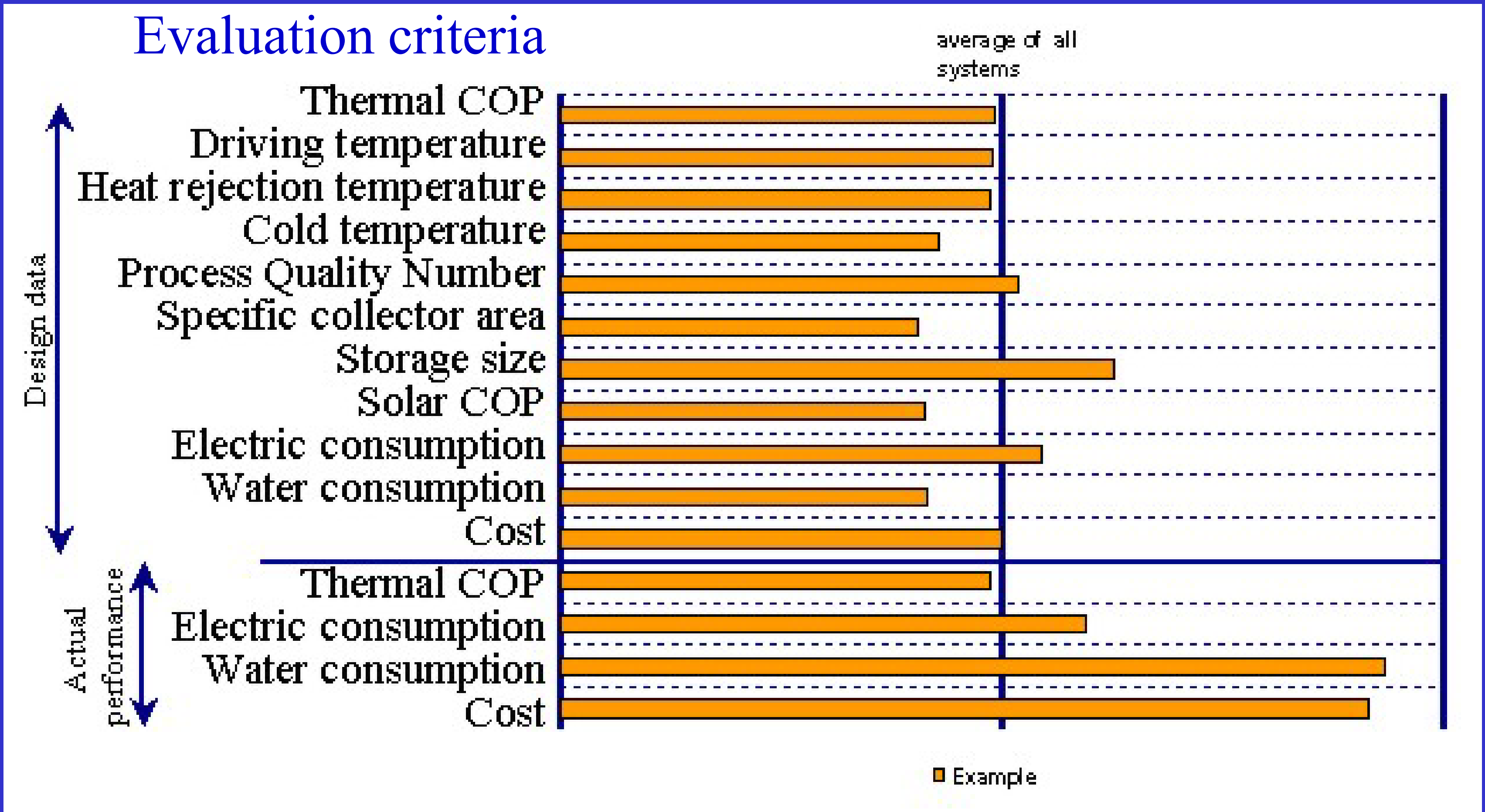


Solar cooling – Current status in Europe

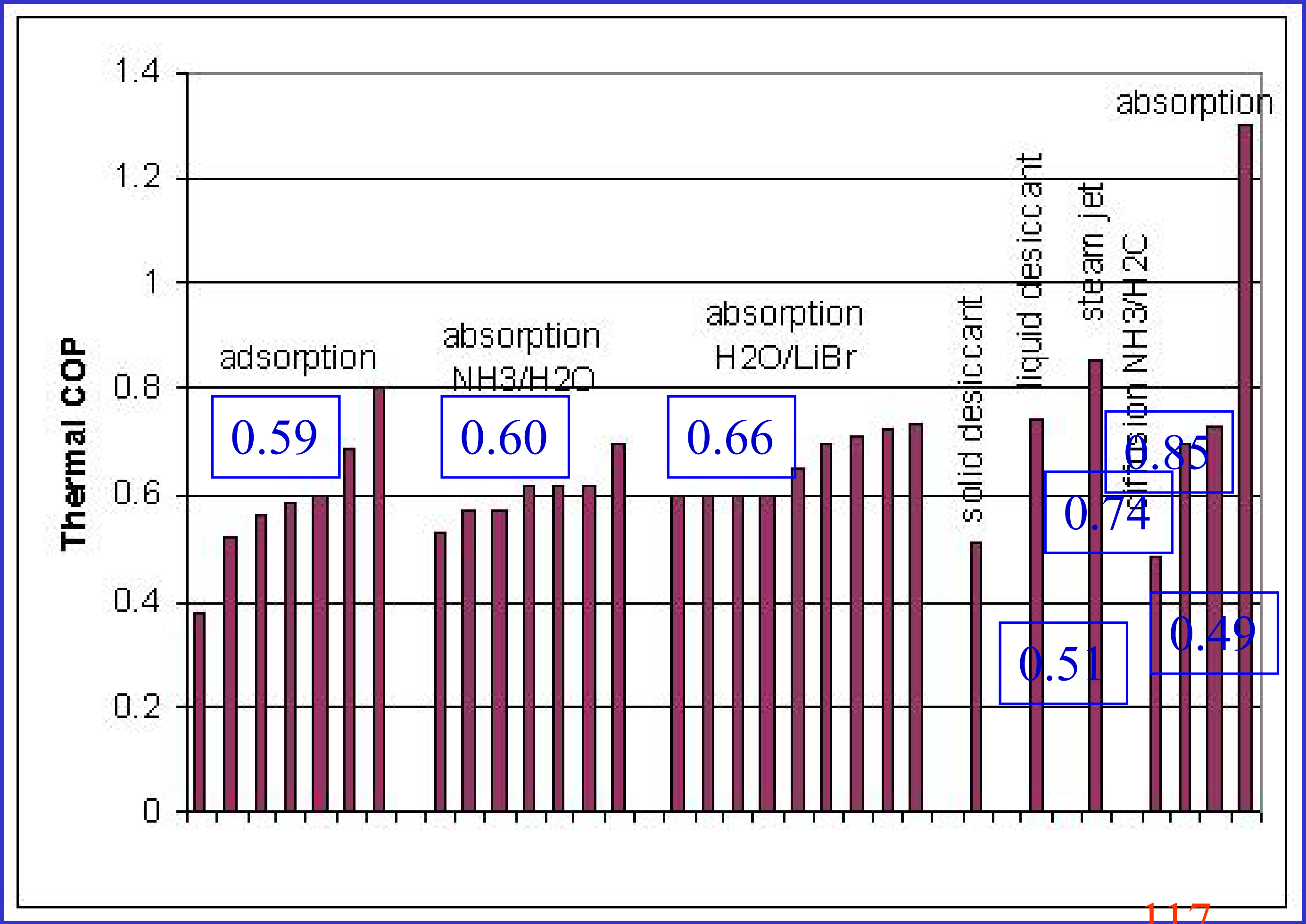
Projects & applications identified and evaluated:

- 12 in Germany
- 2 in Austria
- 3 in Malta
- 1 in Croatia
- 5 in Greece
- 1 in Spain
- 1 in Kosovo
- 4 in Israel
- 15 from Cordis
- 10 IEA projects

Comparative assessment



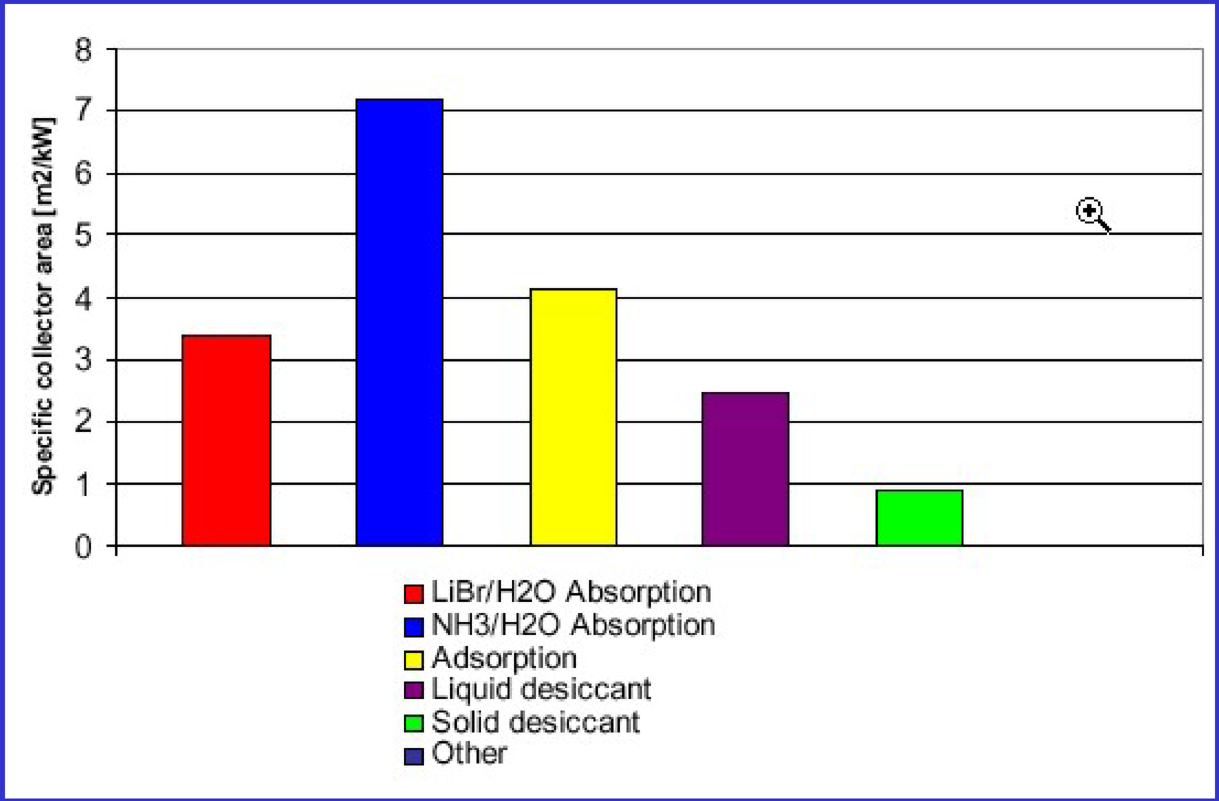
COP



T_{hot} (^oC) 52-82 60-110 66 117 120

Solar collectors used

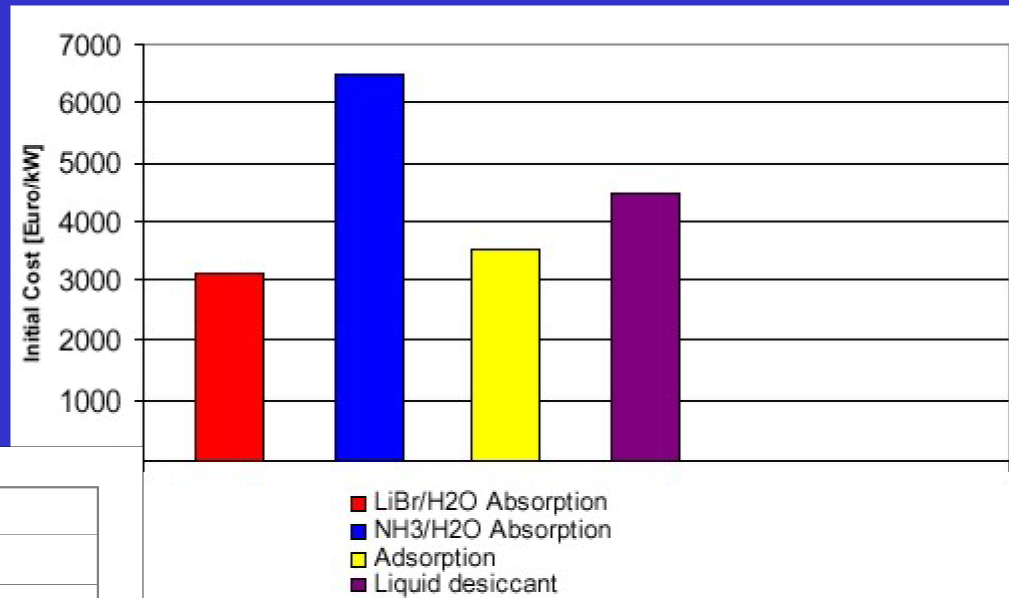
Flat-plated (63%)
Vacuum tube (21%)
Parabolic
- Fixed (10%)
- Moving (6%)

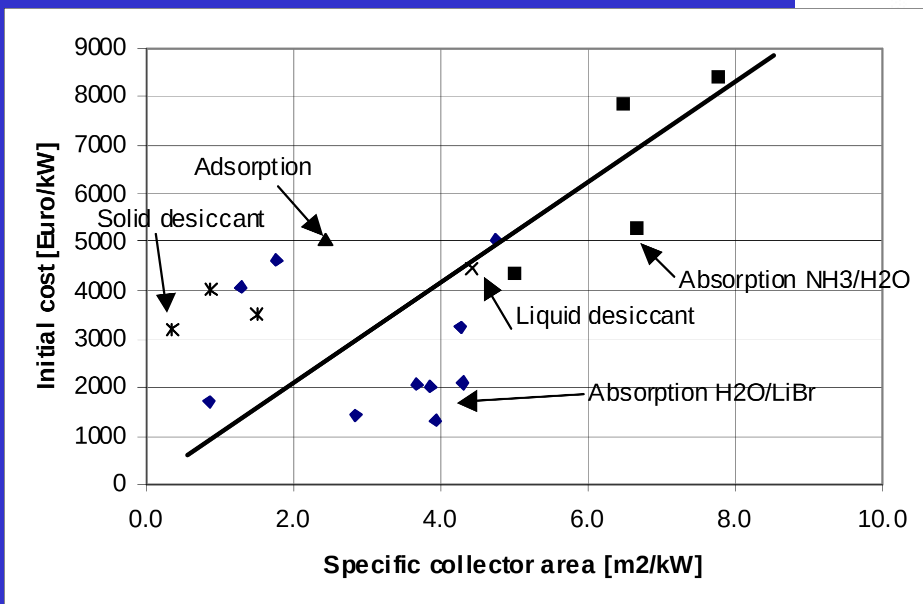


Average specific collector area
3,6 m^2/kW

Investment cost

Depends on:
- power rate
- collector type
- development phase
- operating principle





Average investment
4012 Ευρώ/kW

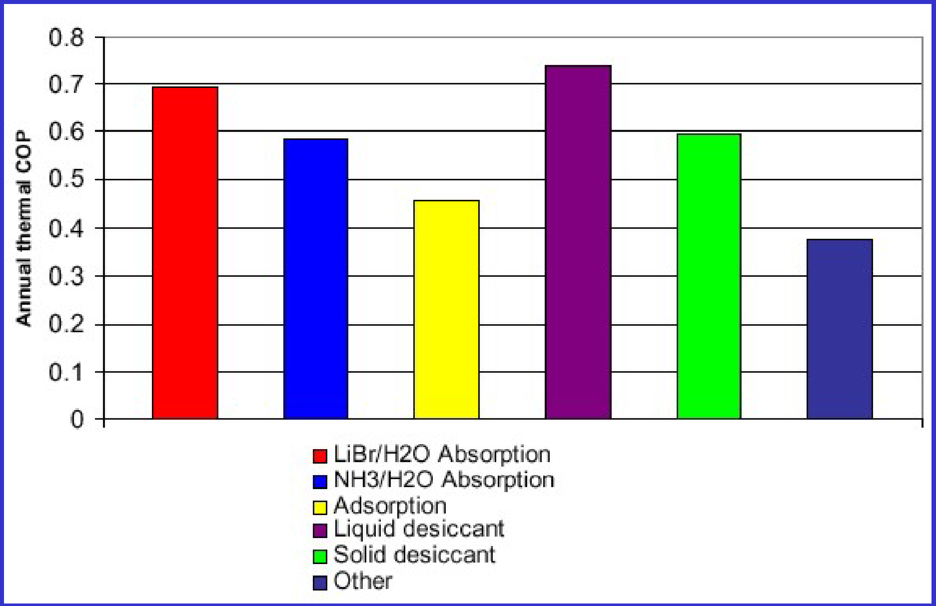
Performance data

Highest performance

LiBr / H_2O systems

Lowest performance

NH_3/H_2O diffusion system



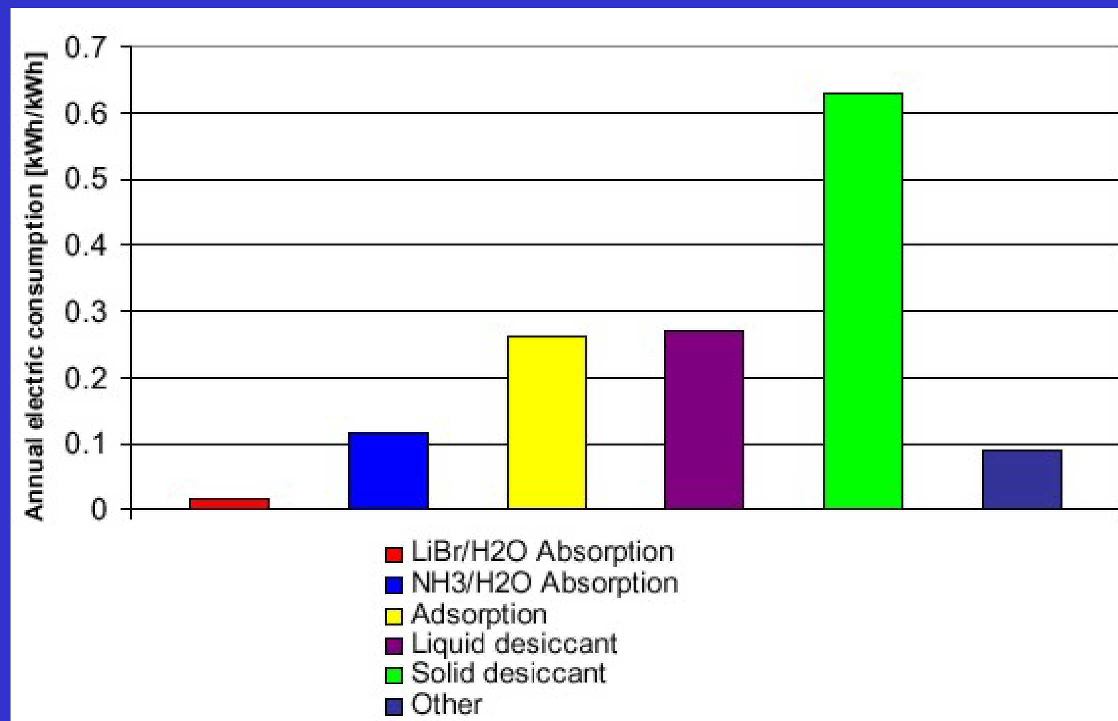
Average annual COP = 0.58

Consumption of auxiliary equipment

Lowest consumption:

Absorption systems

LiBr/H_2O systems = 0.018 kWh/kWh

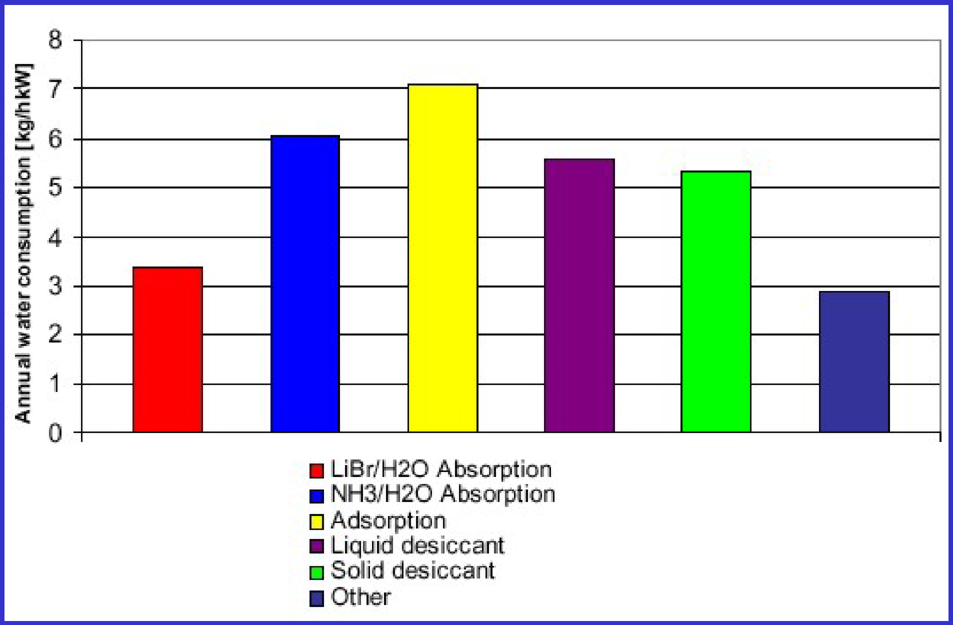


Mean annual electricity consumption of fans and pumps = 0.225 kWh/kWh

Water consumption

Highest consumption
Adsorption systems:
7.1 kg.h^{-1}/kW

Majority of systems:
4-6 kg.h^{-1}/kW



Mean annual water consumption
= 5.3 kg.h^{-1}/kW

Practical design guidelines

Detailed calculation of the energy budget of the application

Energy savings depend on other energy sources used, i.e. gas boiler, auxiliary cooler, pumps, fans etc.

Low COP coolers, require higher solar fraction and vice versa.

Combined solar heating / cooling systems are more interesting financially

Conclusions (1)

- Solar cooling is still in the development phase

- There are technological problems that need to be addressed mainly concerning the hydraulic circuit and the controllers

- Enough applications exist, but not enough performance data

- Reliable performance data and experience are available only from few systems

Conclusions (2)

- Additional experience regarding the operation of real scale installations is necessary in order to develop model projects and solutions regarding network design and automatic control.

- Their market penetration requires further subsidies,
  <u>but</u>
  only for systems that achieve important energy savings (e.g. >30%) with respect to conventional systems at a cost lower than a maximum price e.g. 0,1 € per kWh of primary energy.

Research priorities – LiBr systems

Increased performance and reduction of cost of solar collectors

Increased performance and reduction of cost of storage systems (e.g. thermochemical)

Development of low capacity absorption machines

Development of low capacity air-cooled absorption machines

Increased performance of the various heat transfer processes in the machine

Research priorities – NH_3 systems

Improved reliability, at low cost, independent control of the cooling medium

Improved pump reliability at low cost

Improved reliability of the fluid level sensors

Increased performance of the various heat transfer processes in the machine

Simplified system concepts