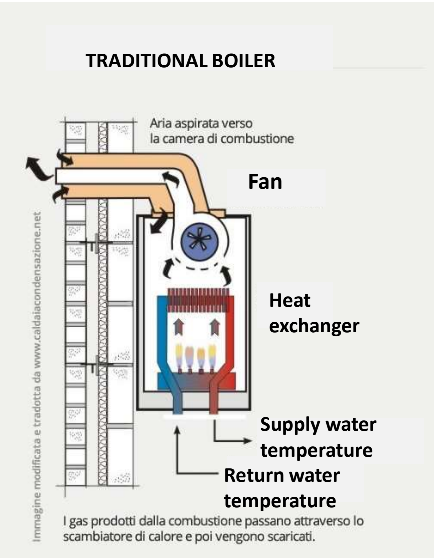
GENERATION SYSTEMS

Michele De Carli

FOSSIL FUEL BOILERS



Source:
http://www.caldaiacondensazione.net/funzionamento/

Boilers use fossil fuels: natural gas, LPG, oil.
The following generation losses are present:

- **Combustion**
- **Losses in the envelope**
- **Chimney losses**
- **Pre-cleaning**

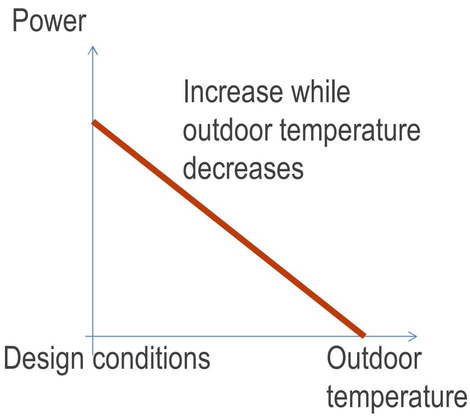
Trend of boilers over the years

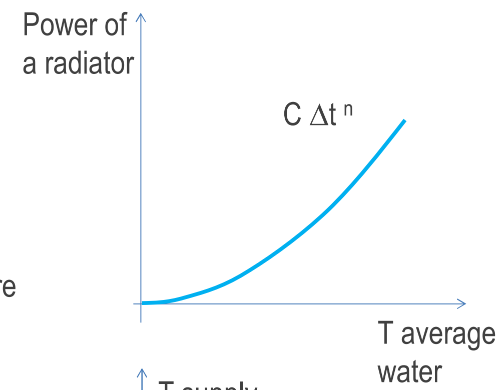
Boilers technology improved:

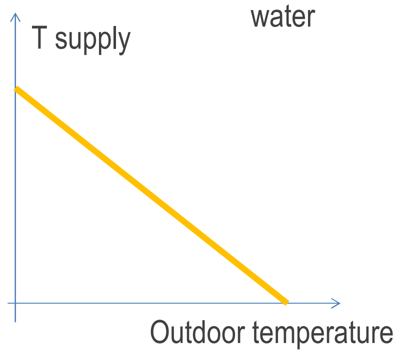
- **Increase of insulation of the envelope (reduction of losses)**

- **Variable-temperature generators with (not yet condensation boilers):**
  - **Reduction in the generation losses**
  - **Use of water tanks as storage**
  - **Improve the control (climatic control/variable temperature)**

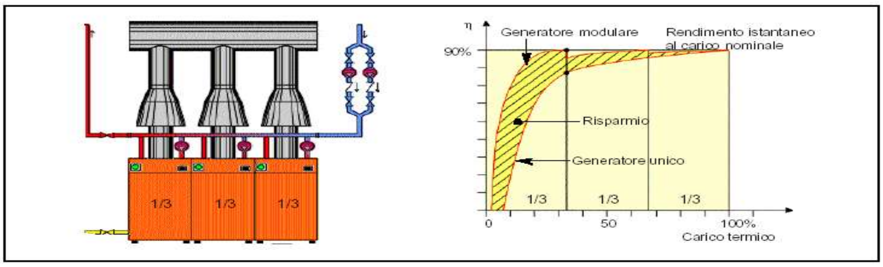
$$P = (H_t + H_v)(t_e - t_i)$$



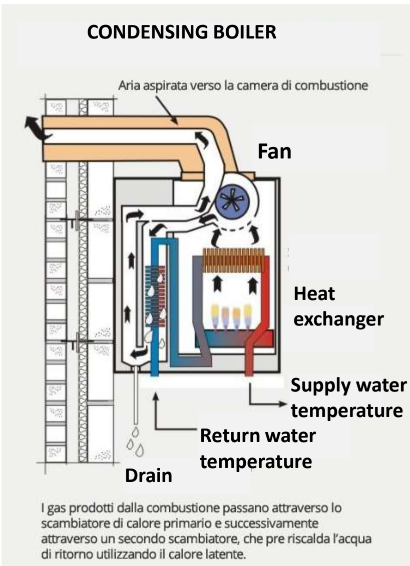


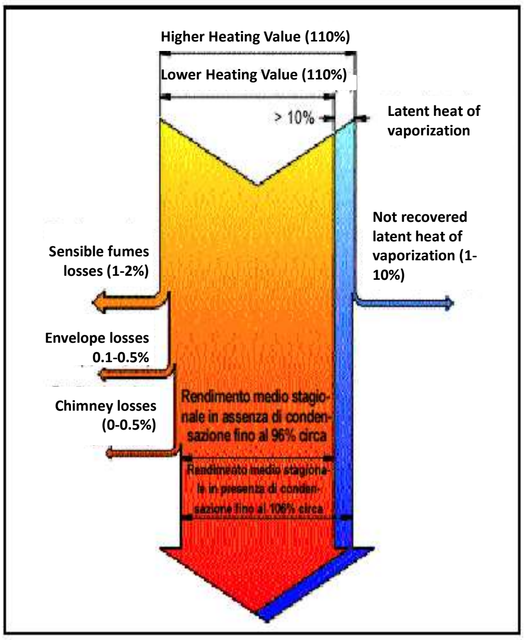


- **Modular boilers (centralized systems):**
  - **Allow to reduce the load (increase of efficiency);**
  - **Reliability (they can work even with one module fault**
  - **Limit the generation losses**
  - **Easy installation in a technical room**

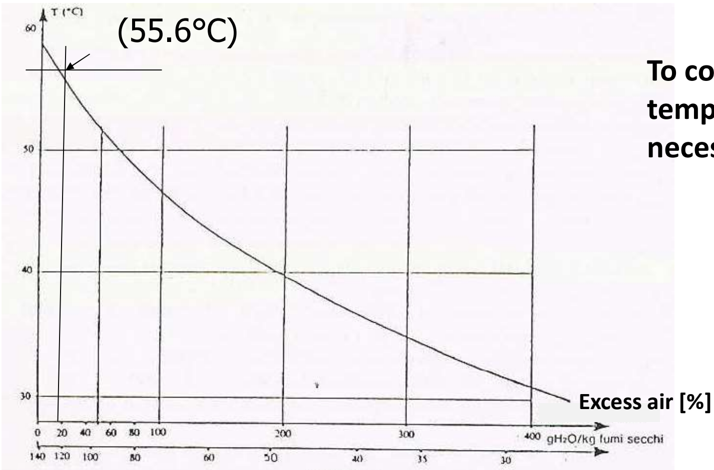


Condensation boilers





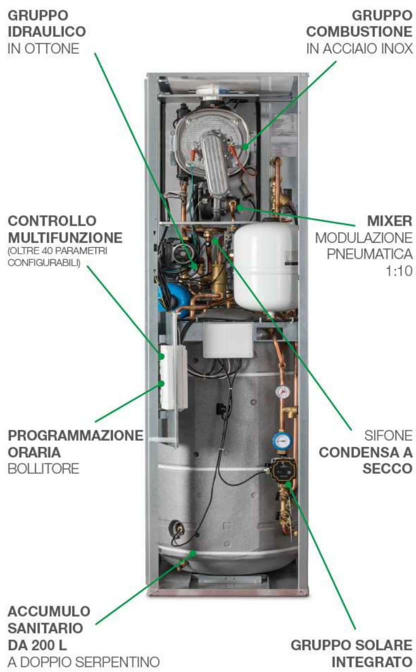
Dew point temperature of fumes



To condense return temperature is necessary at 55°C

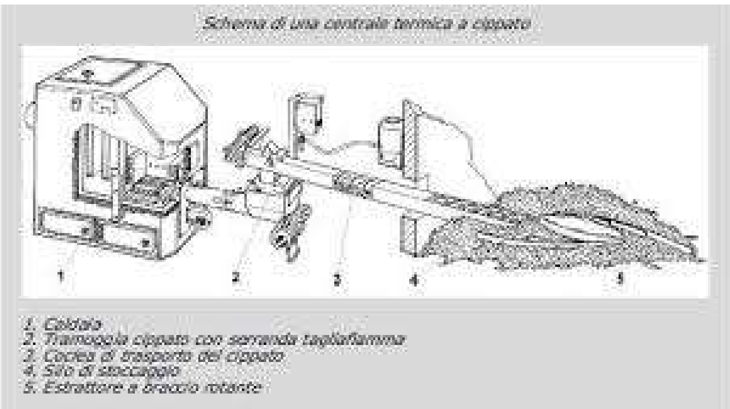
Condensing mudulating boilers

- **They allow to reduce the load factor operation (increasing the efficiencies);**
- **Water tank for the DHW is necessary**



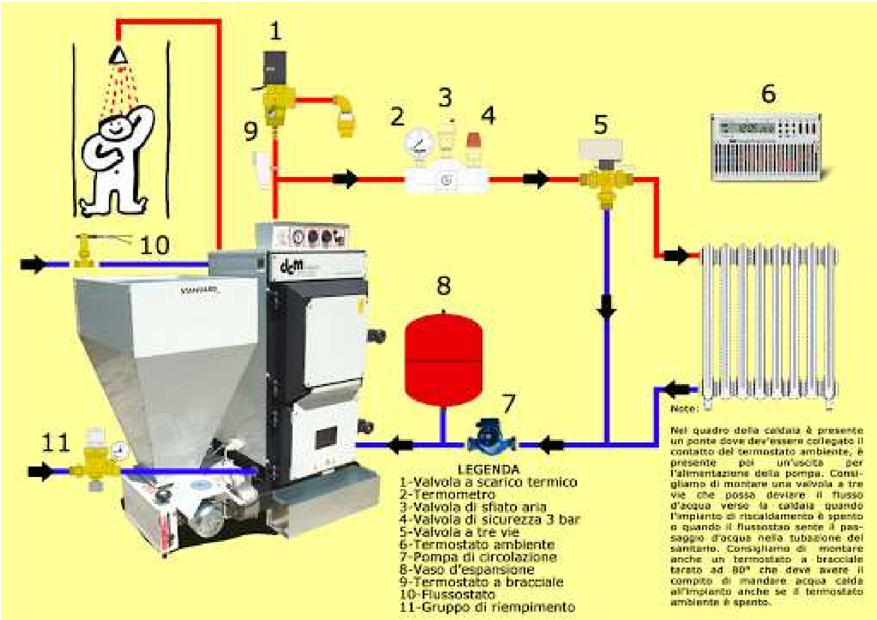
BIOMASS BOILERS

- **Wood-chips boilers (large plants)**



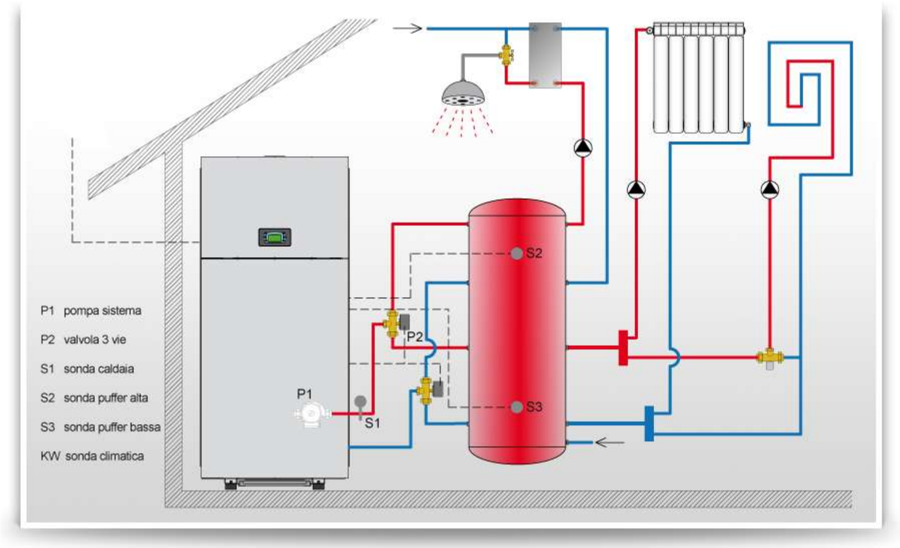
- **Wood-log and pellet boilers (residential applications)**

Pellet boilers 1/2



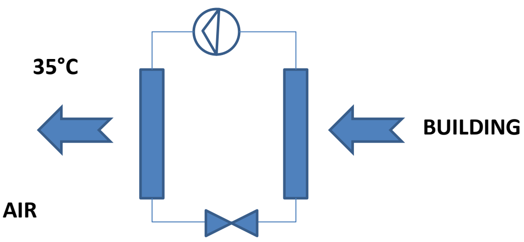
Source: DCM caldaie

Pellet boilers 2/2



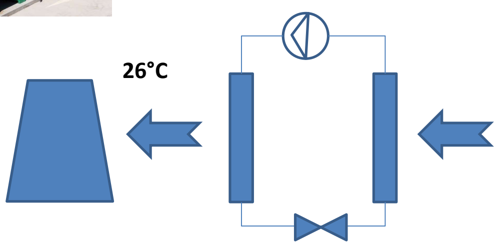
Source: D'Alessandro

AIR TO WATER CHILLER

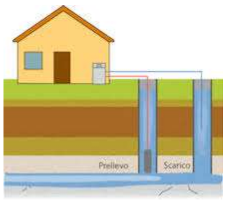


WATER TO WATER CHILLER

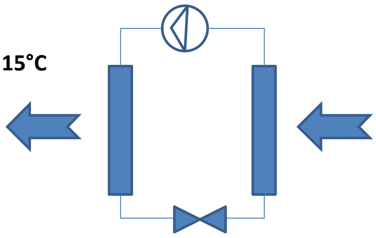
COOLING TOWER



BUILDING

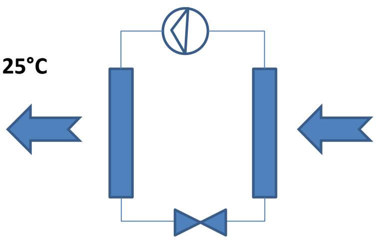


AQUIFER

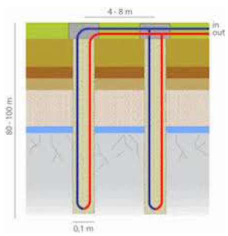


BUILDING

GROUND HEAT
EXCHANGER



BUILDING

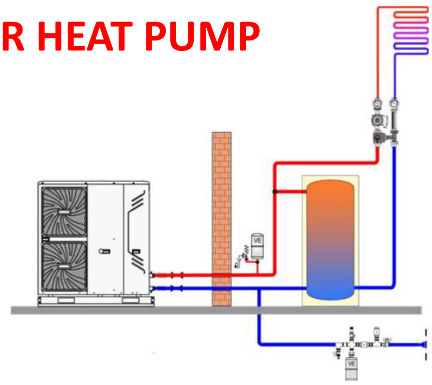


HEAT PUMPS

Source	Fluid
Air	Air
Air	Water
Water	Air
Water	Water

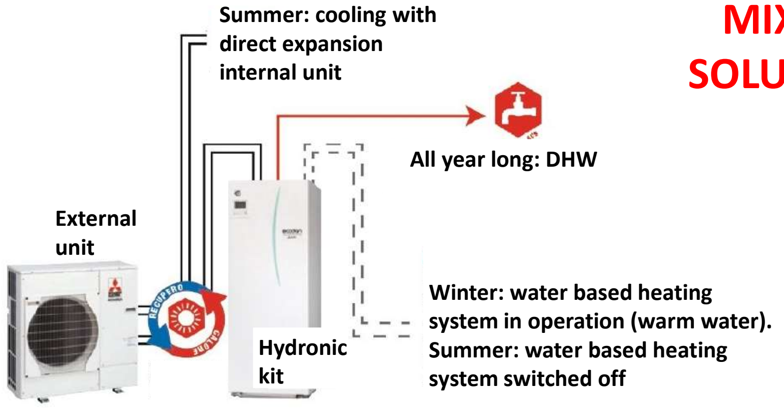
MONOBLOCK AIR TO WATER HEAT PUMP

The whole machine is outdoor.
Cheap solution.
Need to provide antifreeze solution for the water of the plant.



SPLIT AIR TO WATER HEAT PUMP

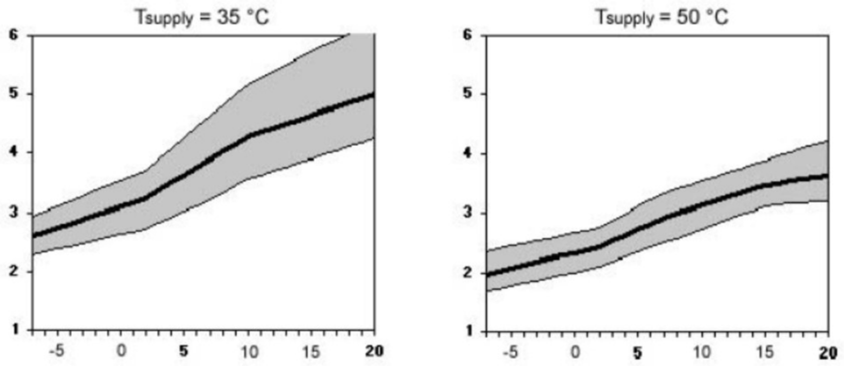
Part of the machine is installed outdoor. More efficient solution. Possibile plug&play solutions with integrated hydronic kit



MIXED SOLUTION

External unit which can provide heating and cooling.
An hydronic kit allows to generate DHW (with a tank) all over the year and in winter warm water for the radiant system.
In summer the system works as a usual direct expansion cooling system.

Performance of air to water heat pumps as a function of outdoor air in winter



Statistical data from the Swiss laboratory WTZ in Winterthur-Töss, where the thick line represents the average value and the grey area the dispersion of measured data.

Reference standard for the heat pumps

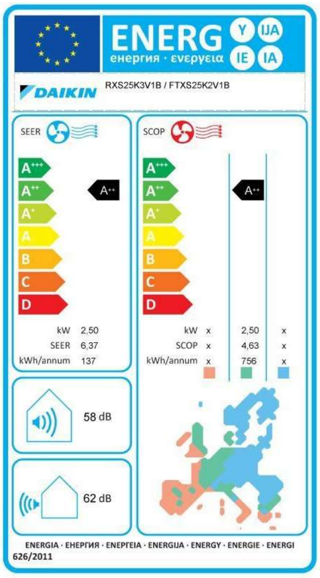
The most relevant reference standards are:

- EN 14825 (product standard)

  Based on a standardized load profile in 3 different climates in Europe the seasonal COP and EER are defined (SCOP and SEER). It is useful to compare different heat pumps. It does not represent the efficiency for the specific building

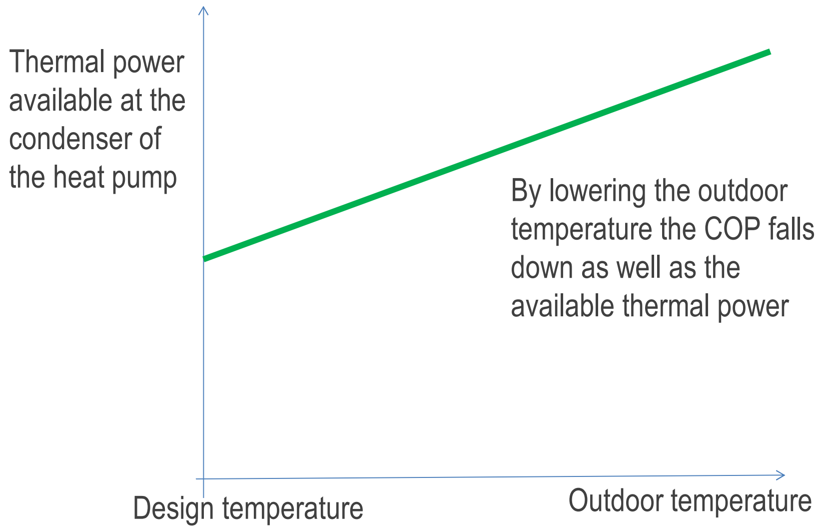
- Italian standard UNI/TS 11300-4 (system standard)

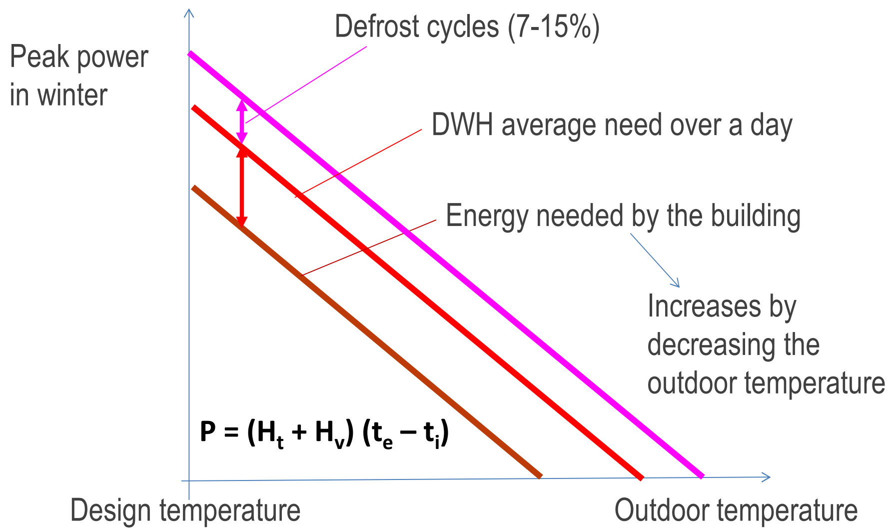
  It is used to evaluate the seasonal performance of the heat pump of the considered actual building. SPF (Seasonal Performance Factor)

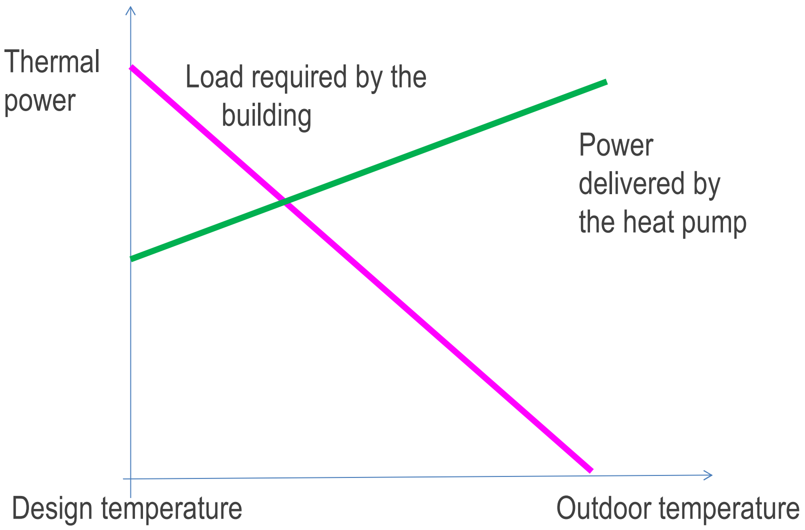


19

Sizing method for an air to water heat pump


Thermal power available at the condenser of the heat pump
By lowering the outdoor temperature the COP falls down as well as the available thermal power
Design temperature
Outdoor temperature

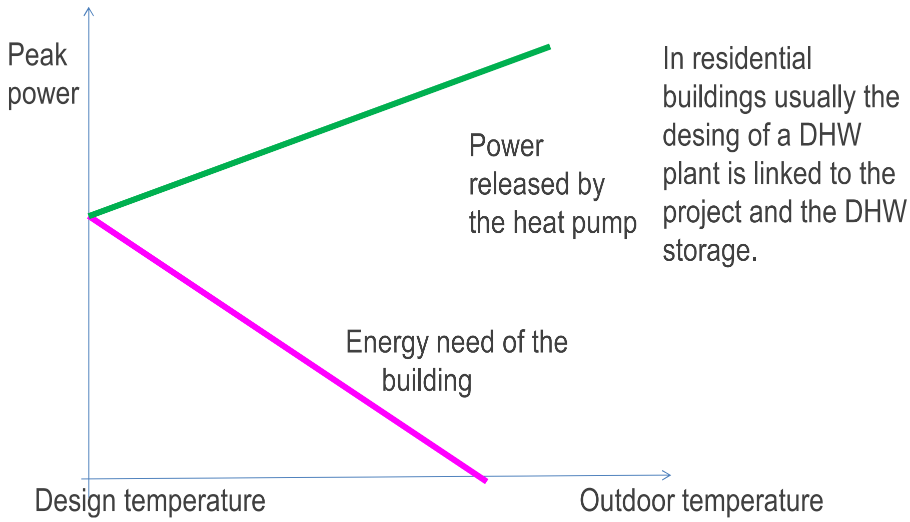

Peak power in winter
Defrost cycles (7-15%)
DWH average need over a day
Energy needed by the building
Increases by decreasing the outdoor temperature
P = (H_t + H_v) (t_e – t_i)
Design temperature
Outdoor temperature



23

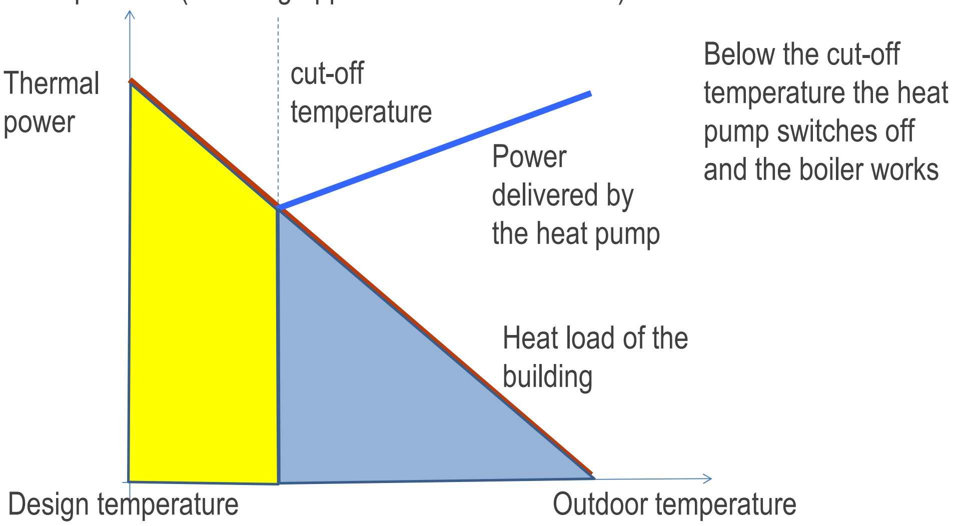
Case 0 – New or retrofitted building: limited load required thanks to the insulation level. Low tempretaure heating system (radiant system, fan-coil, active beams, fan-coil beam)

The heat pump is sized based on the peak load in outdoor design conditions



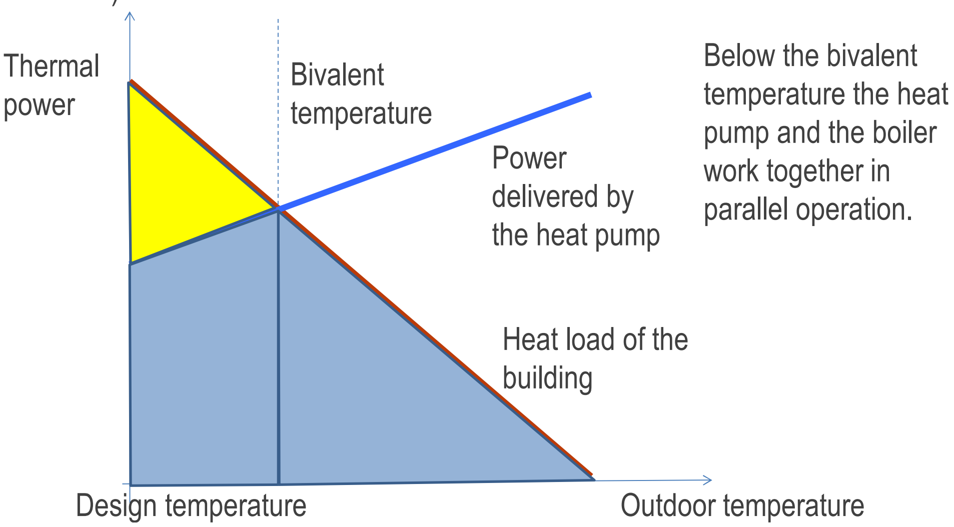
Case 1 – Alternate operation.

Existing building: consistent heat load; the plant works at average or high temperature. The heat pump is sized to work down to a a certain temperature named «cut-off» temperature. The heat pump is sized for this temperature (including approx. 10% for the defrost).



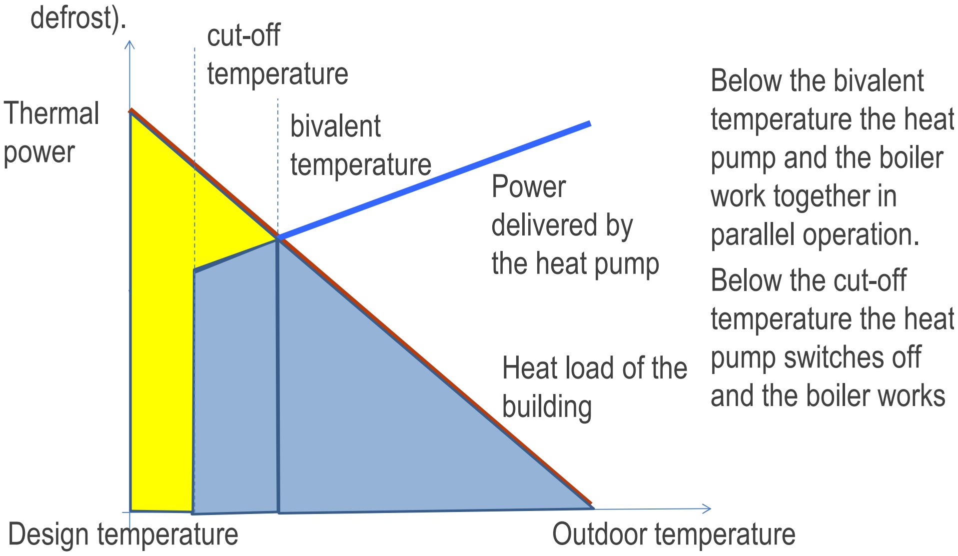
Caso 2 – Parallel operation

Existing building: consistent heat load; the plant works at average or high temperature. The heat pump is sized for the "bivalent temperature". The heat pump is sized for this temperature (including approx. 10% for the defrost).



Case 3 – Partially parallel operation

Existing building: consistent heat load; the plant works at average or high temperature. The heat pump is sized for the “bivalent temperature”. The heat pump is sized for this temperature (including approx. 10% for the defrost).



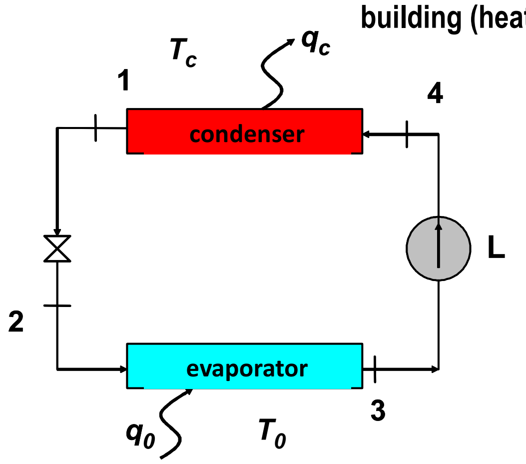
Resuming

0) The sizing of the heat pump is done for the design temperature. The heat pump has to deliver the power needed by the building + DHW + defrost cycle.
1) Alternate operation: the heat pump is sized to work until the “cut-off” temperature. Below this this temperature the boiler works and the heat pump switches off.
2) Parallel operation: the heat pump is sized to work at the “bivalent temperature”. Below this temperature the heat pump and the boiler works simultaneously (the boiler covers the residual heat that the heat pump is not able to provide).
3) Partially parallel operation: the heat pump is sized to work at the “bivalent temperature”. Below this temperature the heat pump and the boiler works simultaneously (the boiler covers the residual heat that the heat pump is not able to provide) until the “cut-off” temperature is reached. Below this temperature the heat is provided just by the boiler and the heat pump switches off.

Evaluation of COP and EER for heat pumps and chillers in different operating conditions

Heat pump operation

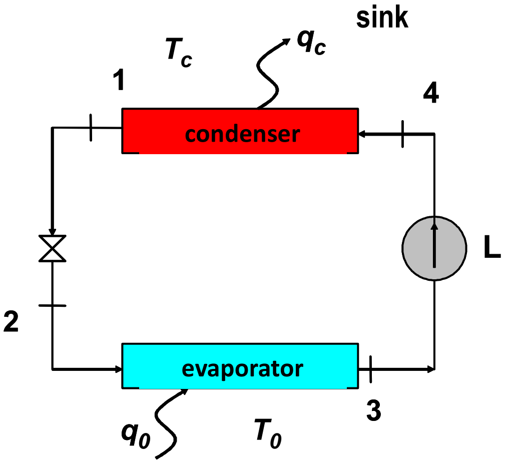
Heat released to the building (heat load)



Heat absorbed by the source (renewable part of the energy provided to the building)

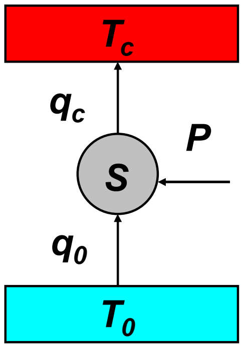
Cooling operation

Heat released to the sink



Heat absorbed by the building (including sensible and latent cooling load)

COP of the heat pump



$$COP = \frac{q_c}{|P|}$$

Limit value (Carnot cycle):

$$COP^* = \frac{T_c}{T_c - T_0}$$

Although this value is an ideal value, it may be useful to interpolate the real COP of the heat pump

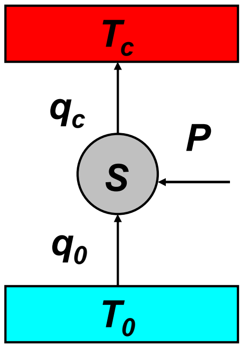
T_0 = 3°C = 276 K
T_c = 40°C = 313 K

$$COP^* = \frac{313}{313-276} = 8{,}6$$

T_0 = 12°C = 285 K
T_c = 30°C = 303 K

$$COP^* = \frac{303}{303-285} = 16{,}8$$

EER in cooling



$$EER = \frac{q_0}{|P|}$$

Limit value (Carnot cycle): $$EER^* = \frac{T_0}{T_c - T_0}$$

Although this value is an ideal value, it may be useful to interpolate the real EER of the heat pump

T_0 = 3°C = 276 K
T_c = 40°C = 313 K

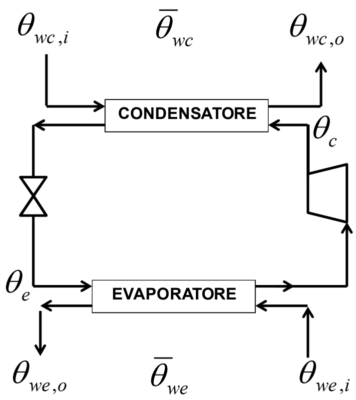
$$EER^* = \frac{276}{313-276} = 7{,}5$$

T_0 = 12°C = 285 K
T_c = 30°C = 303 K

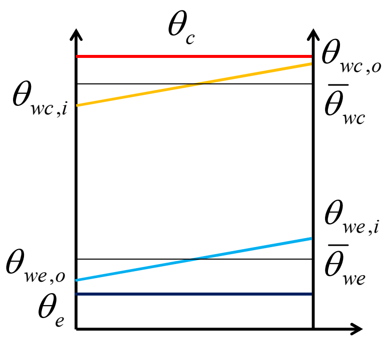
$$EER^* = \frac{285}{303-285} = 15{,}8$$

How can we use the COP and EER of the Carnot cycle?

The COP and EER of the heat pumps can be interpolated by means of the Carnot cycle values. In particular the ratio between two different operating conditions are similar for the real cycle and for the Carnot cycle. It is important to refer to the real operating conditions. The interpolation is accurate if the temperature range is not too wide.



$$\theta_c = \bar{\theta}_{wc} + \Delta\theta_c$$



$$\theta_e = \bar{\theta}_{we} - \Delta\theta_e$$

Condensing heat released to water fluid

$\Delta\theta_c$ = + 5°C related to the average water temperature

Evaporation absorbing heat from the water

$\Delta\theta_e$ = - 5°C related to the average water temperature

Condensing heat released to the air (fin coil)

$\Delta\theta_c$ = + 15°C related to the outdoor air temperature

Evaporation absorbing heat from the air (fin coil)

$\Delta\theta_e$ = - 10°C related to the outdoor air temperature

Example

Declared value of the COP: 4

t outdoor air= 7°C
t water supply = 35°C

Let's suppose that the water based heating system works between 42°C (supply water temperature) and 38°C (return water temperature). Hence the average water temperature is 40°C. Outdoor air temperature is 3°C.

The operating conditions for the declared COP are:
t ev. = 7°C – 10°C = -3°C = 270 K
t cond. = 35°C + 5°C = 40°C = 313 K

$$COP_{nominal}^{*} = \frac{313}{313 - 270} = 7,3$$

Actual conditions:
t ev. = 3°C – 10°C = - 7°C = 266 K
t cond. = 40°C + 5°C = 45°C = 318 K

$$COP^{*}_{actual} = \frac{318}{318 - 266} = 6{,}1$$

$$COP_{actual} = \frac{COP_{nominal} \cdot COP^{*}_{actual}}{COP^{*}_{nominal}}$$

$$= \frac{4 \cdot 6{,}1}{7{,}3} = 3{,}4$$

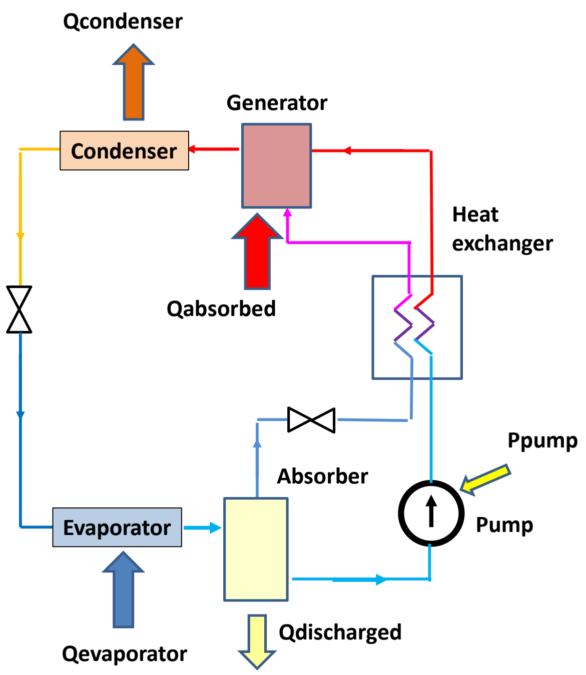
Absorption cycles

Cooling cycle:

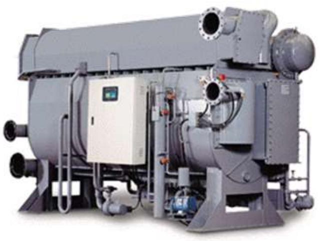
$$\text{Efficiency} = \frac{\text{Qevaporator}}{\text{Qabsorbed}}$$

Heating cycle:

$$\text{Efficiency} = \frac{\text{Qcondenser}}{\text{Qabsorbed}}$$



ABSORPTION CHILLERS



Absorption chillers are able to use hot temperature source.
This can be solar thermal energy, energy waste, heat rejected by a cogenerator (trigeneration).
Usually the most common compound is Lithium Bromide (LiBr) coupled with water.

Usually the minimum temperature of the source should be 90°C.

The efficiency is related to the type of cycle; usually single stage machines are used with a typical value of COP = 0.7

These system can work only in cooling. In heating they are not able to operate as heat pumps.

ABSORPTION HEAT PUMP

Absorption heat pumps are mainly working today with natural gas. .
Usually the most common mixture is water-ammonia.

$$GUE = \frac{Qcondenser}{Qabsorbed}$$

The typical efficiency is GUE = 1.4

These systems are optimized for working in heating conditions. They can work also in cooling conditions, but usually in cooling the performance is poor.

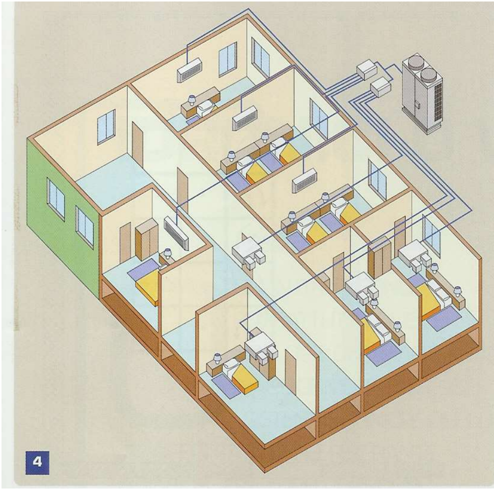
VARIABLE REFRIGERANT FLOW (VRF)
VARIABLE REFRIGERANT VOLUME (VRV)

VRV or VRF have one external unit and more than one terminal direct expansion units. The heat carrier is the refrigerant.

The usual heating/cooling power ranges from 6 kW to 60 kW.

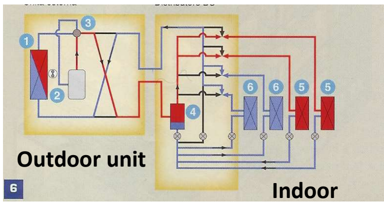
They are equipped with an electronic expansion valve managed by the control system.

The capacity can be controlled by varying the flow rate of the inverter-driven compressor.



PROS:

- **The phase change allows interesting values of the ratio power/mass flow rate (small diameters of pipes)**
- **Quick installation and easy to design**
- **No intermediate heat carriers**



terminal units

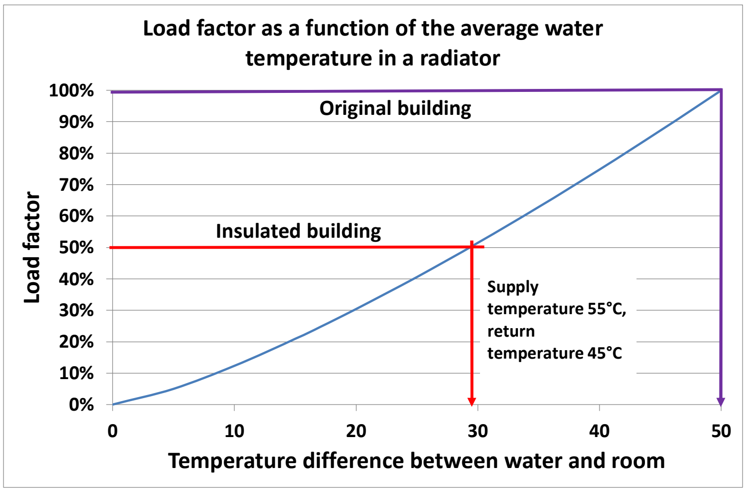
- **Possible heat recovery (when part of the building requires heating and part cooling)**

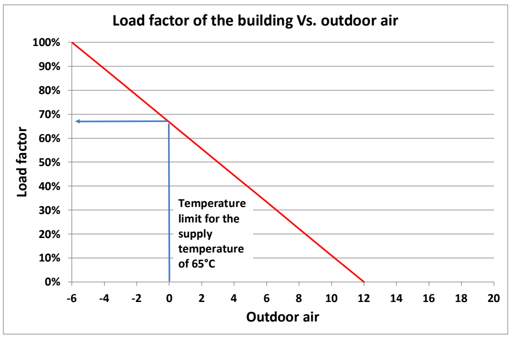
CONS:

- **Need of expert installers**
- **In case of fault all the technology and know-how belongs to the producer**
- **Refrigerant fluid inside the building (new low-GWP fluids are slightly flammable).**
- **Limited distance between outdoor unit and indoor units.**

Possibilities and limits of heat pumps for high terminal units

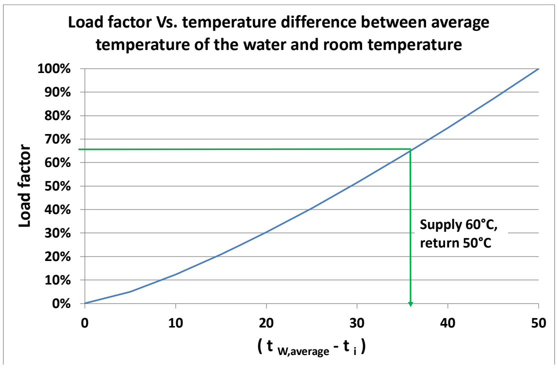
In new buildings it is possible to keep the radiators and use a heat pump

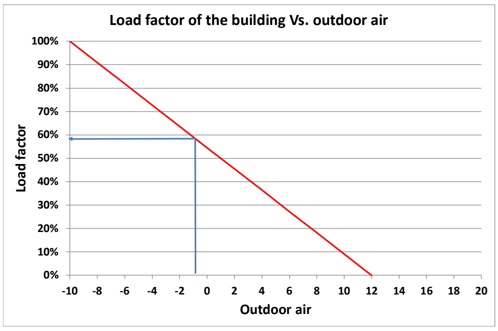




Radiators and heat pumps in a stock building (no retrofit of the envelope)

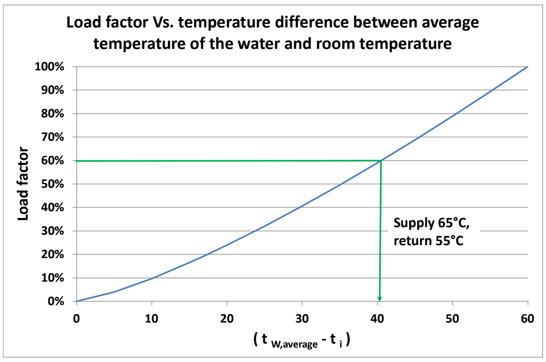
Mild climate

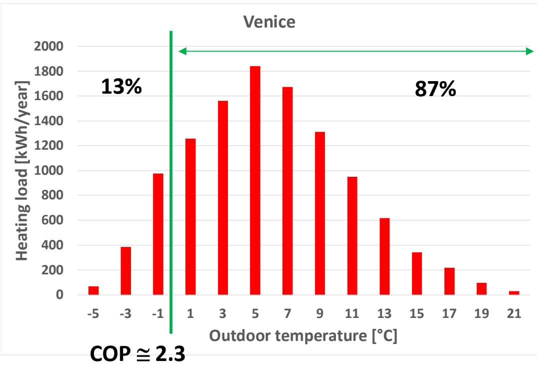




Radiators and heat pumps in a stock building (no retrofit of the envelope)

Cold climate

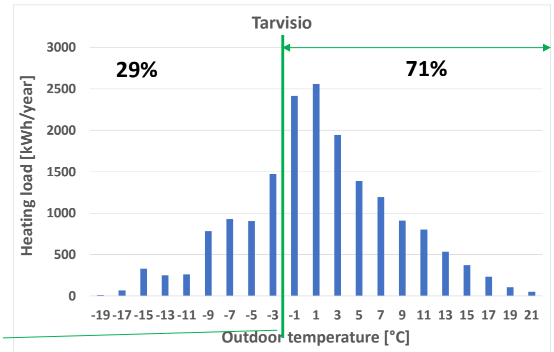




2300 DDH

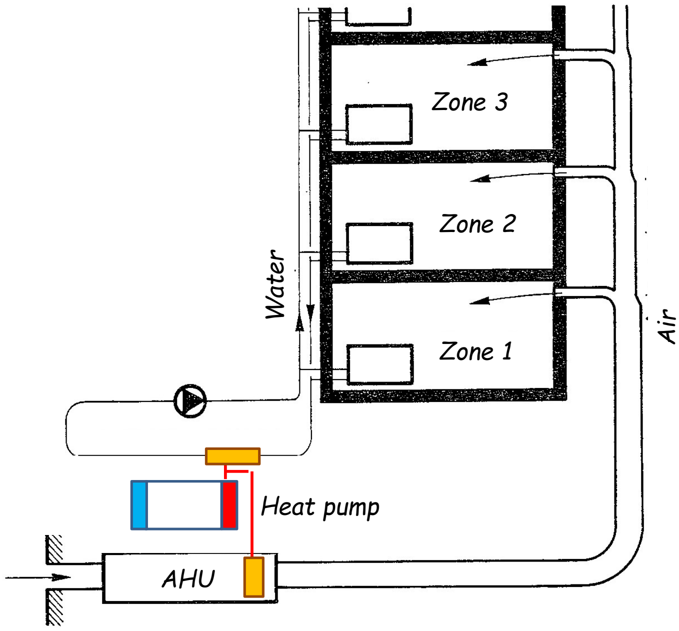
COP ≅ 2.3

4000 DDH



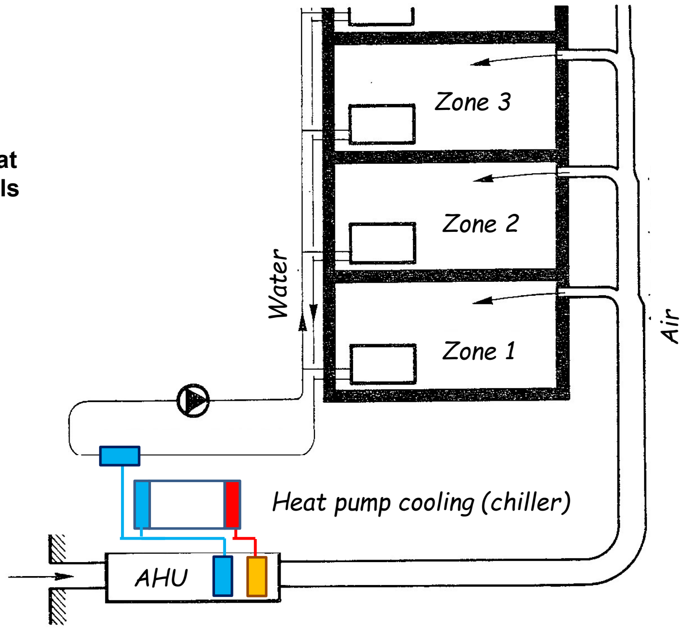
COP ≅ 2.0

Air-water systems with heat pumps: heating



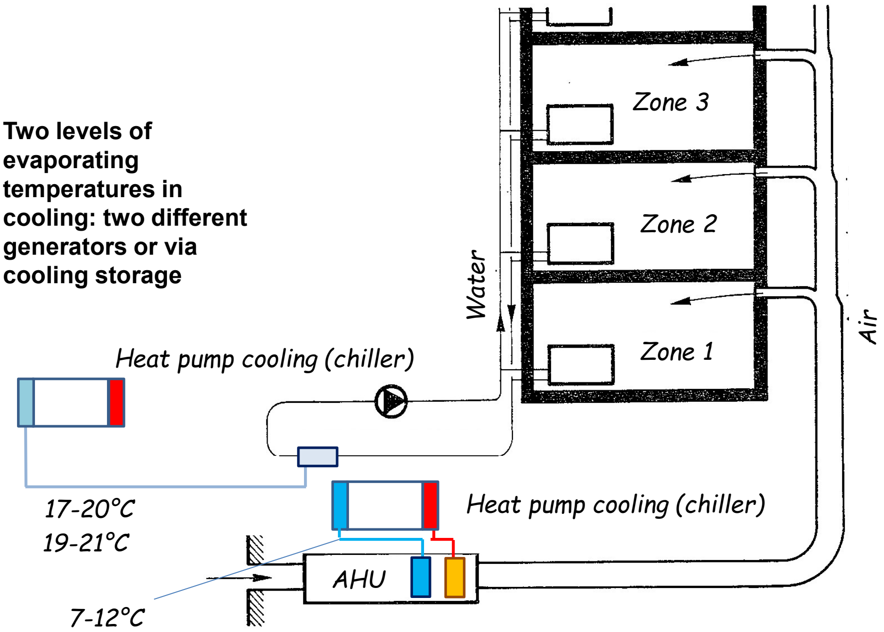
Air-water systems with heat pumps: cooling

Heat recovery: condensation heat for the reheat coils

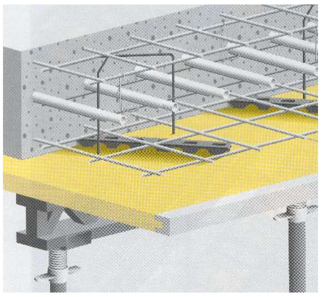


Air-water systems with heat pumps: cooling

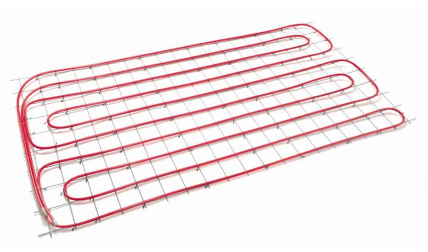
Two levels of evaporating temperatures in cooling: two different generators or via cooling storage



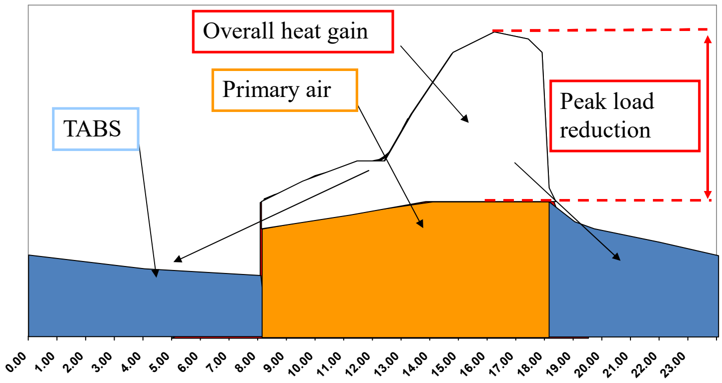
Example of energy storage in cooling: TABS (Thermo-Active Building System)



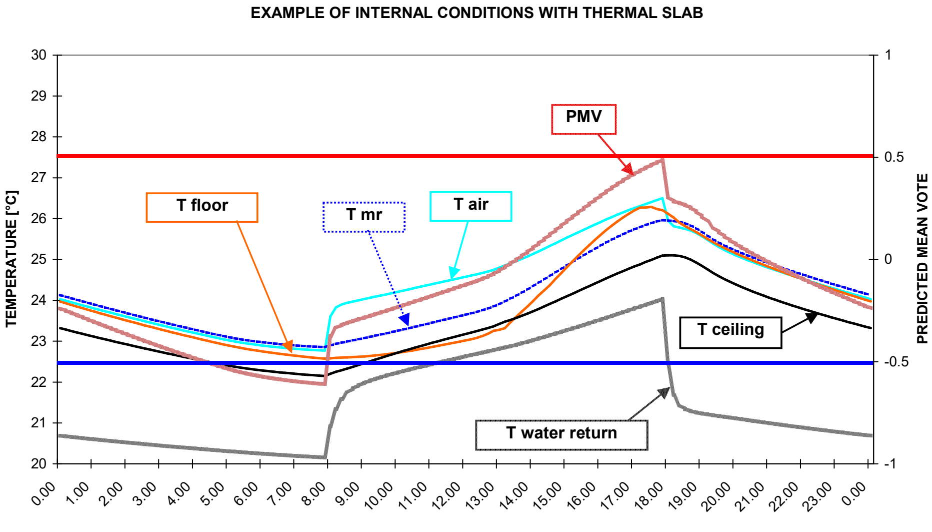
Pipes are embedded in the full concrete slab used also for structural purpose. It is also possible to use prefabricated elements easy to install on site.



Principle of operation of the TABS
(Thermo-Active Building System)



Indoor conditions during a summer day

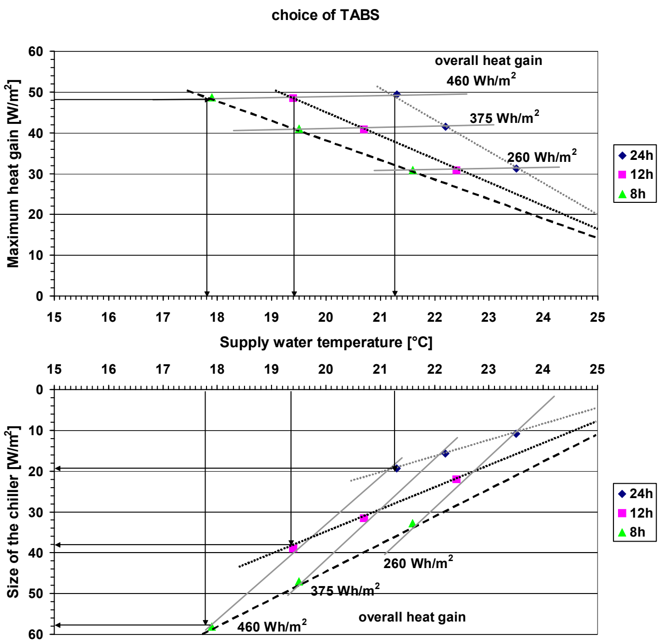


Advantages

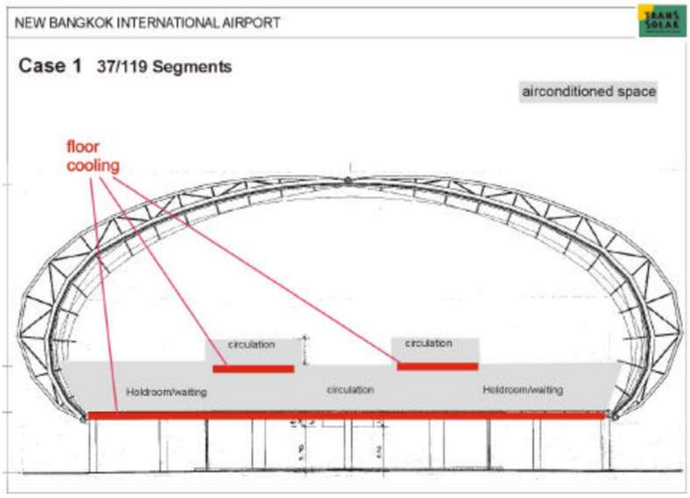
- Low temperature difference between water and room
- Limit in the peak power
- Possibility to operate at 2 different levels of temperatures (high COP during night)
- Working overnight electric energy could be cheaper

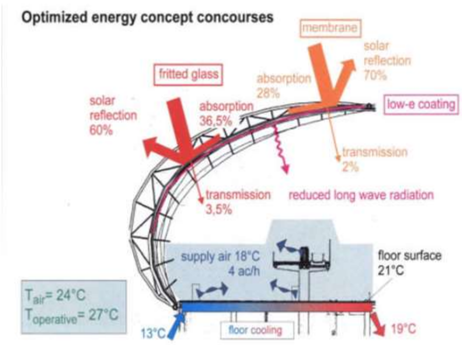
Critical aspects

- Optimization of the envelope (max. heat gain circa 55-60 W/m^2)
- Weight of structures
- Need to use dynamic simulations for fine tune sizing

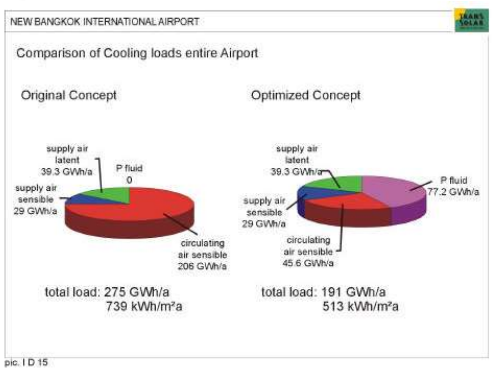


Another interesting application: radiant floor + displacement ventilation in large buildings





Energy saving: 30%



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