Design and control of cooling systems

Heating, Ventilation and Air Conditioning Systems
A.A. 2022/23

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30/5/2023

Regulation valves

Regulation

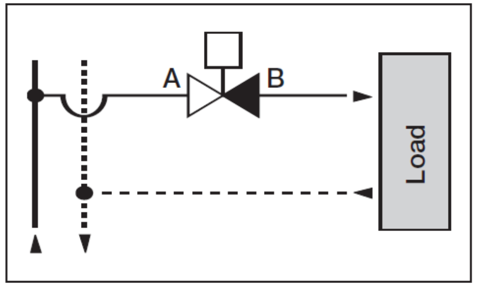
Adjusting temperature/flow rates in a hydronic circuit so that users are satisfied in different operating conditions (e.g. partial loads)

Balancing

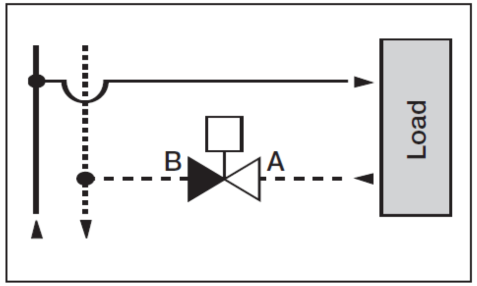
Adjusting pressures/flow rates in a hydronic circuit so that flow/heat is evenly distributed at full load.

Regulation valves

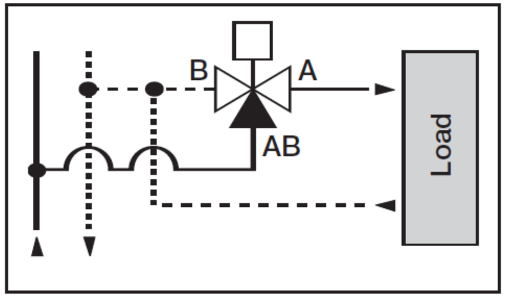
2-way vs 3-way valves



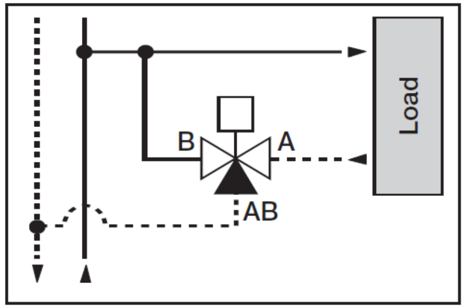
2-way installed on the supply



2-way installed on the return



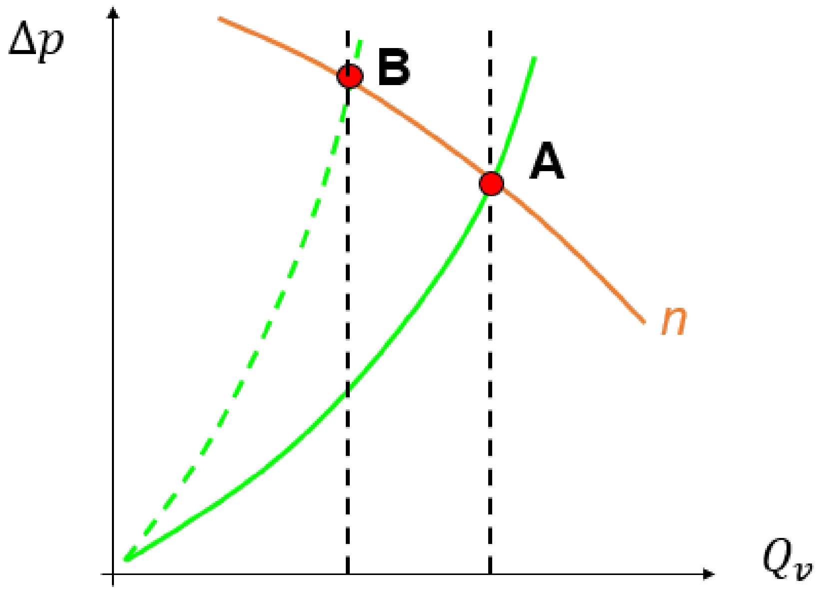
3-way installed on the supply in diverting configuration

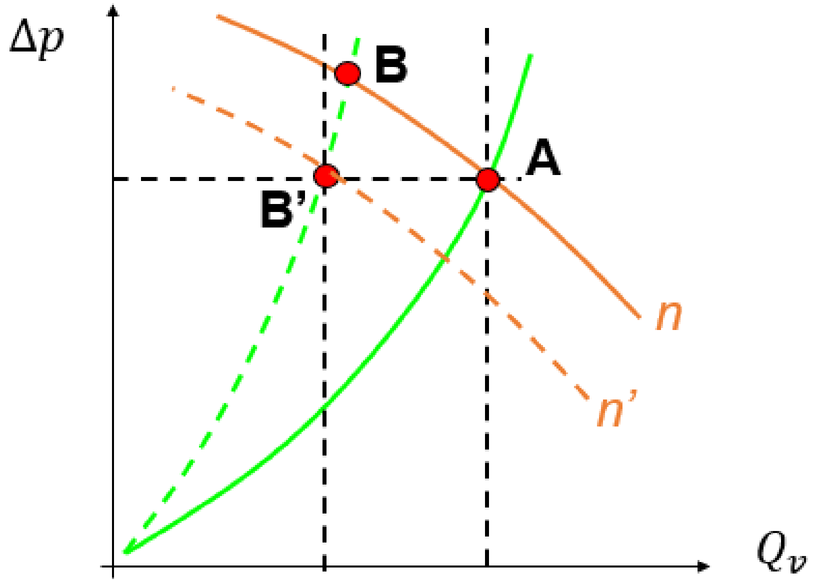


3-way installed on the return

Pumps

Constant-speed vs variable-speed pumps





Cooling plants

Limits on mass flow in the evaporators

In cooling supply stations, one or more chillers produce cold water.

The flow rate through evaporators must be:

- High enough to keep a high convective heat transfer coefficient on the cold water side to avoid ice formation and increase chiller’s efficiency;
- Low enough to avoid excessive pressure drops, that lead to high energy consumption for pumping.

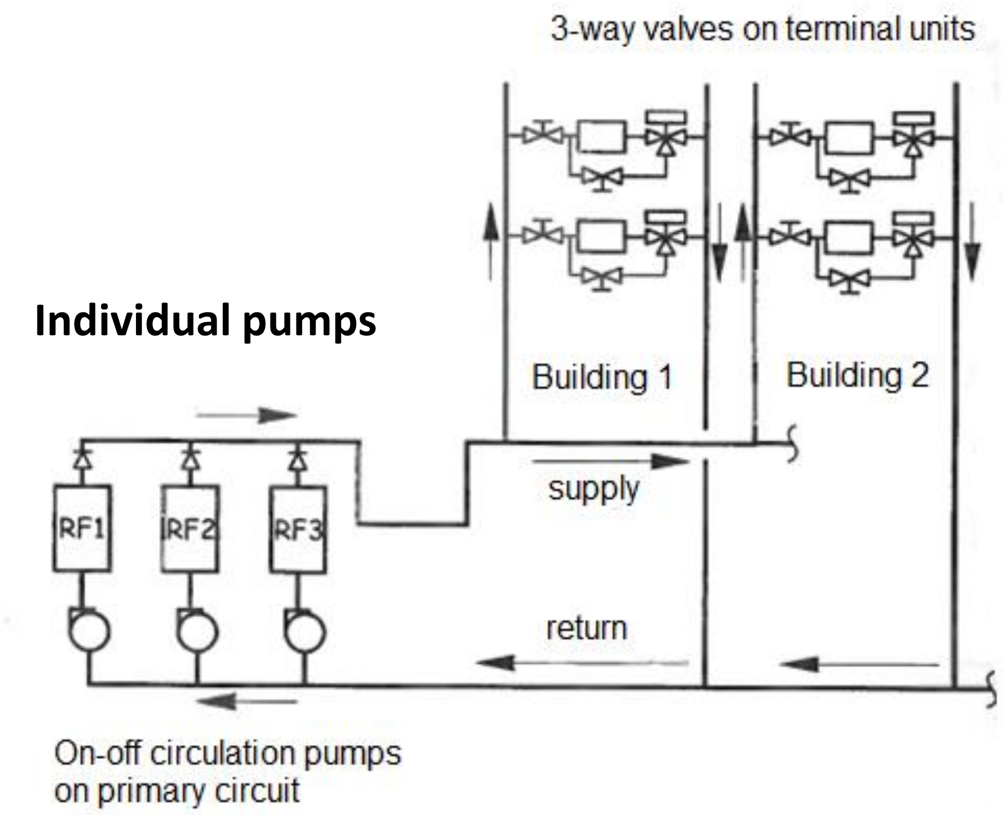
Cooling plants

Limits on mass flow in the evaporators

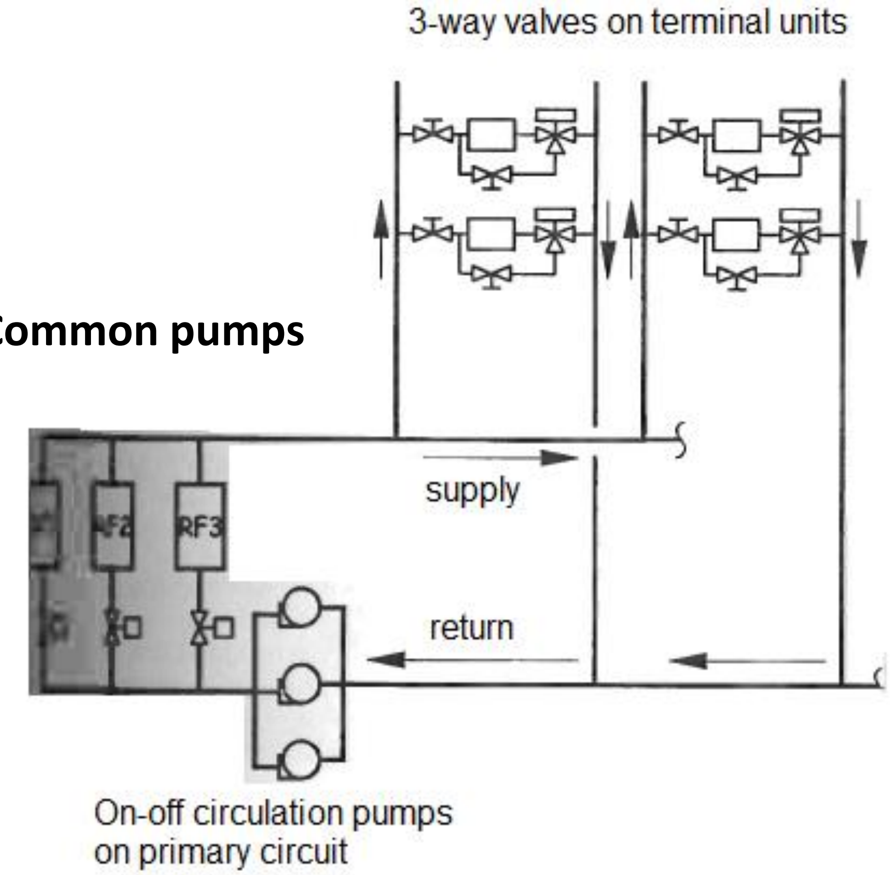
- Once the design mass flow rate has been defined, it must be kept constant even during part load operation to avoid instable operation of chillers and formation of ice in the evaporators.
- The choice of the hydronic distribution system is constrained by this requirement (constant mass flow in the evaporators).

Coupled distribution

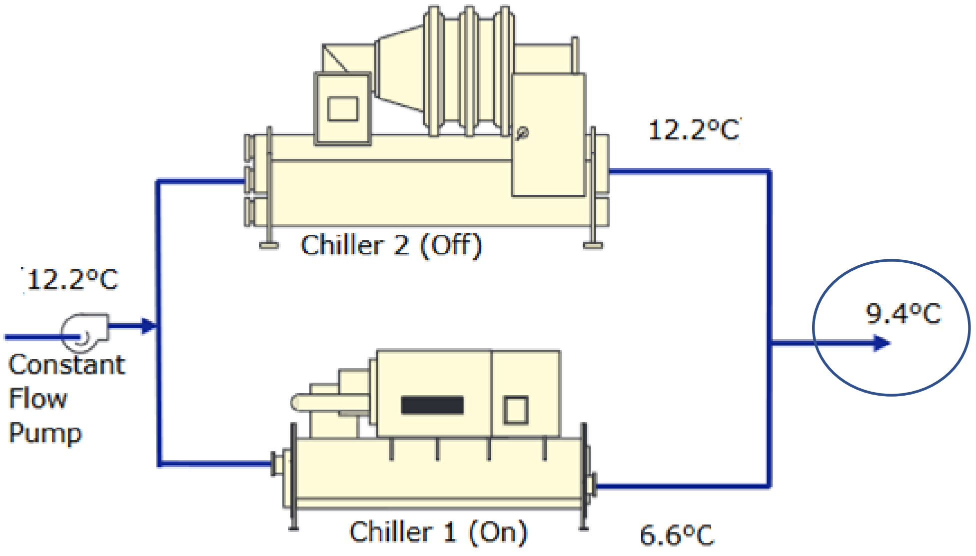
Individual pumps



Common pumps



Coupled distribution

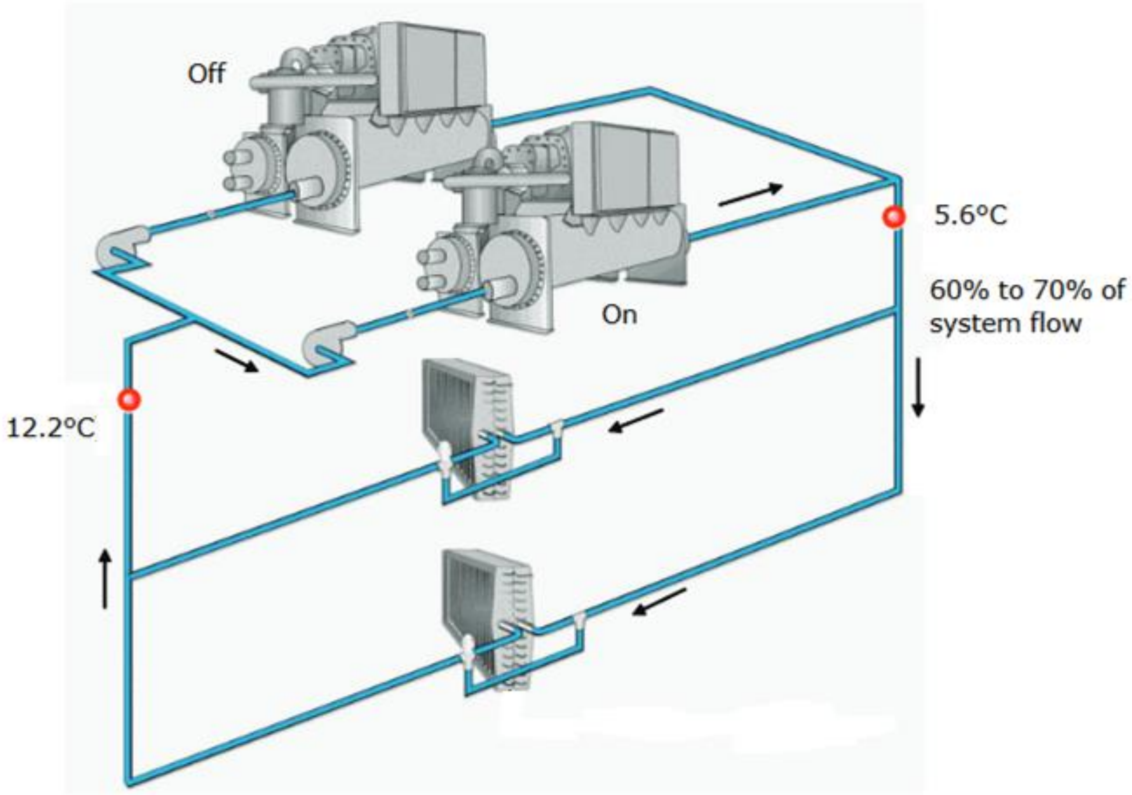


[source: www.tranebelgium.com]

Common chiller pumps

- High supply temperature in case one chiller is shut off can result in inadequate dehumidification / inability to satisfy specific loads;
- Imposing lower supply temperature of chiller 1 ($T_{su,1}$) leads to lower efficiency
- Lower limit to $T_{su,1}$(≈3°C) → not frequent with more than two chillers

Coupled distribution



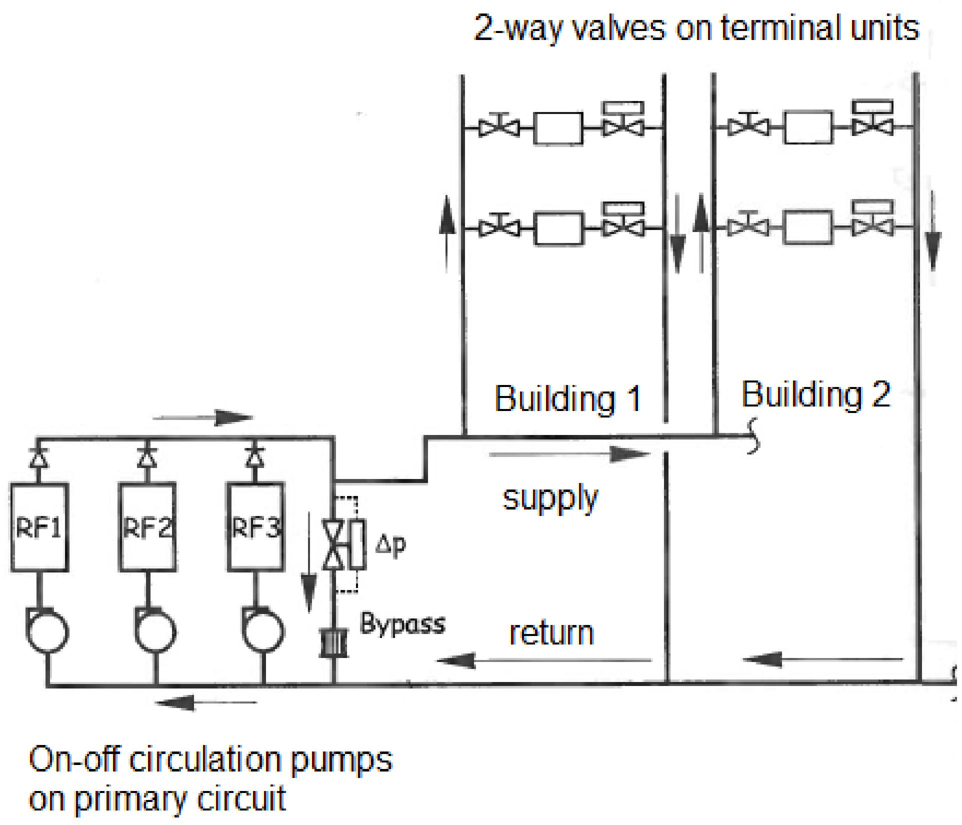
[source: www.tranebelgium.com]

Individual chiller pumps

- Shut-off of chiller units and corresponding pumps results in very low flow at partial load as a consequence of Δp-Q curve.
- When cooling load is lower than 50%, there is a 60-70% drop in flow rate → insufficient supply to furthest terminal units or to rooms with high internal gains.

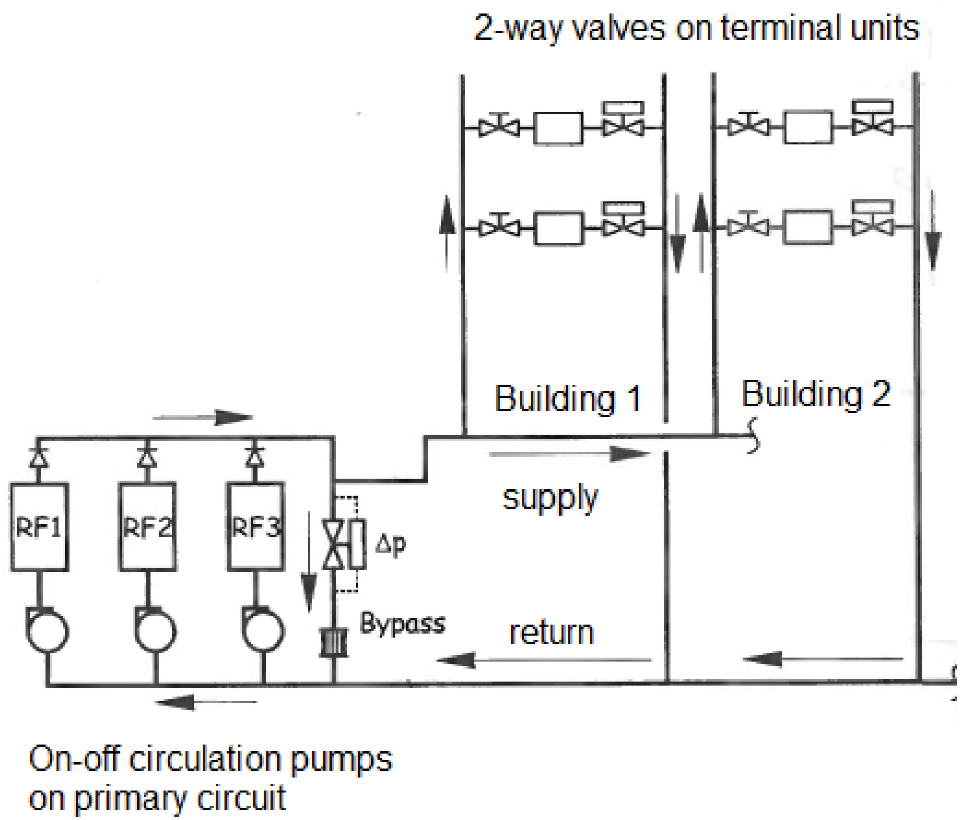
Decoupled distribution

Bypass – no pumps on secundary circuit

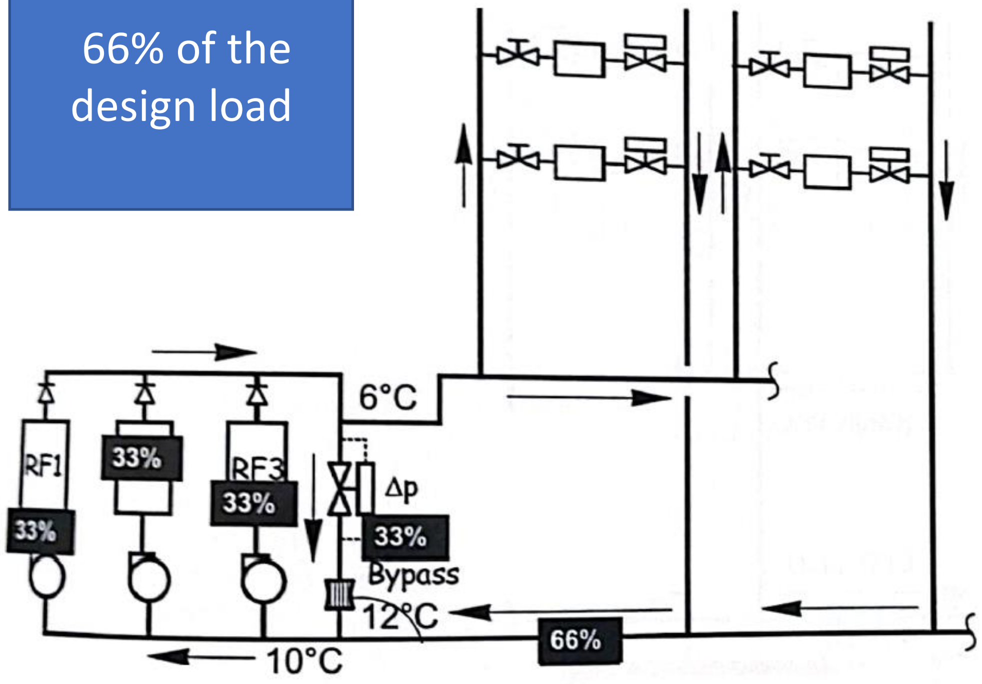


Decoupled distribution

Bypass – no pumps on secundary circuit

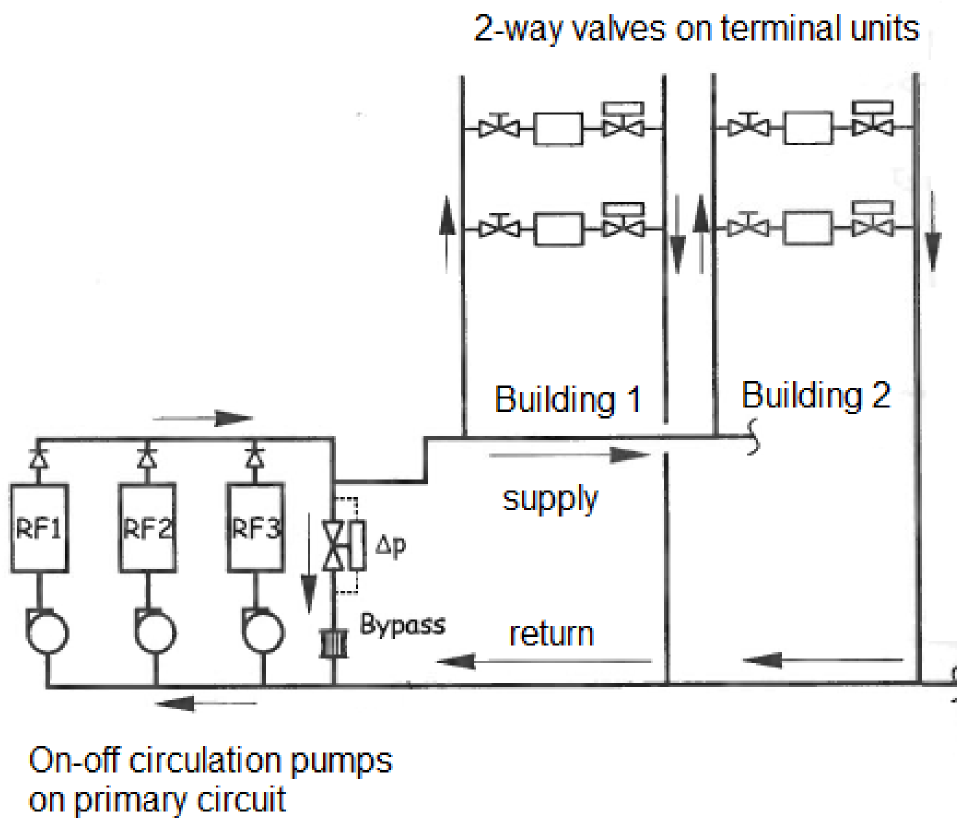


66% of the design load

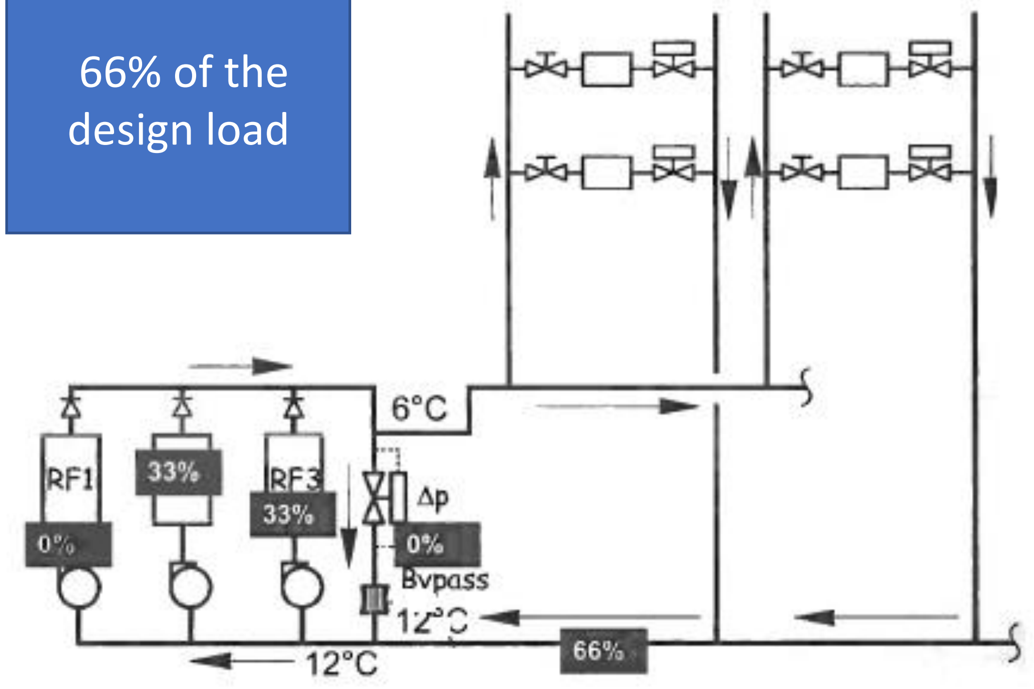


Decoupled distribution

Bypass – no pumps on secundary circuit

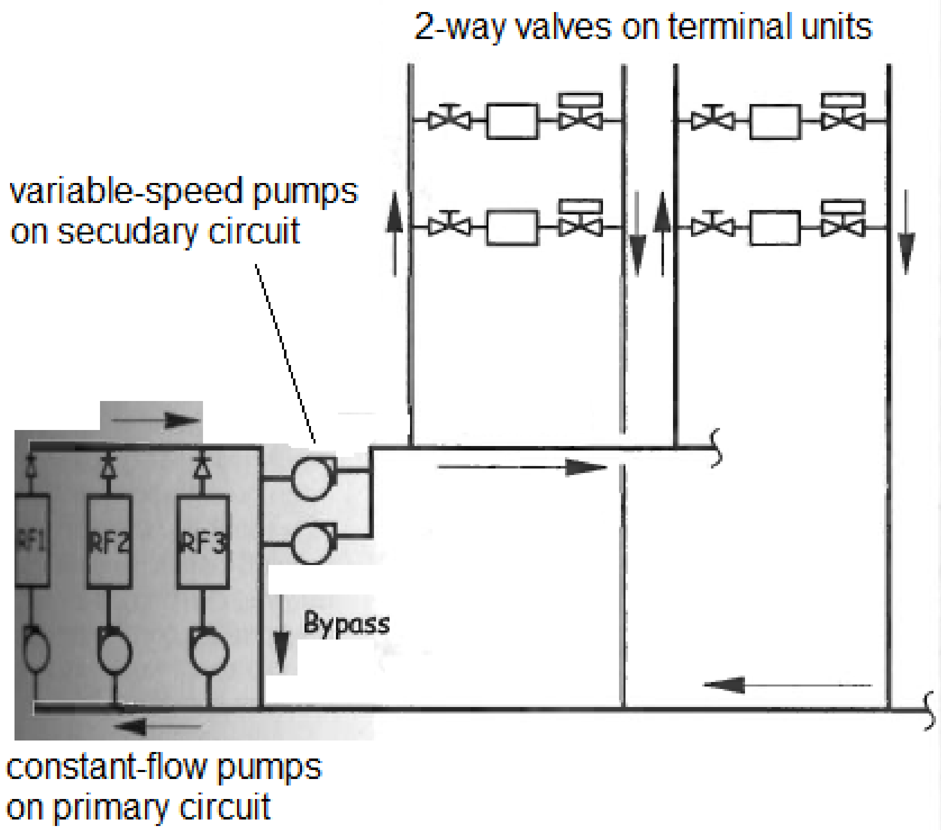


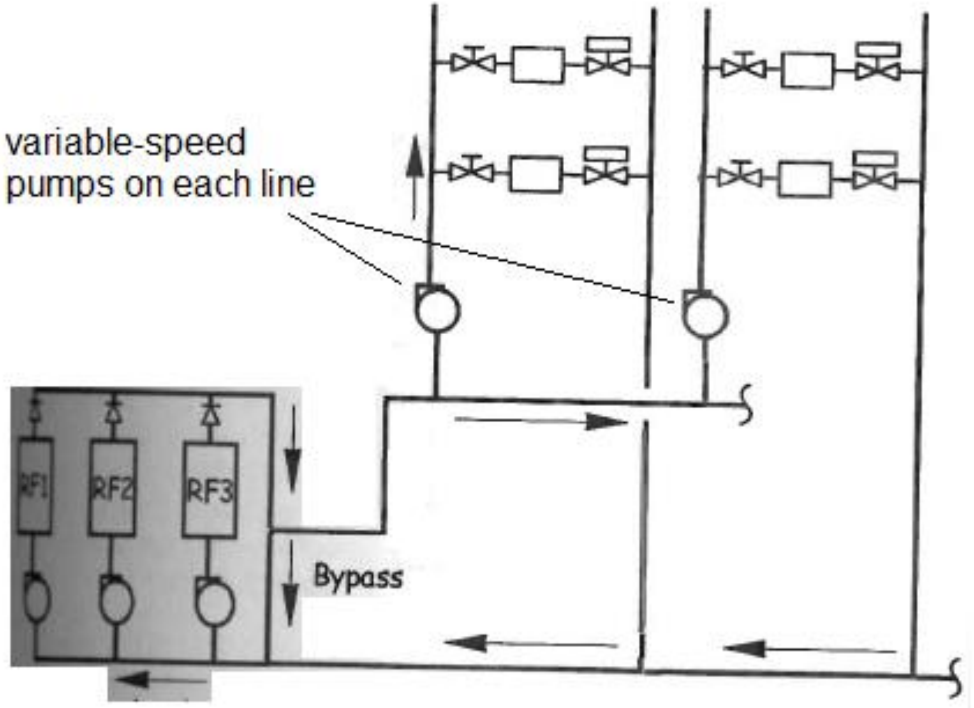
66% of the design load



Decoupled distribution

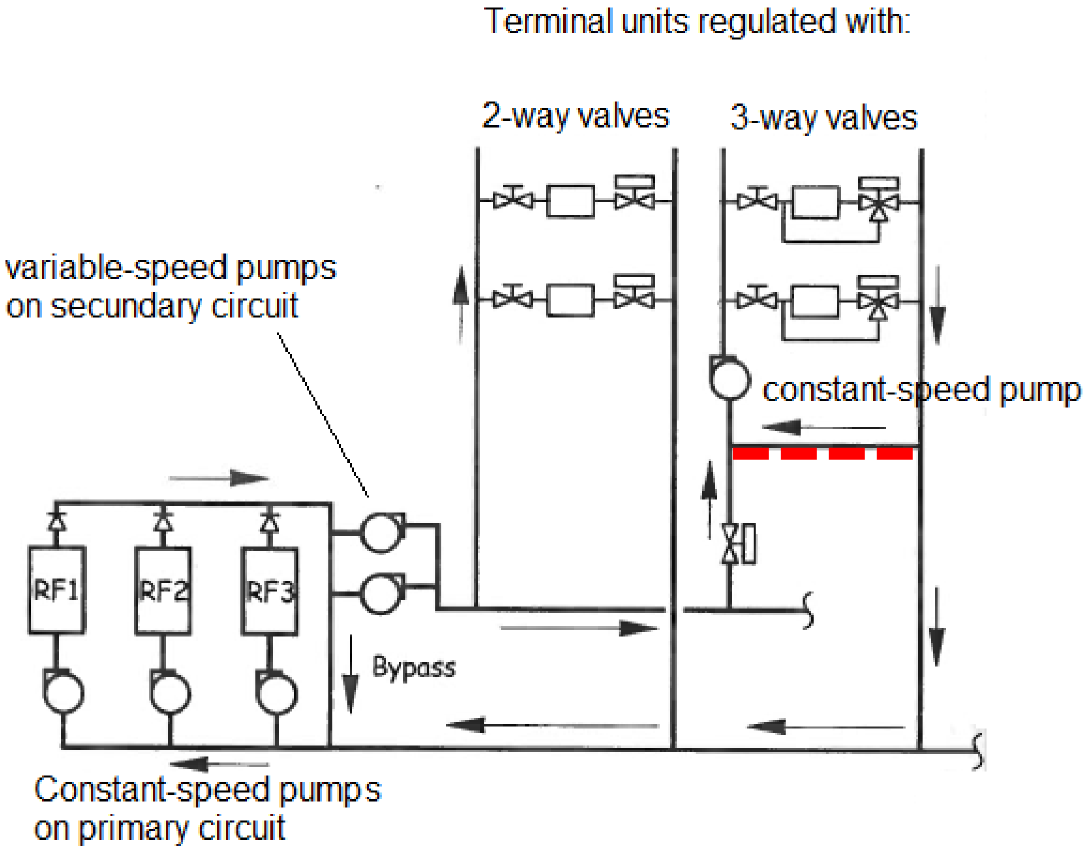
Variable-speed pumps on secundary circuit

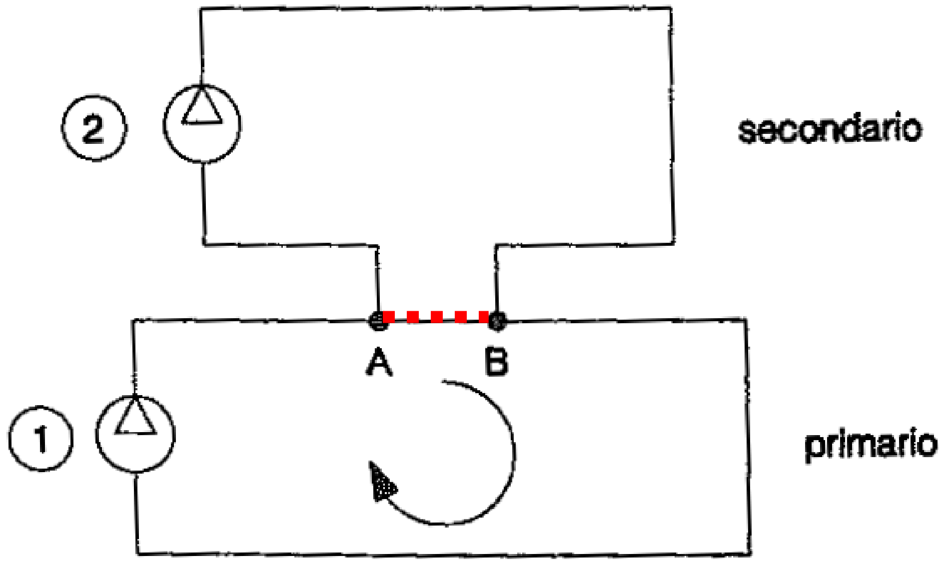




Decoupled distribution

Constant and variable speed pumps on secundary circuit





Regulation of chillers

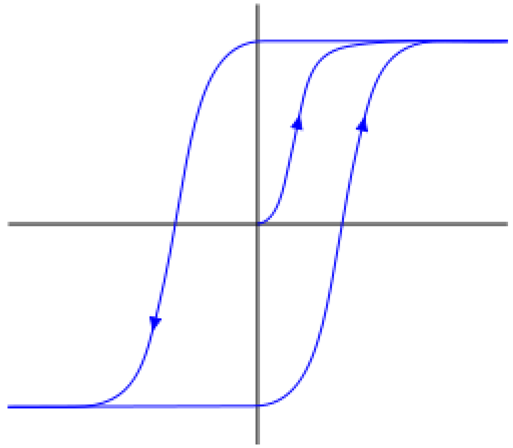
Control of chiller units

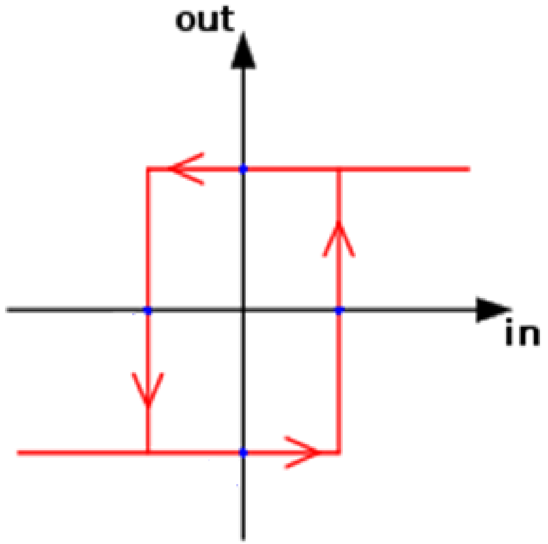
- The cooling loads are a highly time-varying parameter depending on weather conditions and internal loads.
- Need for refrigeration units to be able to modulate the refrigeration output according to the energy needs by means of a control system.
- The modulation capacity of chillers depend on their type.

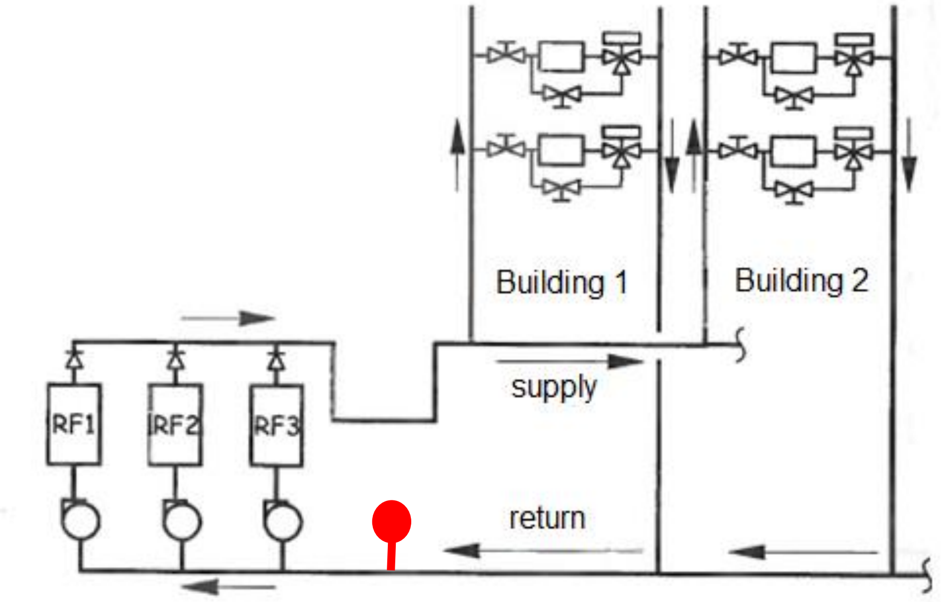
Regulation of chillers

Hysteresis

- The typical controller to regulate a cooling system is a thermostat on the return pipe of the cooling system, i.e. on the evaporator inlet (chilled water side).

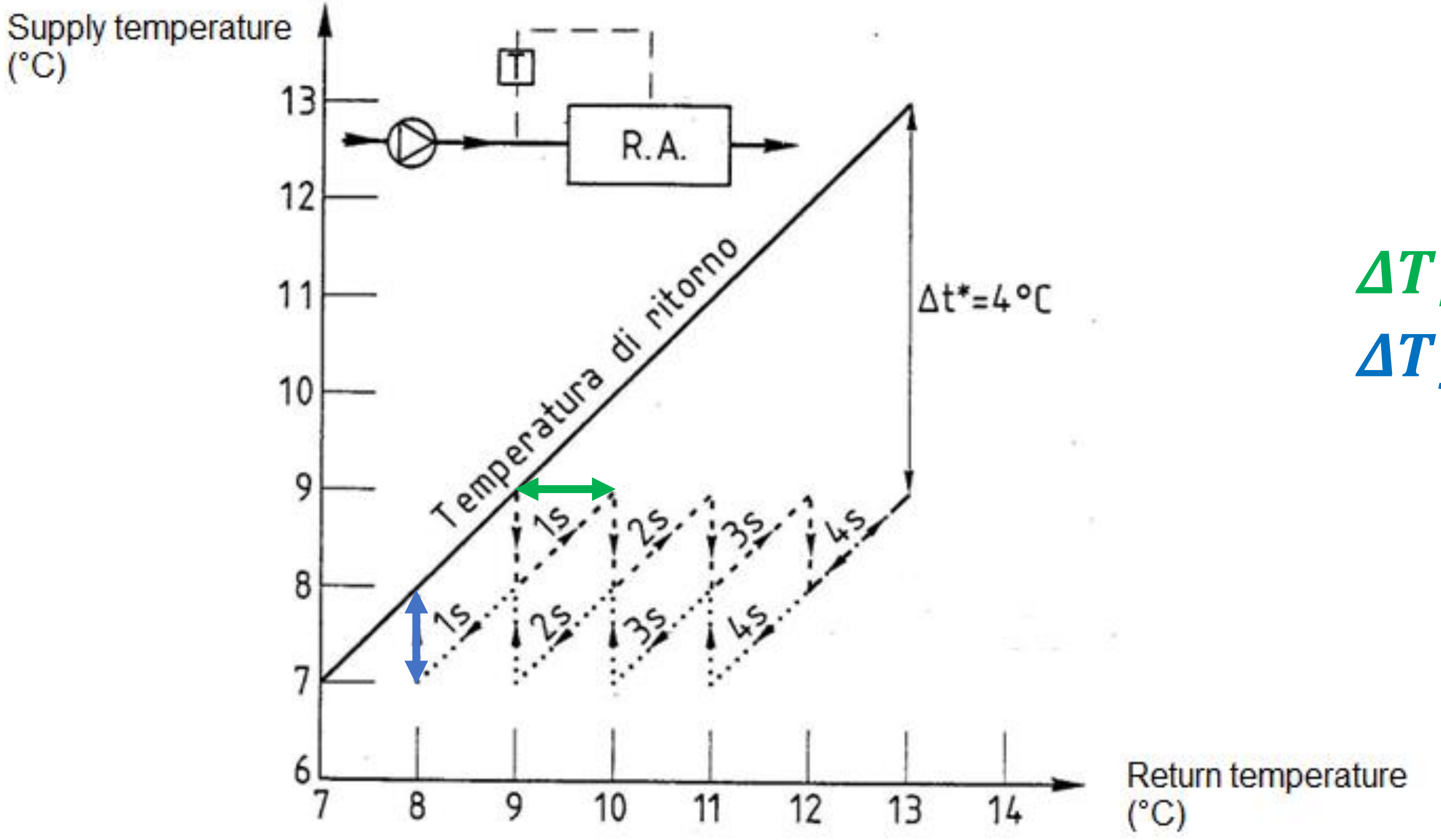






Regulation of chillers

Hysteresis

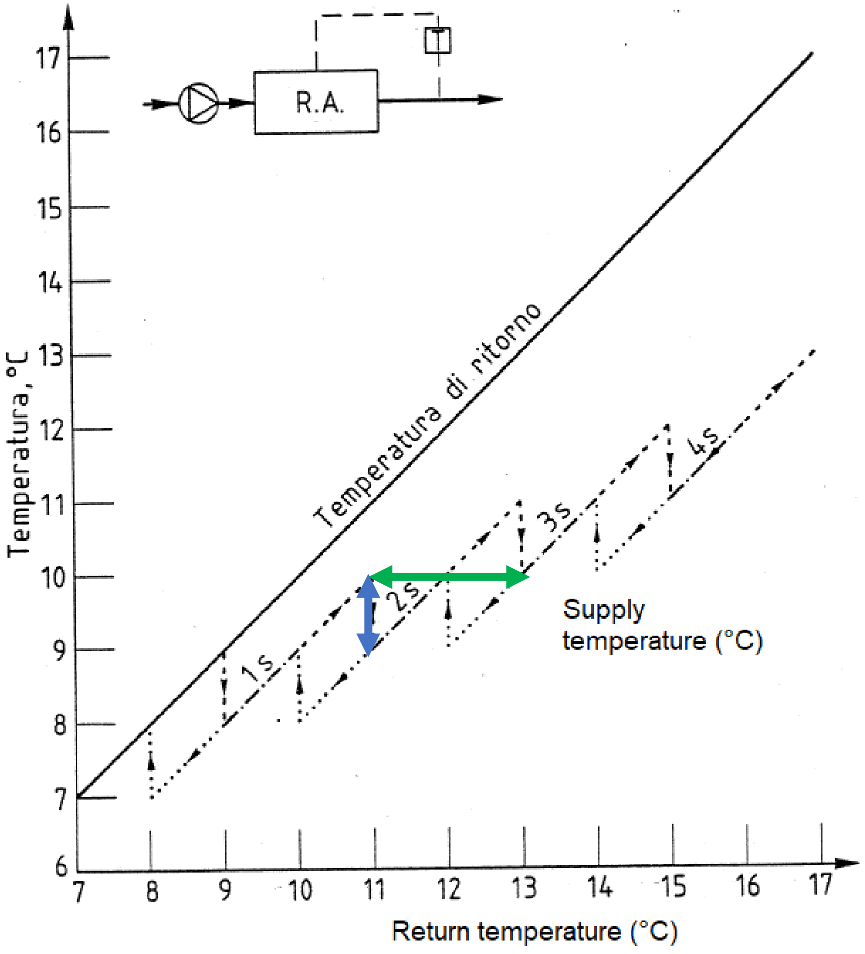


$\Delta T_{hys} = 1\ K$

$\Delta T_{steps} = 1\ K$

Regulation of chillers

Hysteresis



$\Delta T_{hys} = 2\ K$

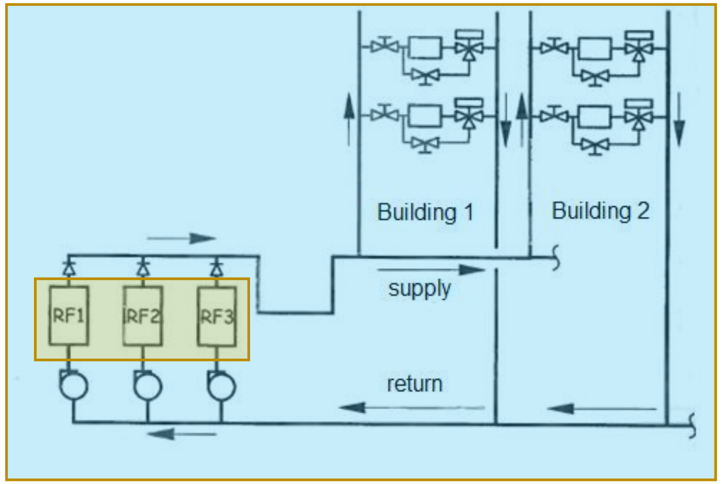
$\Delta T_{steps} = 1\ K$

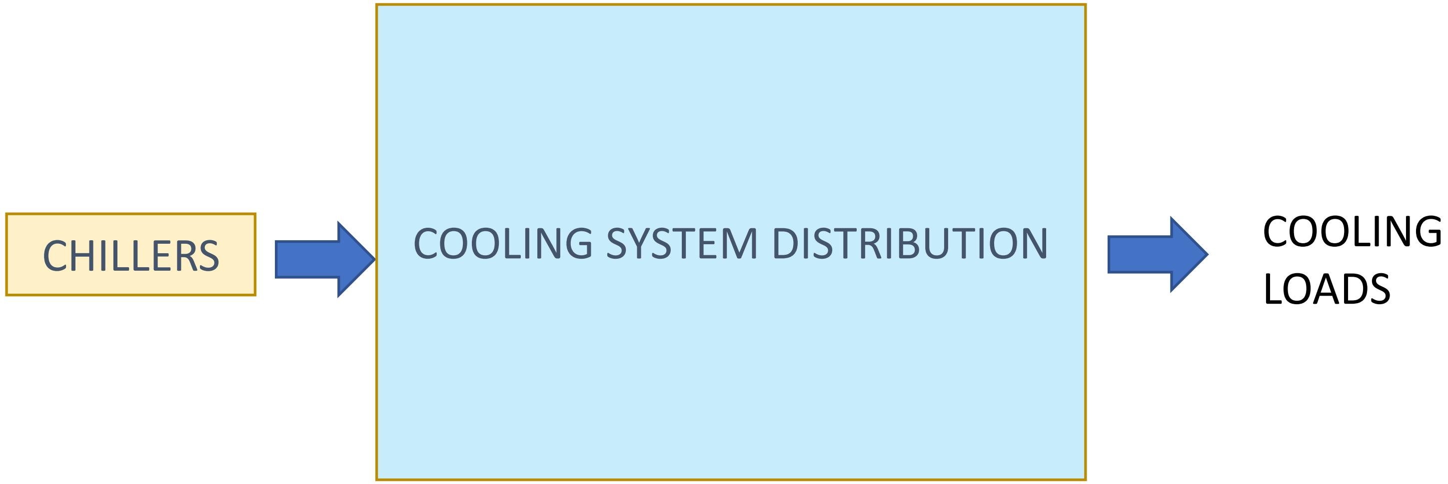
Design of cooling systems

Minimum water volume

Cooling systems (in general any hydronic system) is a dynamic system.

$$\rho V c_p \frac{dT}{dt} = P_{in} - P_{out} - P_{loss}$$



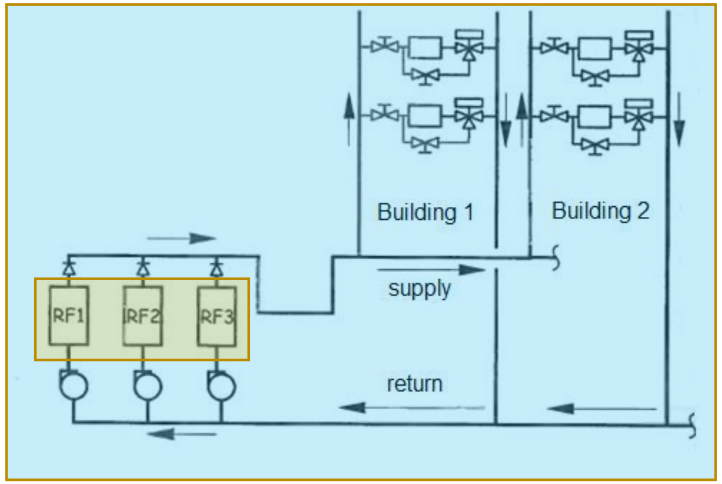


Design of cooling systems

Minimum water volume

Cooling systems (in general any hydronic system) is a dynamic system.

$$\rho V c_p \frac{dT}{dt} = P_{chiller} - P_{loads}$$



Assumptions:

- Most critical situation is when the cooling load is half of the chiller capacity in the last modulation step
- A maximum of 6 start-ups per hour are allowed

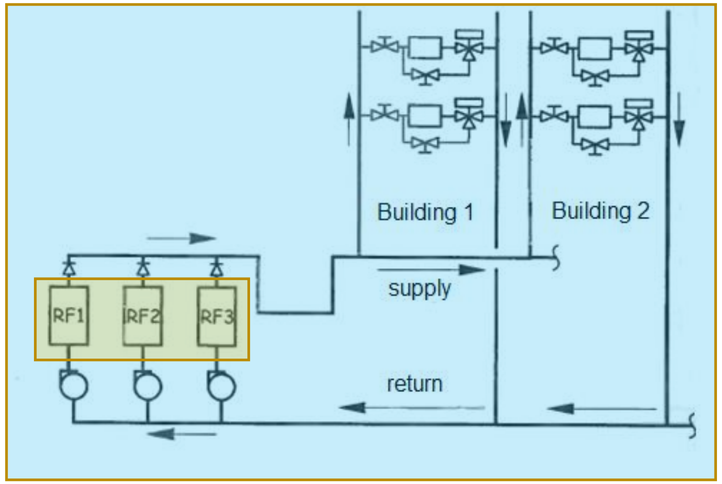
$$\mathrm{M}\, c_p \frac{dT}{dt} = \frac{P_{chiller}}{N} - 0.5\,\frac{P_{chiller}}{N}$$

$$\mathrm{M}\, c_p \frac{\Delta T}{\Delta t} = 0.5\,\frac{P_{chiller}}{N}$$

Design of cooling systems

Minimum water volume

Cooling systems (in general any hydronic system) is a dynamic system.



$$M\ c_p \frac{\Delta T}{\Delta t} = 0.5\ \frac{P_{chiller}}{N}$$

$$\Delta t > \Delta t_{min}$$

$$\Delta t = \frac{M\ c_p\ N\ \Delta T_{hys}}{0.5\ P_{chiller}}$$

$$\Delta t > \frac{0.166}{2}\ [hr]$$

$$M > \frac{P_{chiller}}{24\ c_p\ N\ \Delta T_{hys}}$$

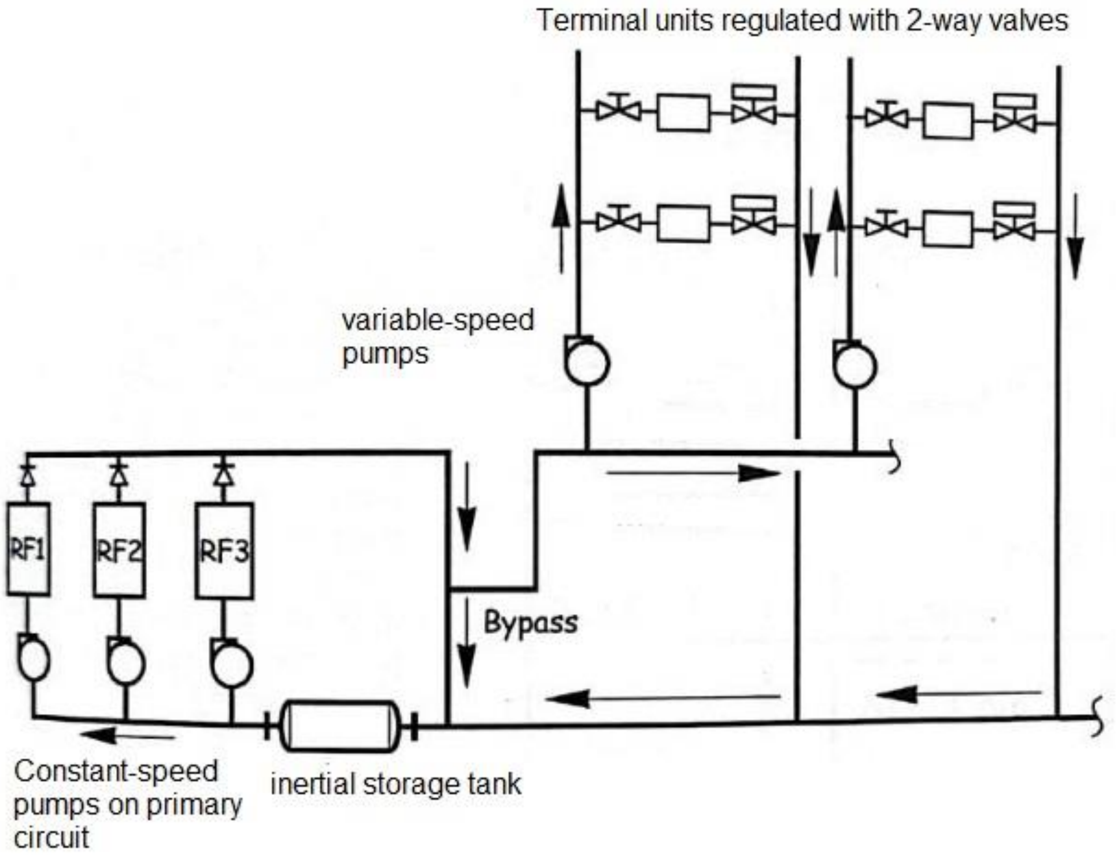
Design of cooling systems

Rules of thumb

- Checking the water content is necessary for systems with limited hydraulic circuit development.
- When such condition is not satisfied, it is recommended to use inertial storage tanks to reduce the frequency of the compressor cycles.

Design of cooling systems

Inertial storage tank on the return



Design of cooling systems

Inertial storage tank on the return

When the required cooling capacity exceeds 200-300 kW, it is recommended to install more than one cooling unit :

- to guarantee a minimum reserve of cooling capacity for the operation of the system, in the event of a failure;
- to have a unit operating with heat recovery at the condenser for DHW production.

Rule-based controllers

P, PI, PID

Thermostats are not the only controllers used in HVAC systems.

Control in general is based on maintaining a chosen set value (e.g. a temperature, a flow rate, a water level) with the help of an actuator (a motor, pump or valve).

Let's define an error between a measured variable and the corresponding setpoint (desired) value:

$$e(t) = T(t) - T_0$$

Rule-based controllers

P, PI, PID

Three different actions may be used in order to reach the desired value of the measured quantity:

- **Proportional action**: it represents the present value of the error and the correction action is proportional to the difference between actual and set values.

$$proportional\ correction\ \cong K_p\ e(t)$$

Rule-based controllers

P, PI, PID

Three different actions may be used in order to reach the desired value of the measured quantity:

- **Integral action:** it represents the past values of the error and is practically the algebraic sum of the past errors. It allows for the exact correction of the error and is tuned by the integration time τ_i :

$$integral\ correction \cong \frac{1}{\tau_i}\int_o^t e(t)\,dt$$

Rule-based controllers

P, PI, PID

Three different actions may be used in order to reach the desired value of the measured quantity:

- **Derivative action**: it represents the future values of the error. The latter is predicted for the next time step using the error slope and the derivation time τ_d :

$$derivative\ correction\ \cong \tau_d \frac{de(t)}{dt}$$

Rule-based controllers

P, PI, PID

Controllers with different properties can be achieved by combining these actions.