Design and control of cooling systems

J. Vivian

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).

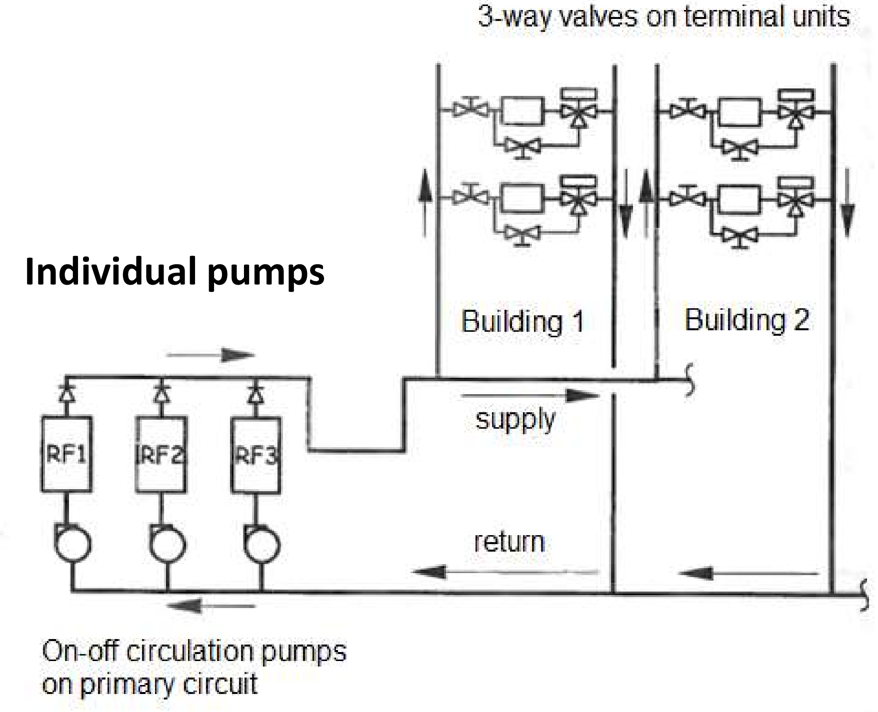
Cooling plants

Distribution

- COUPLED DISTRIBUTION: constant flow both on primary and secondary circuit (3-way valves on terminal units).
- DECOUPLED DISTRIBUTION: constant flow on primary circuit and variable flow on secondary circuit (bypass on main supply line).

Coupled distribution

Individual pumps



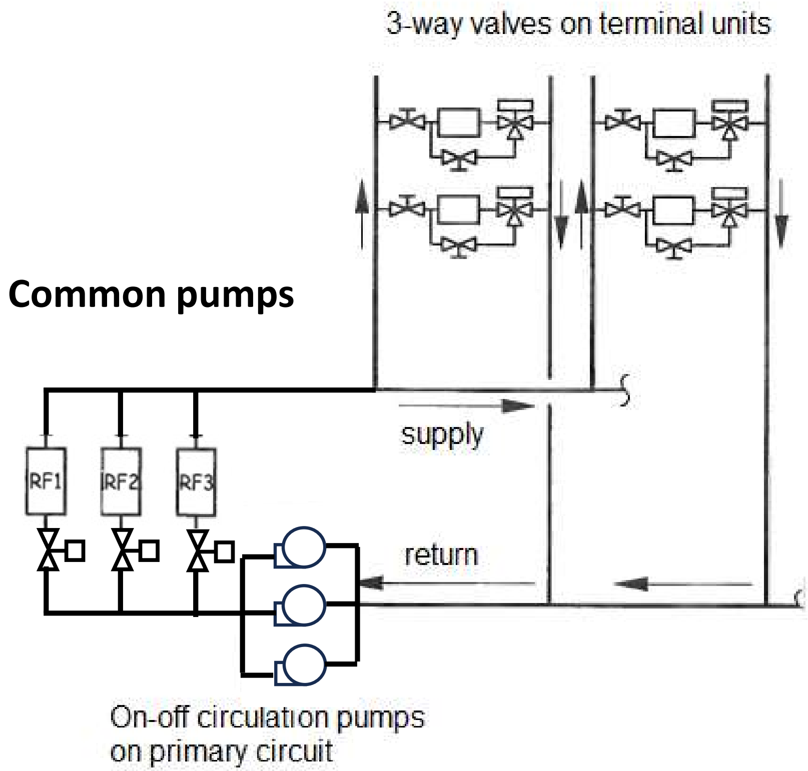
- **3-way valves in mixing mode on the return of terminal units** modulate the flow supplied to the single terminal units

- The system operates always at constant flow (even at partial loads) and constant supply temperature: no energy saving for pumping at partial loads

- **All chillers receive a constant (design) flow**.

- They need to **synchronize their power output** at partial loads.

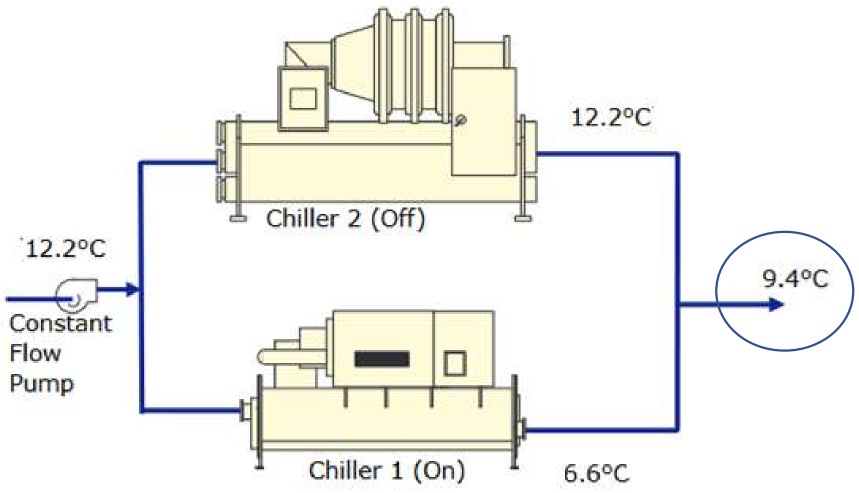
Coupled distribution



- Number of pumps can be lower than number of chillers. Only one back-up pump is enough. Ok when all chillers have similar size. Stopping one chiller would lead to losing control of the supply temperature.

- **Note: in both cases, the secundary circuit must be sized according to the design flow rates of all terminal units, even if loads do not occur simultaneously**

Coupled distribution

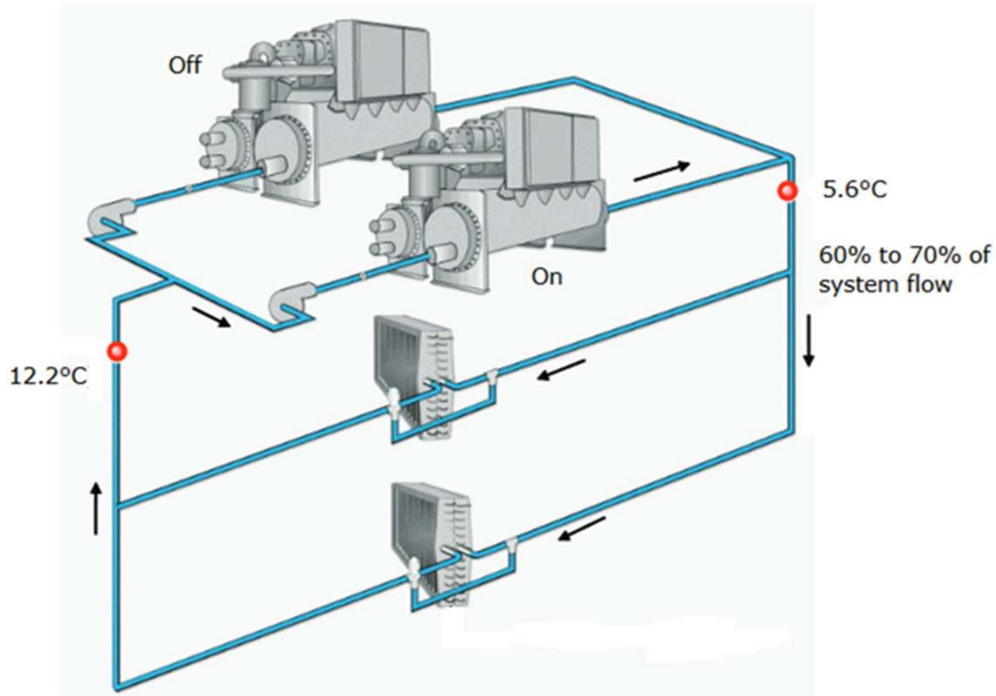


[source: www.tranebelgium.com]

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 (EER)
- Lower limit to $T_{su,1}$(≈3°C) → not frequent with more than two chillers

Coupled distribution



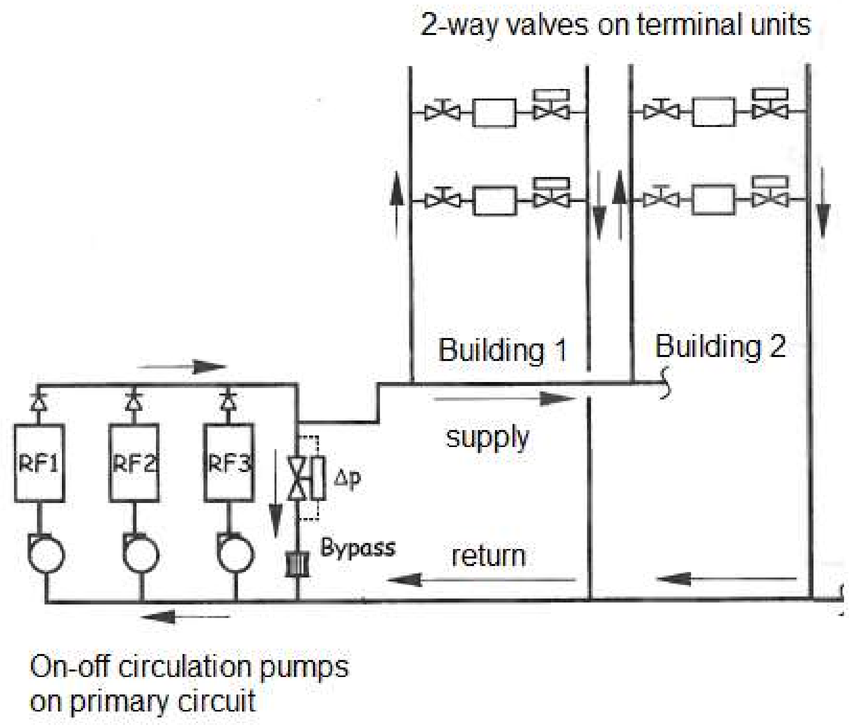
[source: www.tranebelgium.com]

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

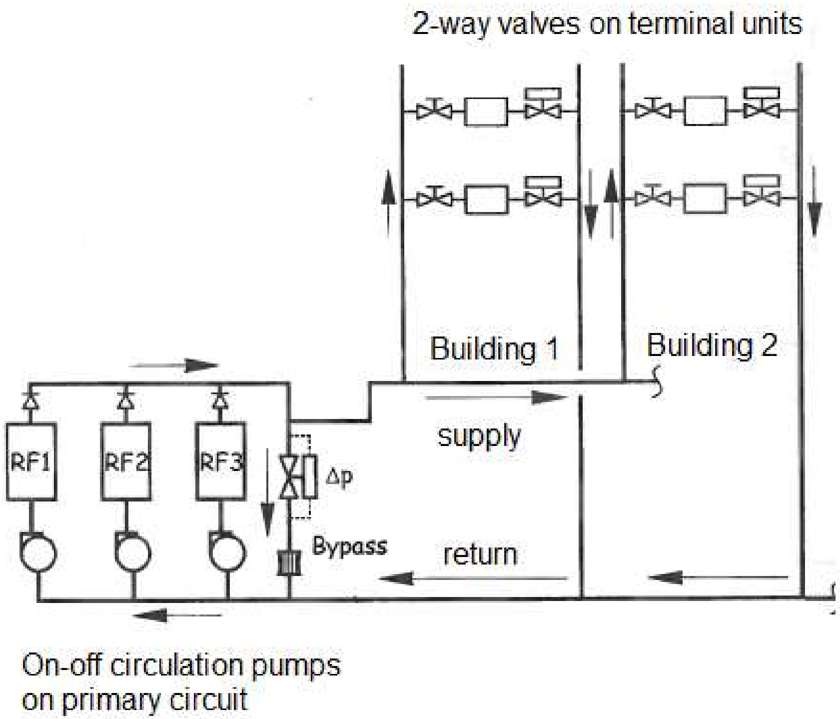


- total flow on the secundary circuit is variable
- A bypass pipe allows to decouple the flow on the primary and secundary side
- The extent of decoupling depends solely on the restriction (or lack of restriction) in the bypass pipe. Total decoupling is accomplished only if the bypass piping has zero pressure loss at any flow. Since this is not possible, some negligible pump coupling will exist. The important issue is to keep the bypass piping free of unnecessary restrictions such as check valve.

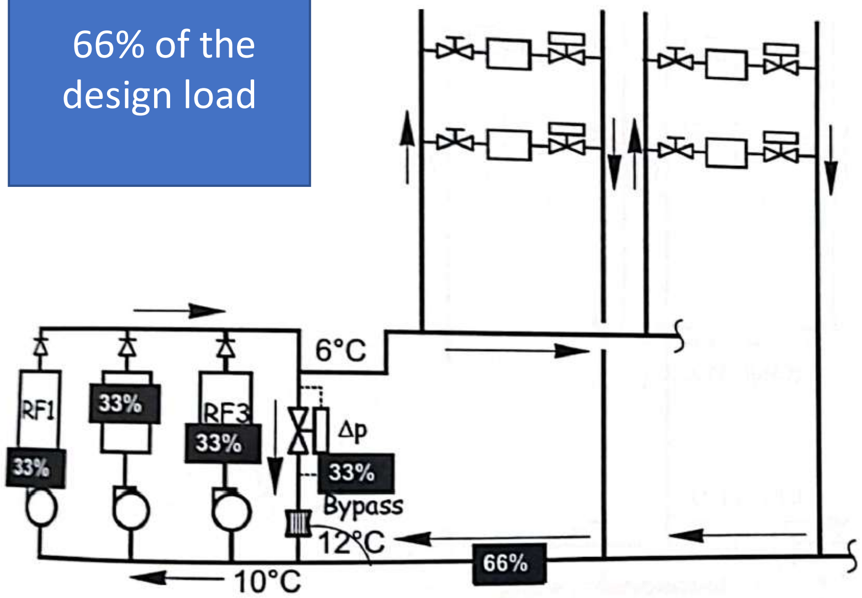
Decoupled distribution

Bypass – no pumps on secundary circuit

- **Note: in this case, the secundary circuit must be sized according to the maximum simultaneous flow on each building/riser/section**
- All chillers receive a constant (design) flow, equal to 33% of the system design flow rate.



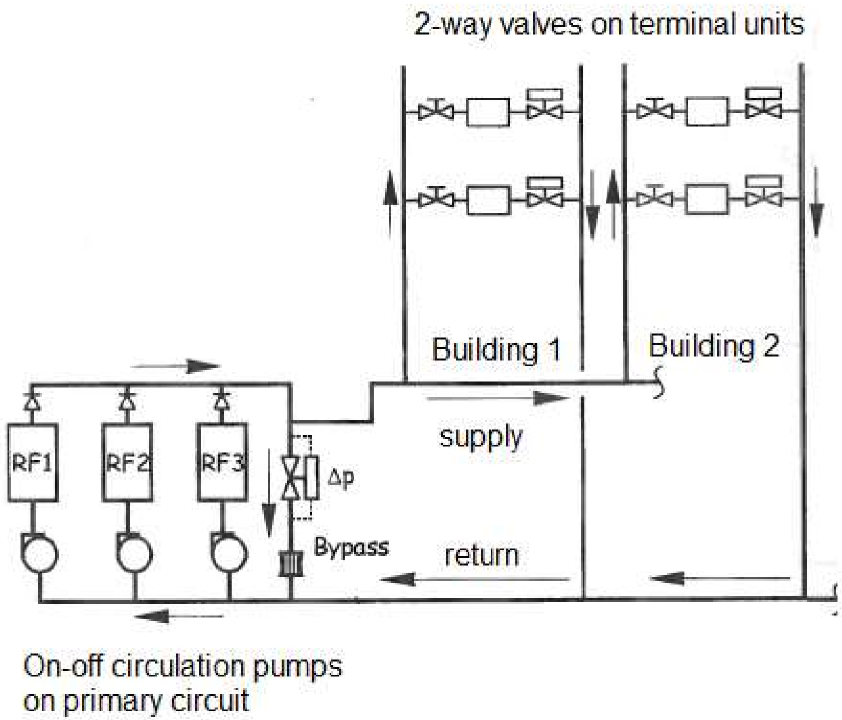
66% of the design load



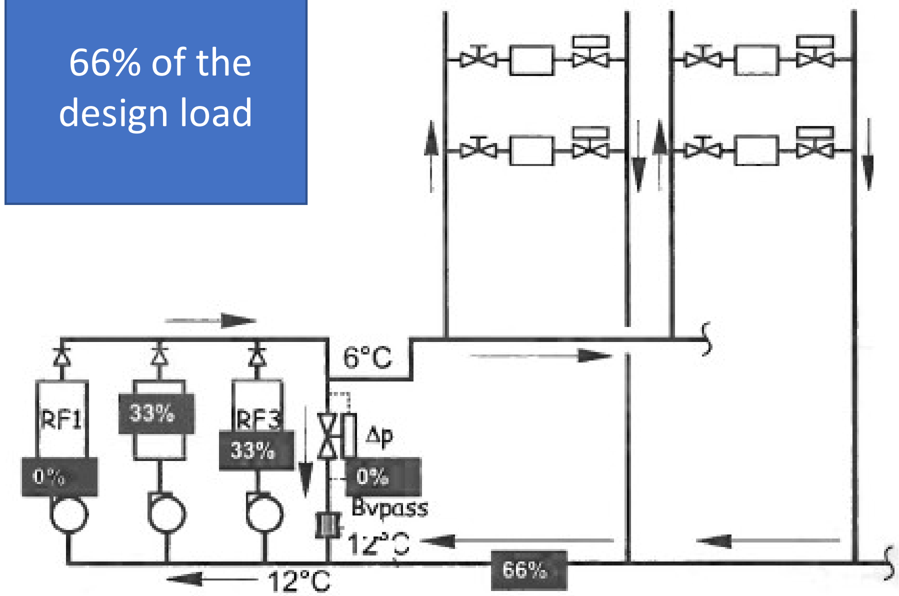
Decoupled distribution

- In this case the chiller n. 1 is shut off and 33% of the nominal flow rate is supplied to chillers 2 and 3.

Bypass – no pumps on secundary circuit



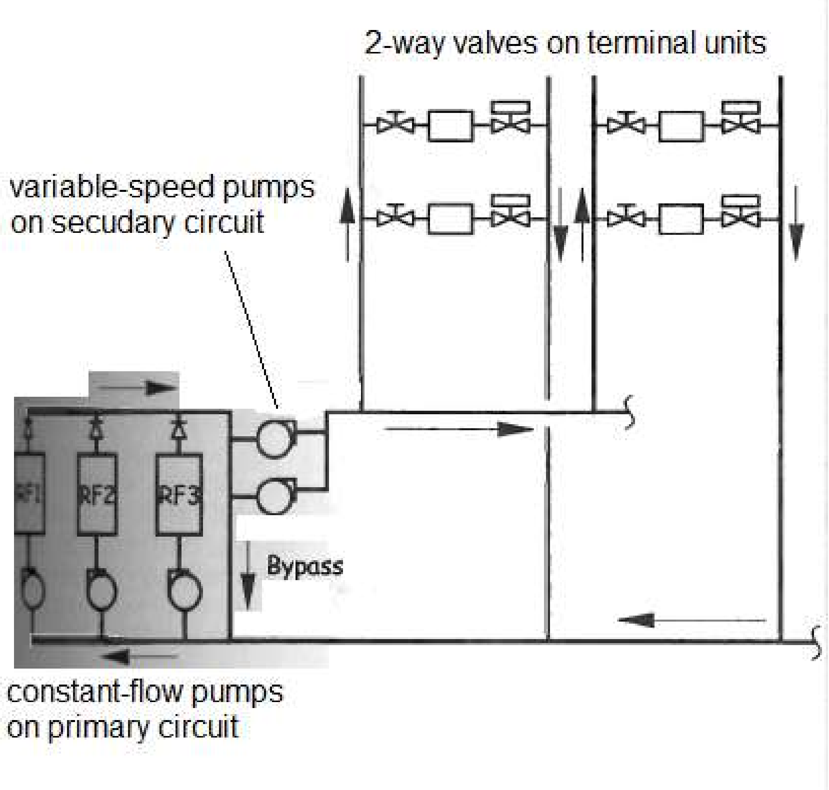
66% of the design load

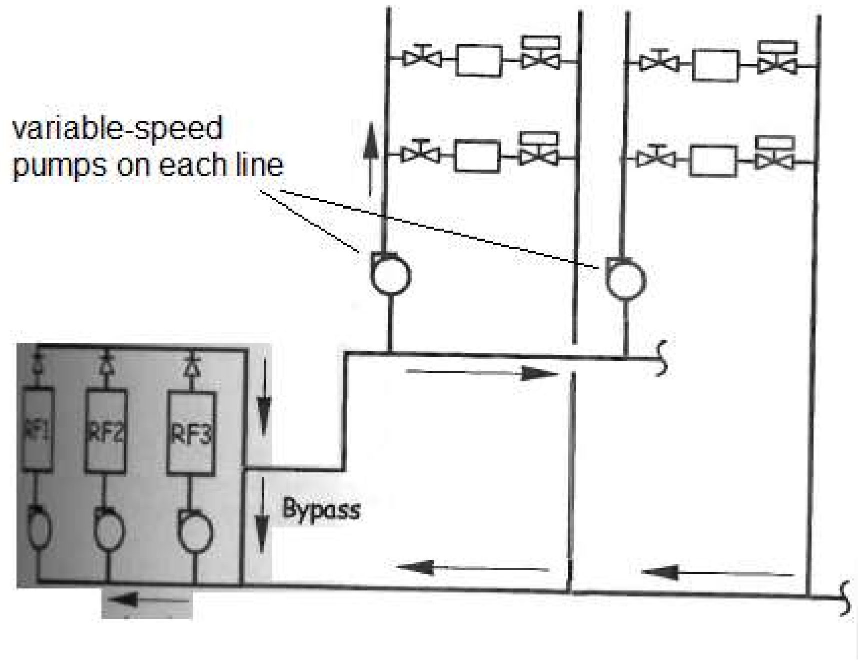


Decoupled distribution

- The second solution (right) is preferable when the circuits on the secundary side have different pressure losses, i.e. when they require pumps supplying different heads

Variable-speed pumps on secundary circuit





Regulation of chillers

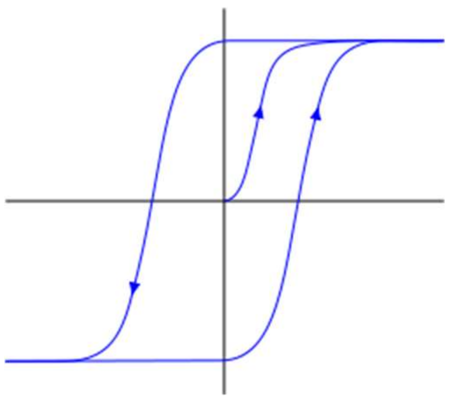
Control of chiller units

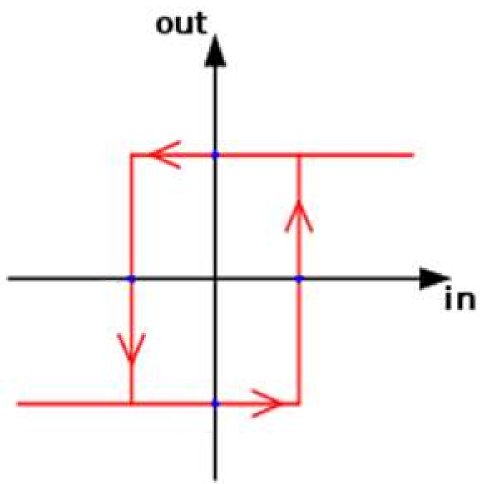
- The cooling loads are a highly time-varying parameter depending on weather conditions and internal loads.
- Need for refrigeration units to be able to modulate the refrigeration output according to the energy needs by means of a control system.
- The modulation capacity of chillers depend on their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

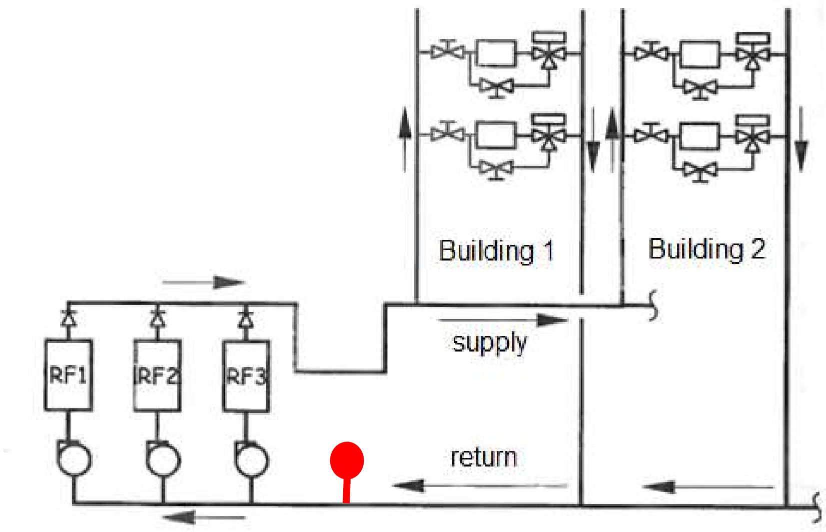
Regulation of chillers

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).



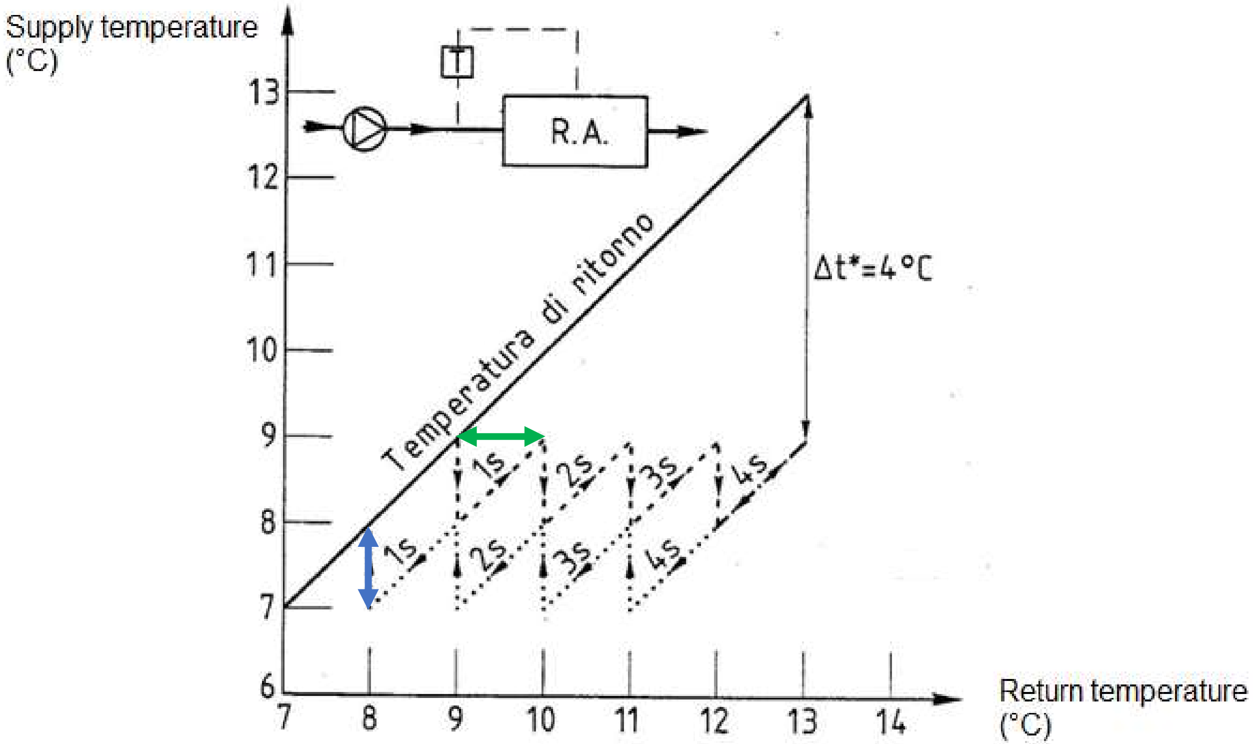




Regulation of chillers

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

Hysteresis

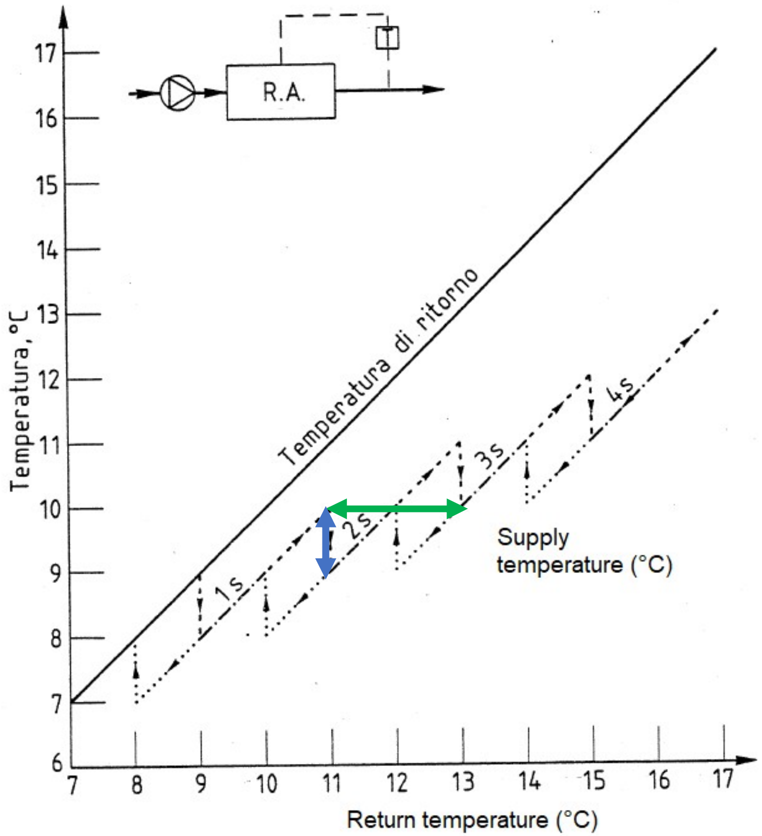


hystheresis differential : deltaT between on and off of a single modulation step (green)

Steps differential : difference between on and off of consecutive modulation steps (blue) = cooling deltaT due to chillers cooling output

Regulation of chillers

Hysteresis



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

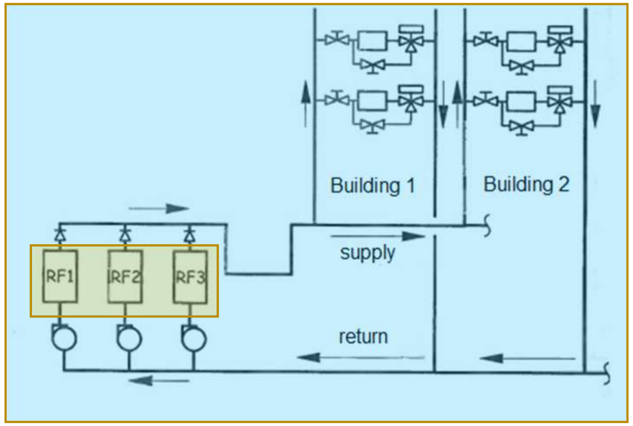
$\Delta T_{steps} = 1\ K$

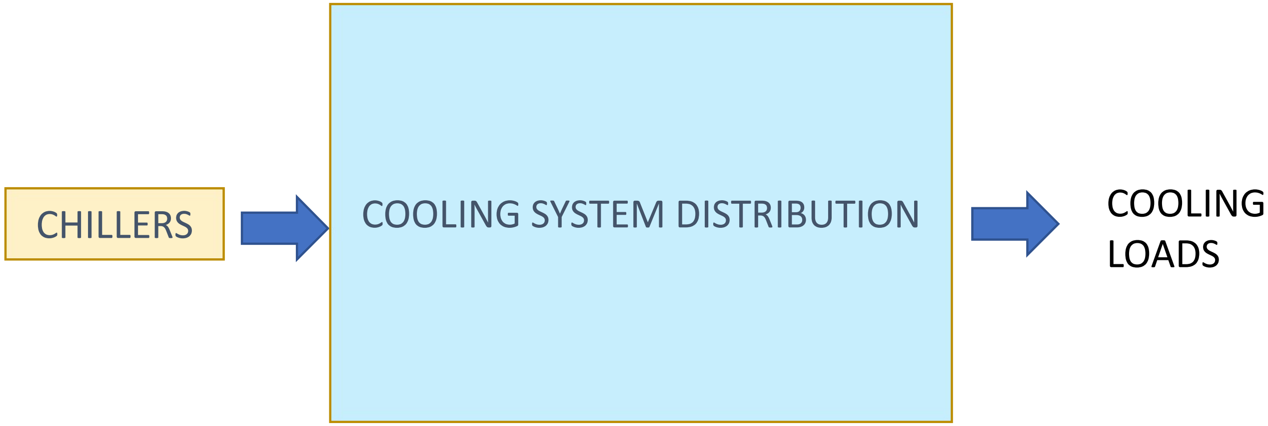
Design of cooling systems

Minimum water volume

Cooling systems (in general any hydronic system) are dynamic systems.

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



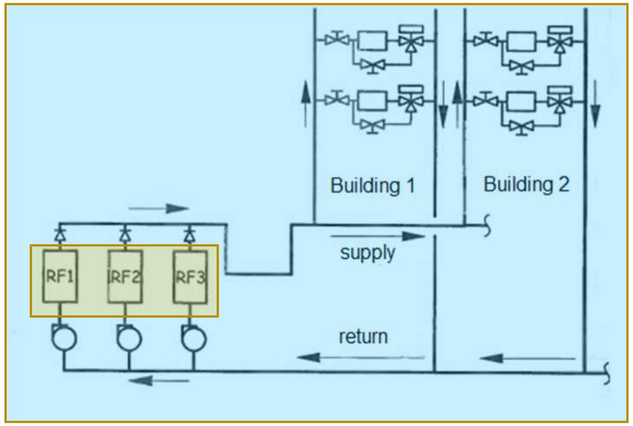


Design of cooling systems

Minimum water volume

Cooling systems (in general any hydronic system) are dynamic systems.

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



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

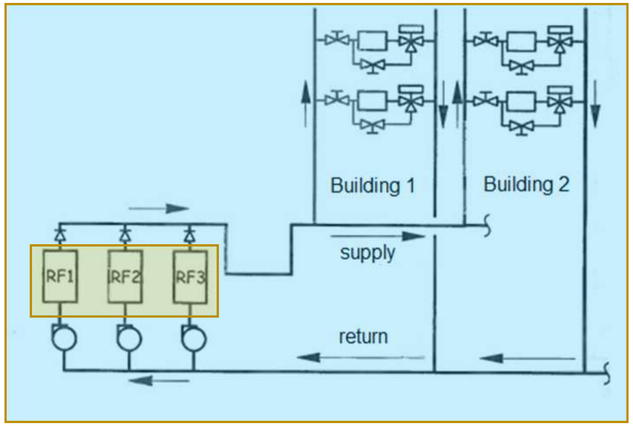
$$M\ c_p \frac{dT}{dt} = \frac{P_{chiller}}{N} - 0.5\ \frac{P_{chiller}}{N}$$

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

Design of cooling systems

Minimum water volume

Cooling systems (in general any hydronic system) are dynamic systems.



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

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

$$\left\{ \begin{array}{l} \Delta t = \dfrac{M\ c_p\ N\ \Delta T_{hys}}{0.5\ P_{chiller}} \\ \Delta t > \dfrac{0.166}{2}\ [hr] \end{array} \right.$$

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

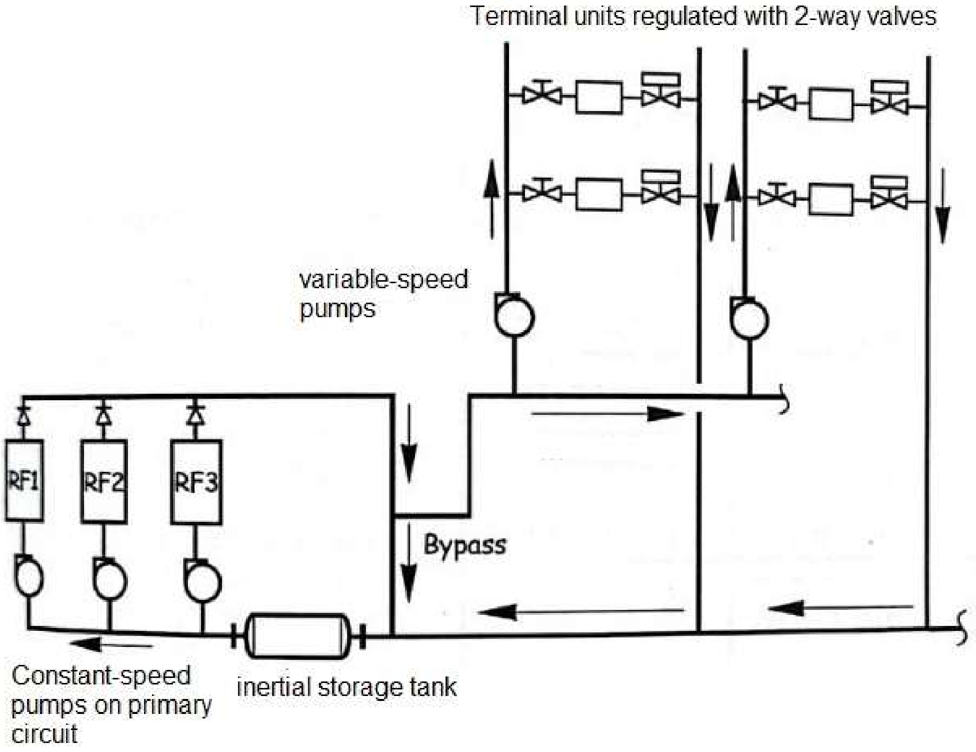
Design of cooling systems

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.