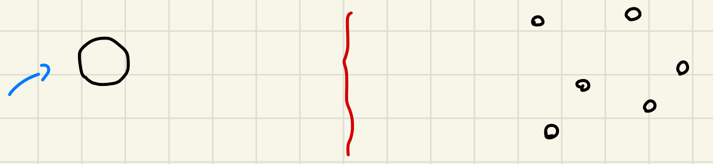
1. HEAT NETWORKS

Idea: have one (few) heat generation facilities and many utilisers



economies of scales, (one/few large gen. instead of tons) better pollution control..

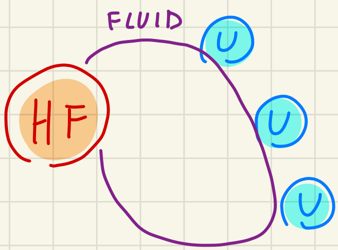
network (in between)

NO pollutant emission here!

BUT need to transport energy → impelling cost, losses

- Terminology:

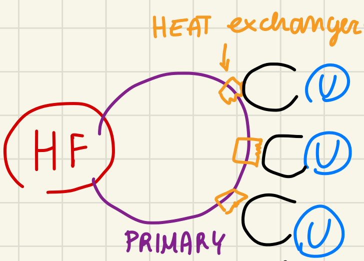
- **Direct heat network (HN)**: Fluid from heating (or cooling) facilities flows also through utilisers



single fluid circulation → can be open net..

less equipment needed (no heat exch)

- **Indirect HN**: Fluid from HFs does not flow through utilisers



Better separation of PRI & SEC controls, better HF isolation (NO mass exchang.)

in general Primary fluid: closed network (same fluid circulating) while SECONDARY: can be open networks, for example tap water

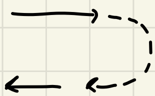
↓

makeup ("Reintegrate") water := to decrease losses!

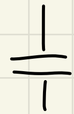
you can mix up open-close network on my heating system...
↓
depending on my case..
⇒ what are control problems, control schemes... ←(FOCUS)

how to take heat out of a ~~network~~ circuit
(Fluid circuit)
↳ "circulating"

IF send heat

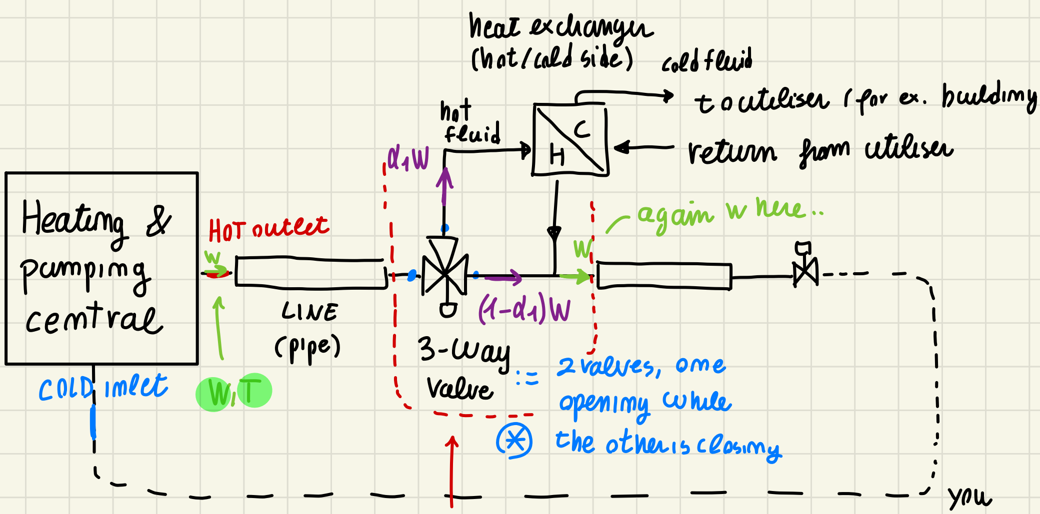


It is better to take it back ≃



like big capacitor

• IDEA 1 : "ring" network SELDOM (if ever) used today



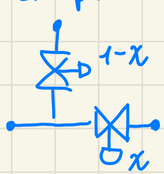
3-Way Valve := 2 valves, one opening while ⊛ the other is closing

steady-state

you close the syst.

we can safety control flow rate W and temp T (on OUTLET) ← { fluid can always circulate through the net, valves never closed! }

⊛ correspond to



single device working in this way!

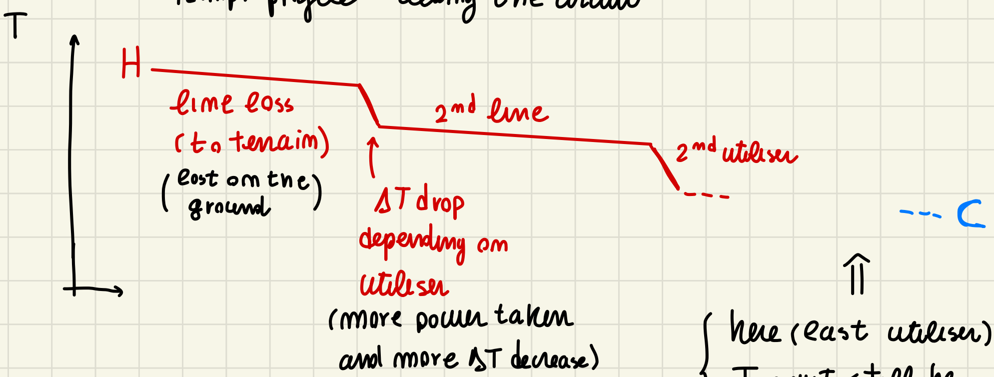
α_i := depends on valve positions (∀ utiliser) & pressure → NON LIN Relation

depending on 3way-valve position... I know flow rates out..

supposing the system @ steady state : All constant

⇓

Temp. profile along the circuit



⇑

{ here (last utiliser) T must still be high enough to serve }

considerations:

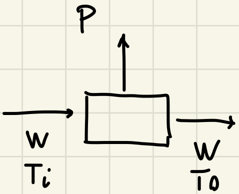
- More utilisers ⇒ cause larger H–C temperature difference (more energy drop)

(disadvantage!)

OR larger Flow Rate W

IF increase W, all the Ws decrease and ΔT↓ for same power

⇒ more losses and/or more pumping power



$CW(T_i - T_o) = P$

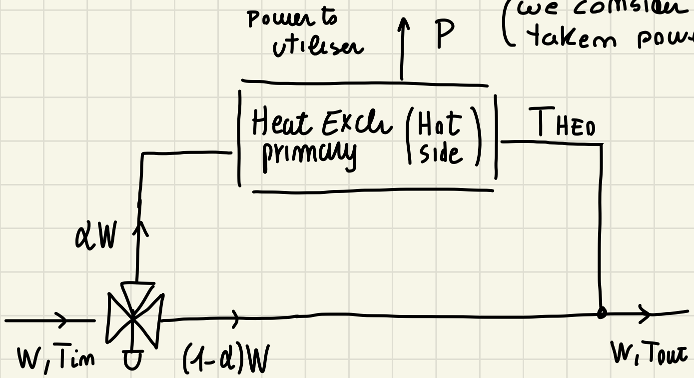
{ @same P but less W → less To ! }

"STATIC" argument in the disfavour of such a topology

we study a static behaviour problem...

- About control : Focus on a utiliser

(we consider the taken power an exogenous disturbance)



{ you may have integrating flow control → with sensors.. devices with positioner, to fix W request }

$C :=$ heat capacity of HE primary side

balance:

$$\underbrace{C \dot{T}_{HEO}}_{\simeq \dot{E}_{HEO}} = \alpha W \cdot c \cdot (T_{in} - T_{HEO}) - P$$

$\dot{T}_{HEO}$: outlet as state var.

c: Fluid specific heat

PROBLEM 1:

$$\dot{T}_{HEO} = -\frac{1}{C} c W \alpha T_{HEO} + \frac{1}{C} c W \alpha T_{in} - \frac{1}{C} P$$

α: control input → to decide how much energy

W: controlled by pumping central, $W \simeq$ constant (water always circulating, never stop) even if nobody take it

T_{HEO}: STATE VAR.

αT_{in}: DISTURBANCE (*) — disturbance times state N.L

} non linear system

"input times state" non linearity

(*) T_{in} disturbance lead to PROB. 2 ⟹

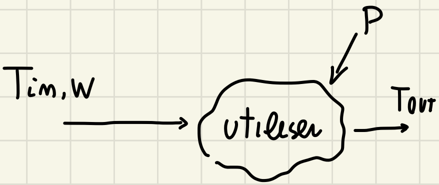
PROBLEM 2. When the i-th taken power changes, so does the i-th T_{OUT}, hence the $(i+1)$-th T_{IN}

$\Downarrow$

(upstream disturb me changing T $\rightsquigarrow$ becoming my inlet!)
(i OUT) (i+1 IN) disturb!

- Summing up :

(inlet Power from outside)



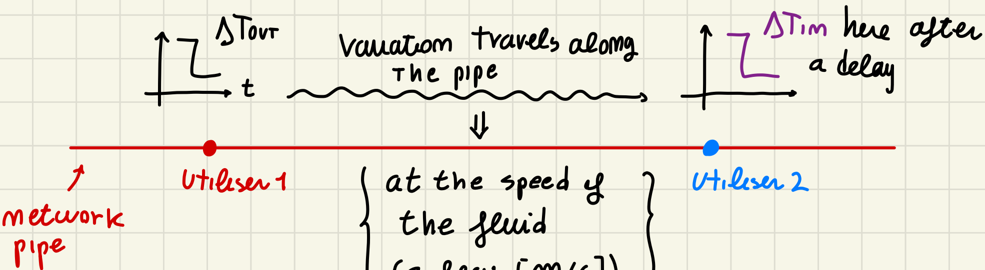
One can attempt to operate so as to maximize the exchange efficiency. But in any case at steady state

{ You can make changes on secondary side (W, T..) } $\leftarrow$ $cW(T_{in} - T_{out}) = P$

What happens then along the circuit ?

Variation travels along the pipe

$\Downarrow$



{ at the speed of the fluid (a few [m/s]) }

$\hookrightarrow$ disturb propagate along the pipe

$\uparrow$ because of technical reasons, sizing of pipe such fluid < 2m/s speed

some secs to travel all

$\Downarrow$

as consequence...

... "dynamic" arguments in the disfavour of this topology

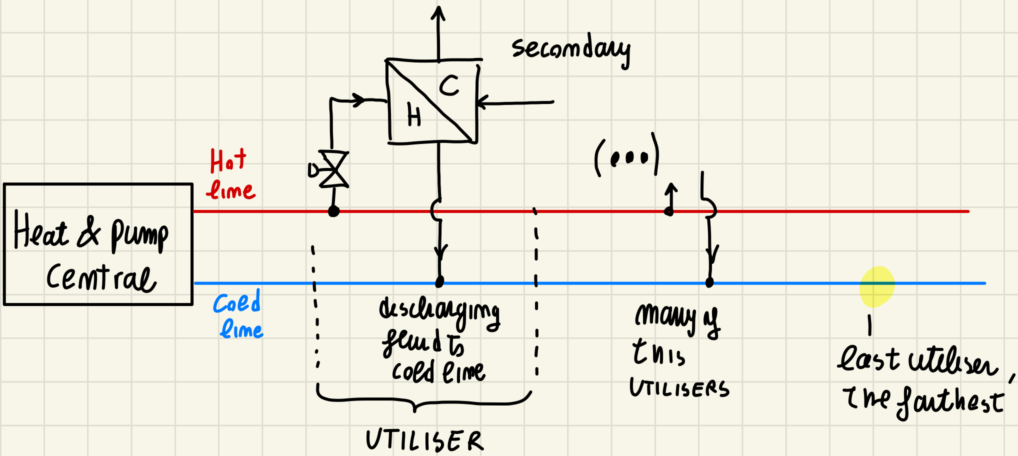
- no means to compensate timely for upstream-generated disturbances ($\Delta T_{OUT} \rightarrow \Delta T_{IN}$) if not by transmitting signals (downstream)
  ↓ imply costs + all ask to same authoroty
  ↳ you can have compatibility issue !

- delays can be relevant

- N.L system both regarding control & disturbance inputs

Only advantage : minimum amount of piping

• **IDEA 2**: twin-pipe network (practically the only used topology)



• steady-state T profile along the network

H

↑ on hot side only terrain losses! ↓ taking fluid @ same Temp if no loss..

Just losses to terrain

↑ all utilisers take at (ideally) the same T

(...) topologically there can not be a connection

drop when flow rates from PRIMARY outlets mix in

C

(PROS)

↖ the amplitude of these drops is irrelevant as long as one can control T in point H

↓

[as long as Heater has enough power to restore required T for utiliser, I don't care about amplitude]

---

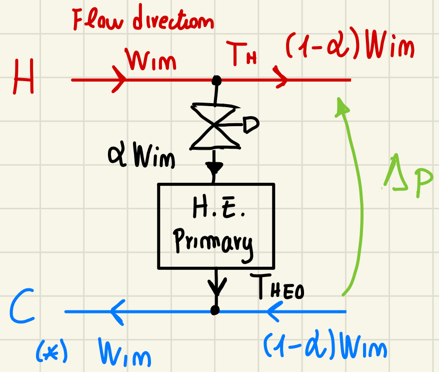
on this case: (If all valve closed.. there is NO CIRCULATION) ← { We don't need closure as long as somebody takes... }

we need some way on H&P to deal with it! → you need to shut down the pump if nobody take it! some way?

{ complex H&P control } ←

↓

NOTE: If nobody takes ⇒ No circulation : H&P control must cope with that (logic / storage) utiliser balance on this case



IF Δp is well controlled, the value easily governs α

$$\Longrightarrow P = \alpha W_{in} (T_H - T_{HEO}) \quad \text{(statically)}$$

↓

[NO MIX]

along delivery line H downstream means upstream for C

↑ further in the direction of H

↑

{ downstreams you can have other utilisers.. taking/restoring to cold line (*) (IT came back) }

IF the intake by utiliser i changes, utiliser $i+1$ (downstream along H) sees a FLOWRATE (not T) variation, and this is practically instantaneous (travels @ sound speed on fluid)

{ on IDEA 1, the upstream user disturb by changing T, while here flowrate changes instantaneously (T does not change) }

⟹ one Flow meter and the downstream utiliser knows about such a disturbance through the process (NO DATA transmission)

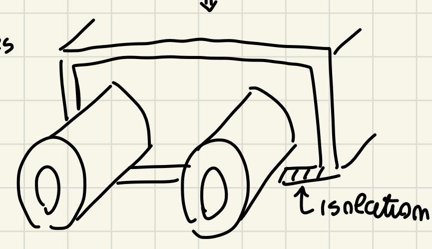
{ ↳ I don't care if utiliser i has equipment of different company... don't care if don't communicate }

Only disadvantage: twice the piping

⇒ however: components available

⇓

isolated pipes coupled, mounted (twin pipes)



CONTROL HEATING NETWORKS, CONTROL PROBLEMS!

CONTROL PROMPLEMS im HNs

→ indirect networks (using H.E between net/U)
While direct net are not lot used in distrib.

- im heating & Pumping stations

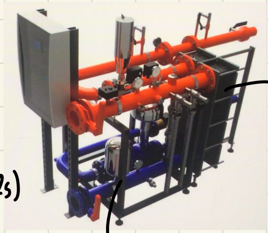
↓ CONTROL OF:

- outlet temperatine
- Δp across the outlet - inlet (H-C) flanges
- W through the network and/or the heating element

↑ always circulate a certain w to mantain a good efficency

- im utilisers (SUBSTATION) ↳

↓ CONTROL OF:



primary & secondary

heat exchangers (plates H.E)

expansion vessel..

- secondary outlet T
(typically care of local controls)

↑ NOT under the authority of the Heat Net manager → (manager guarantee T and you can take a certain w!)

- primary outlet T IF possibee
(IF utiliser is taking a certain Power, controlling II temp, authority of primary one)
(sometimes limit controllers)
↳ if below a certain threshold → safety override...

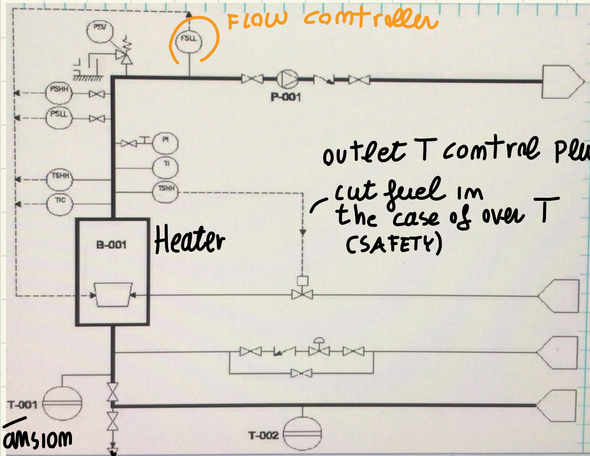
... Examples... ⇒

Examples

- **Ex 1**

Heating & Pumping

Flow controller



H to Network

outlet T control plus, cut fuel in the case of over T (SAFETY)

Heater

{ NO Δp control NOR flow(w) control through heater independent from network }

Fuel

make-up (for water supply)

C From Network

expansion vessel

⇓

on Modelica >ThermSys_Generation > Hcentral_control_case_002

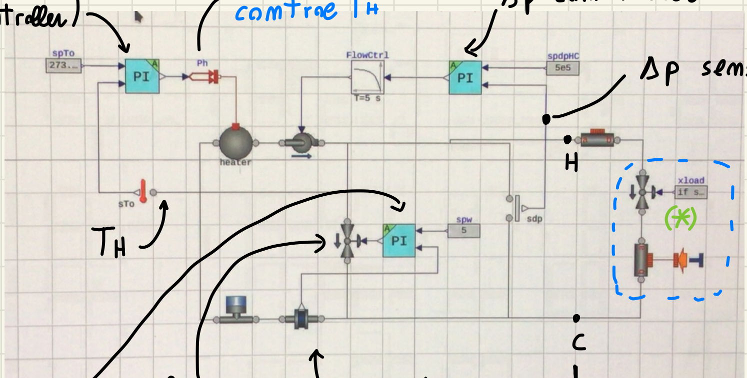
(TH controller)

act on fuel to control TH

Δp controller

{ control Δp acting on the pump }

Δp sensor



H

minimal network (closing the loop)

(*)

T_H

C

heater Flow control

valve recirculating through heater

Flow sensor

station ←

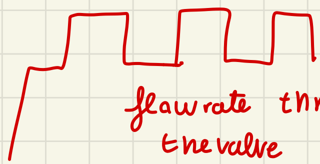
recirculate part of flowrate by heater saving the date if nobody take it..

← OR I'll see an enormous overpressure, so pump shut down until W gives me required Δp (SAFE!)

simulating... looking small set points and process variable
they follow very well!
↓
good behaviour   almost perfect with small variation

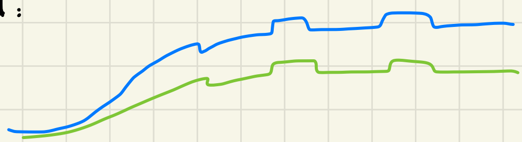
takes time to heat up cold met.. → after some Δt, behaves well as a huge capacity!
↓
like having a big capacitor...
Natural decoupling

and as output valve load (*)



while on the load:

load fluid stream
T↑ power↓



⇑
station control structure!

2/3 loops control   external loop to the network

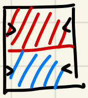
complex structure, not easy to solve by T.F computation,
understand how to properly control → pressure, temp, flow control..

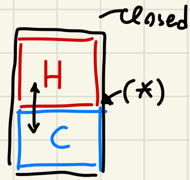
• One can use a **STORAGE ELEMENT** to decouple generation & utilisation

Typical layout with a $\underbrace{\text{stratified storage tank}}_{\text{something in which you store cold water in one side..}}$

on Modelica..

you have some examples with stratified tank



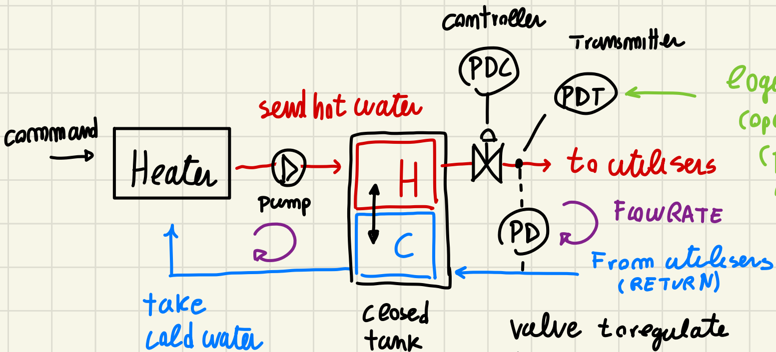


[amount of Hot and Cold can be different]

(*) idealized... no crisp separation, T values continuously along vertical axis (NO STEP function as ideal)

↓

if correct design → we have "stratification" occur (it takes a long time to regime)



logic required here (open the valve..)

(plus, actuation can be more than just a valve!)

principles = heater control has task to maintain a certain state of charge (represented by some Temp) while utiliser take and give back without coupling

flow Rates don't necessity balance..

circulation idraulically..

↓

you can take hot, remove cold → T↑

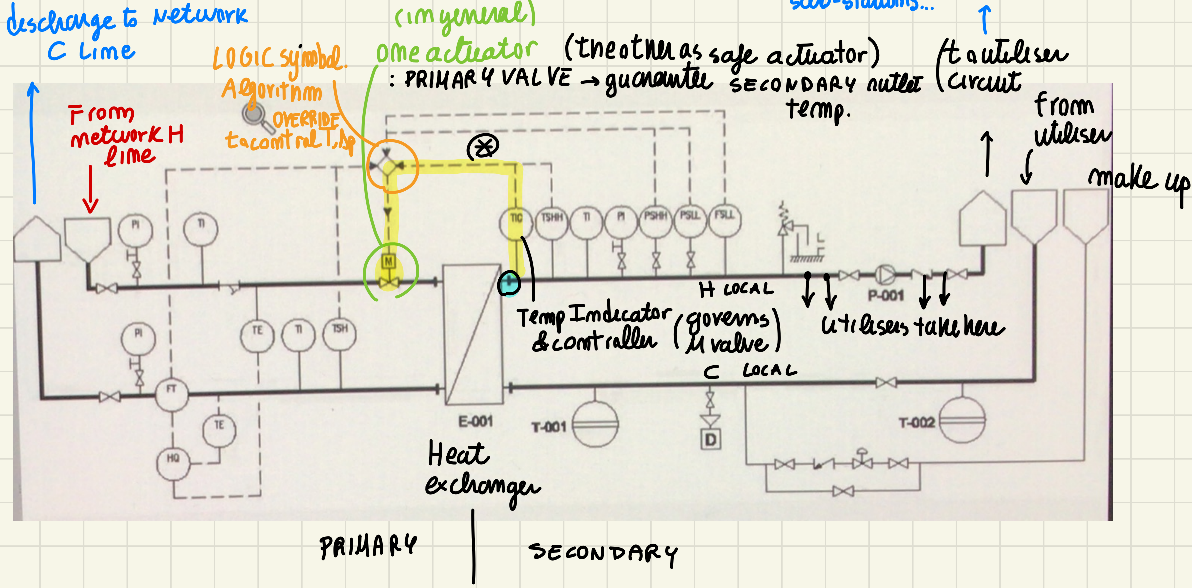
OR take off hot, give back cold → T↓ (more cold water..)

as long as held a certain level → utilisers can take → than restore by heater

when convenient to load the storage you can OVERLOAD by putting more water inside
↓
example of how to solve the problem of schemes without storage

- and you can decide that if heater on → pump at constant flow rate
→ have desired flow rate through heater.. as long as restore hot water enough for you ok
↓
{ without need to control at same time sp and flow rate through heater }
NO coupling! → it's like having a good capacitor

- Substation controls (example)



⊗ main loop: use valve (M) for secondary outlet T

(rejecting disturbance by secondary loop) → requiring more flow rate

you may have OVERRIDE → if valve closes too much, ΔT↑, W↓ → T return ↓ low..

main loop → to control secondary outlet temp... acting on primary valve
+ overrides (logic)

Summing up: multi-level control scheme that relies on decoupling by means of storage (including the piping) and different time scales

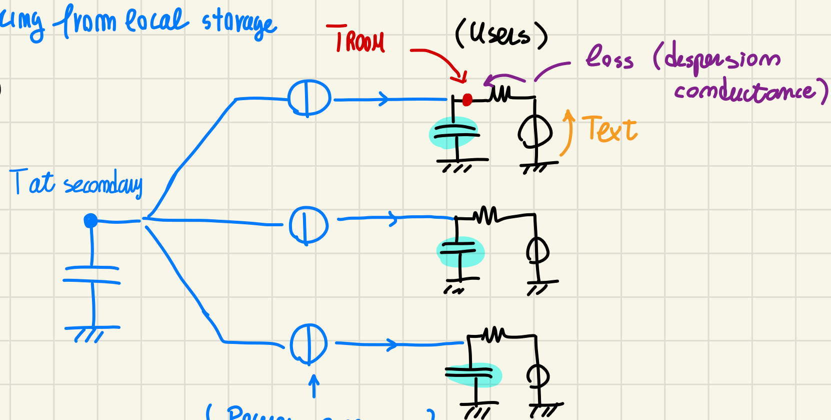
↓

VERY simplified equivalent
(like having a bunch of capacitors) dispersing heat

all users taking from local storage

(as on drawing)

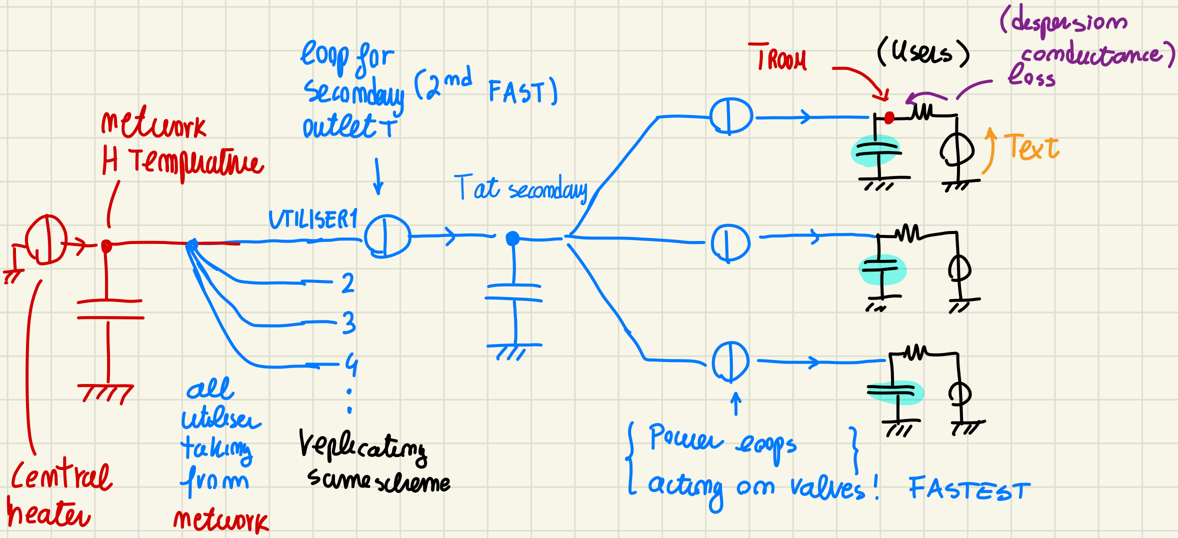
T secondary → as inlet T towards the elements (equivalence)



Power loops acting on valves!

⇐ FASTEST! loop

measuring the released power you can use devices measuring ΔT, W
you take power → so close loop on valve to get a certain power
⇒ fast local power loop (command POWER)



↑
purpose of controlling H Temp of net!
central heater power loop (SLOWEST)

↑ sizing properly separating the bandwidth you obtain it!
↓
bounch of capacitors receiving a controlled power

(ideal technology) ↗
widespread usage of it
in CONTROL of heat system

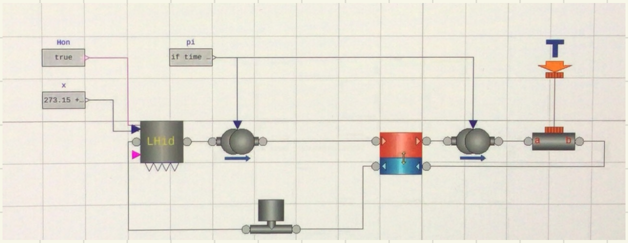
→ constant voltage on controller time scale.
respect my capacitor..

↑

AUTOMATION LAYER

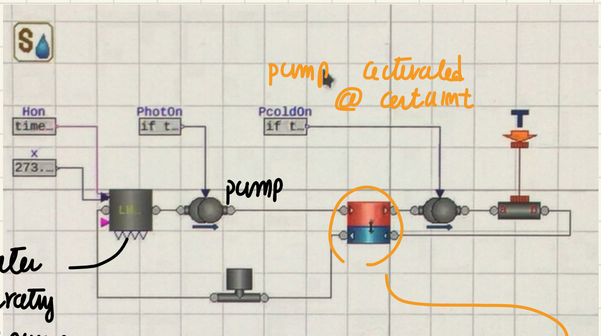
above it... we have optimization layer to take control decisions
↳ profiles to give to controllers (set point)

Modelica > Therm Sys_Transport > Stratified .. _ Case _ 001



utilisation of a storage tank

Case _ 003



heater activating the pump

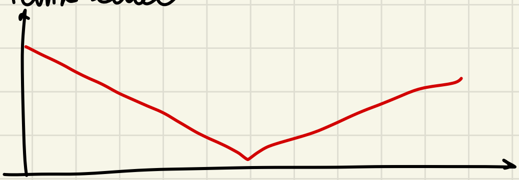
distributed parameter system tank?

... modelled as..

⇓

↓ simulate...

tank level



load tank (more cold water) than load pump

when no cold water & try to take → full of HOT

(energy balance) → ||

full of COLD

```
if lcold<0 and coldIn.w+coldOut.w<0 then /* all hot */
   der(Mcold) = 0;
   der(Ecold) = 0;
   der(Ehot)  = hotIn.w*actualStream(hotIn.h)+hotOut.w*actualStream(hotOut.h)
               +coldIn.w*actualStream(coldIn.h)+coldOut.w*actualStream(coldOut.h);
   coldIn.h   = cp*Thot;
   coldOut.h  = cp*Thot;
   hotIn.h    = cp*Thot;
   hotOut.h   = cp*Thot;
elseif lcold>H and coldIn.w+coldOut.w>0 then /* all cold */
   der(Mcold) = 0;
   der(Ecold) = coldIn.w*actualStream(coldIn.h)+coldOut.w*actualStream(coldOut.h)
               +hotIn.w*actualStream(hotIn.h)+hotOut.w*actualStream(hotOut.h);
```

```
   der(Ehot)  = hotIn.w*actualStream(hotIn.h)+hotOut.w*actualStream(hotOut.h)
               -Gmix*(Thot-Tcold);
   coldIn.h   = cp*Tcold;
   coldOut.h  = cp*Tcold;
   hotIn.h    = cp*Thot;
   hotOut.h   = cp*Thot;
end if;
```

Knowing the two capacities.. → knowing volume, level.. half H/C..
(I parametize the system)

↓ I ask how Δt target
full temp

to parametize resistance

(measured by experiment)

modelling trick → to reduce the model (simple model)

to obtain a fast simulation