Balancing a domestic hot water distribution

In domestic hot water distribution, temperature of water in the pipes drops significantly when consumption is low or zero. As a result, people get disappointed to wait so long time to obtain hot water when required. Moreover, below 55°C, the bacteria (Legionella) proliferate dangerously.

To keep the water hot, a permanent circulation is maintained in pipes to compensate for heat losses. A circulation pump is therefore installed guaranteeing a minimum flow q_1 in the loop (Fig 1)

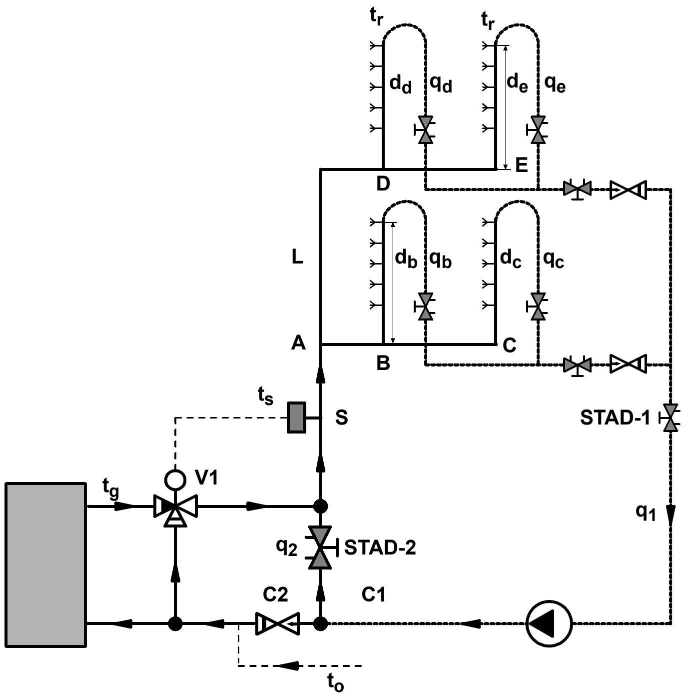

Fig 1: A circulation pump maintains the temperature of water distribution.

Determination of circulation flows

If we accept the most unfavoured user is supplied at a temperature of ΔT below the water supply temperature ts, we can calculate the minimum circulation flow q_1.

$$q_1 = \frac{0.86\, P_m}{\Delta T}$$

where:

- P_m: Heat losses in Watt of the **supply** pipes.
  Pipes concerned: $\sum L + \sum d$ = [SA+AC+AE] + [$d_b+d_c+d_d+d_e$].
- ΔT: Admissible temperature drop (5K).
- q_1 : In l/h.

The supply pipes are generally insulated.

For a ΔT of 40K between the water and the ambience, the heat losses are situated around 10W/metre, independently of the pipe diameter. This is valid if the thickness of the insulation in mm (λ=0.036) equals 0.7 x external pipe diameter (without insulation).

Obviously the best procedure is normally to make calculation according to the insulation really installed. A much better estimation can be done using the following empirical formula:

$$P = \frac{\Delta T}{40}\left(3 + \frac{5\,de}{3.5 + \frac{0.036\,I}{\lambda}}\right)$$ with P in W/m, de external pipe diameter in mm (without insulation)

I = thickness of the insulation in mm, λ in W/m.K.

For $\Delta T = 40$ and $\lambda = 0.036$ (Foam glass), this formula becomes :

$$P = \left(3 + \frac{5\,de}{3.5 + I}\right).$$ with de < 100 mm.

<u>If the distribution is well balanced</u>, a wrong estimation of the total flow does not seem dramatic. If the flow is reduced by 50%, and for a supply water temperature of 60°C, the most unfavoured user will have 51°C instead of 55°C. In this case however, the risk of proliferation of legionella increases.

Hereafter, in the examples, we will consider the following hypothesis:
ts = 60°C, tr = 55°C and P = 10 W/metre. Consequently:

$$q_1 = \frac{0.86 \times 10}{(60 - 55)} (\Sigma L + \Sigma d) = 1.72\ (\Sigma L + \Sigma d)$$

The total flow being known, we have to calculate the flow in each branch. Starting from point S (Fig 1) where the temperature sensor is located, the water temperature at the inlet of branch A can be calculated.

$$t_A = t_S - \frac{0.86\,P_{SA}}{q_1}$$ with P_{SA} = heat losses section SA.

For the first branch, the pipes heat losses are $Z_{AC} = P_{AC} + Pd_b + Pd_c$. So we can calculate successively the temperatures at the nodes and the required flows as shown hereafter.

$q_{AB} = \frac{0.86\ Z_{AC}}{t_A - 55}$	$t_B = t_A - \frac{0.86\,P_{AB}}{q_{AB}}$	$q_b = \frac{0.86\,P_{db}}{t_B - 55}$
$q_{BC} = q_{AB} - q_b$	$t_C = t_B - \frac{0.86\,P_{BC}}{q_{BC}}$	$q_c = \frac{0.86\,P_{dc}}{t_C - 55}$

The flow $q_{AD} = q_1 - q_{AB}$, so we can calculate t_D and the second branch as above. This systematic and simple procedure can be used even for complicated systems.

Knowing the flows, the plant can be balanced normally, using the Compensated Method or the TA Balance Method.

For a rough estimation of the pump head, the pressure losses in the supply pipes can be neglected. Considering just the return pipes, we suggest H [kPa]= 10+0,15 (L_{SE}+de) +3 kPa for each balancing valve in series (3 in this example). L_{SE} is the length of the return pipe that we suppose to be equal to the length of the supply pipe.

If L_{SE}+de = 100 metres for example, H = 10+15+9 = 34 kPa. In this formula we consider 10 kPa pressure drop for the exchanger, check valve and accessories and a pressure drop in the return pipes of 0.15 kPa/m.

Considering just the branch AC in figure 1, but with 4 distribution circuits, we can use the above formulas to calculate the flows. These formulas can be translated in another form, more suitable for a systematic calculation. This other form is explained based on an example hereafter.

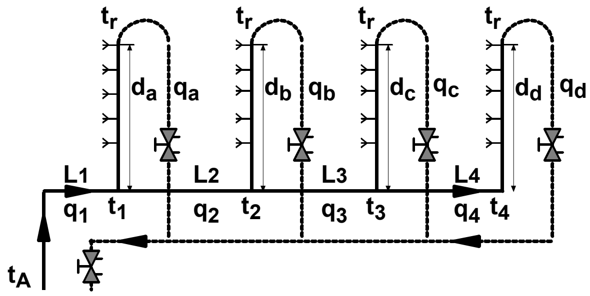

Fig 2: One branch of the distribution with 4 circuits.

Following lengths of pipe (in metres) have been adopted:

L_1	L_2	L_3	L_4
40	25	20	35
d_a	d_b	d_c	d_d
10	9	11	12

Pipe lengths in metres.

The temperature at the supply of the branch is t_A and the expected return temperature is t_r. For instance t_A = 59°C (considering 1°C loss between S and A in figure 1) and t_r = 55°C.
For a $\Delta T = t_A - t_r$ = 4K, and heat losses per metre of pipe equals 10 W/m in average, the total flow q_1 is:

$$q_1 = 0.86 \times 10\ (\sum Li + \sum di)\ /(t_A - t_r)$$

so

$$q_1 = 2.15\ (40+25+20+35+10+9+11+12) = 348\ \text{l/h}.$$

$$\text{and } t_1 = (t_A - 8.6\ L_1/q_1)$$

In order to obtain a more convenient formula, let us transform it in the following way:

$t_1 = 8.6((t_A - t_r)/8.6 - L_1/q_1)+t_r$. We call $(t_A - t_r)/8.6 = \lambda$ and $D_1 = \lambda - L_1/q_1$

Finally $t_1 = 8.6\ D_1 + t_r$. In this example $\lambda = 0.465$.

$D_1 = \lambda - L_1/q_1$	$q_a = d_a / D_1$	$q_2 = q_1 - q_a$	$t_1 = 8.6\ D_1 + tr$
$D_2 = D_1 - L_2/q_2$	$q_b = d_b / D_2$	$q_3 = q_2 - q_b$	$t_2 = 8.6\ D_2 + tr$
$D_3 = D_2 - L_3/q_3$	$q_c = d_c / D_3$	$q_4 = q_3 - q_c$	$t_3 = 8.6\ D_3 + tr$
$D_4 = D_3 - L_4/q_4$	$q_d = d_d / D_4$		$t_4 = 8.6\ D_4 + tr$

Formulas used.

These formulas can be extended the same way for more circuits. We have used them to calculate the flows. *Calculations of the temperatures are not necessary but are given for information*.

D_1=0.465-40/348=0.351	q_a=10/0.351= 29	q_2=348-29=319	t_1=8.6x0.351+55=58.0
D_2=0.351-25/319=0.272	q_b= 9/0.272= 33	q_3=319-33=286	t_2=8.6x0.272+55=57.3
D_3=0.272-20/286=0.202	q_c=11/0.202= 54	q_4=286-54=232	t_3=8.6x0.202+55=56.7
D_4=0.202-35/232=0.051	q_d=12/0.051=232	q_4 is obviously = q_d	t_4=8.6x0.051+55=55.4

Numerical calculations.

Let us point out that the last circuit requires 67% of the branch flow while the first circuit requires only 8%. On the contrary, if the distribution is not balanced, the first circuit will receive more flow than the last circuit.

A rough estimation of the required pump head is:

$$H=10+0.15\ (40+25+20+35+12)+3\times 3=39\ \text{kPa}.$$

Balancing domestic hot water distribution with TA-Therm

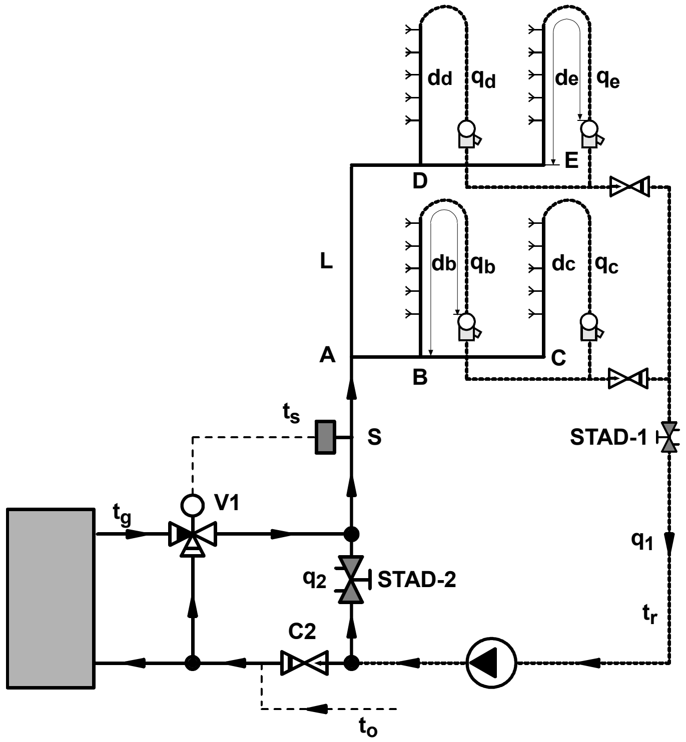

Fig 3: The return temperature of each branch is maintained automatically.

The return of each circuit is provided with a thermostatic valve (TA-Therm) that maintains the return water temperature at an adjustable value. A thermometer may be incorporated in the TA-Therm to measure the temperature obtained. The circulation flows are calculated (See figure 2) to size the return pipes and the pump. For the most remote circuits, the pump head is roughly estimated as follows (for TA-Therm with a Kv=0.3):

Circuit q_e : $H=10+0.1\ (SE+d_e)+(0.01\ q_e\ /0.3)^2+3$.
Circuit q_c : $H=10+0.1\ (SC+d_c)+(0.01\ q_c\ /0.3)^2+3$.

The highest value of H is adopted.

The Kv of 0.3 given above corresponds with a deviation of 2°C, of the water temperature, relatively to the set point of the TA-Therm.