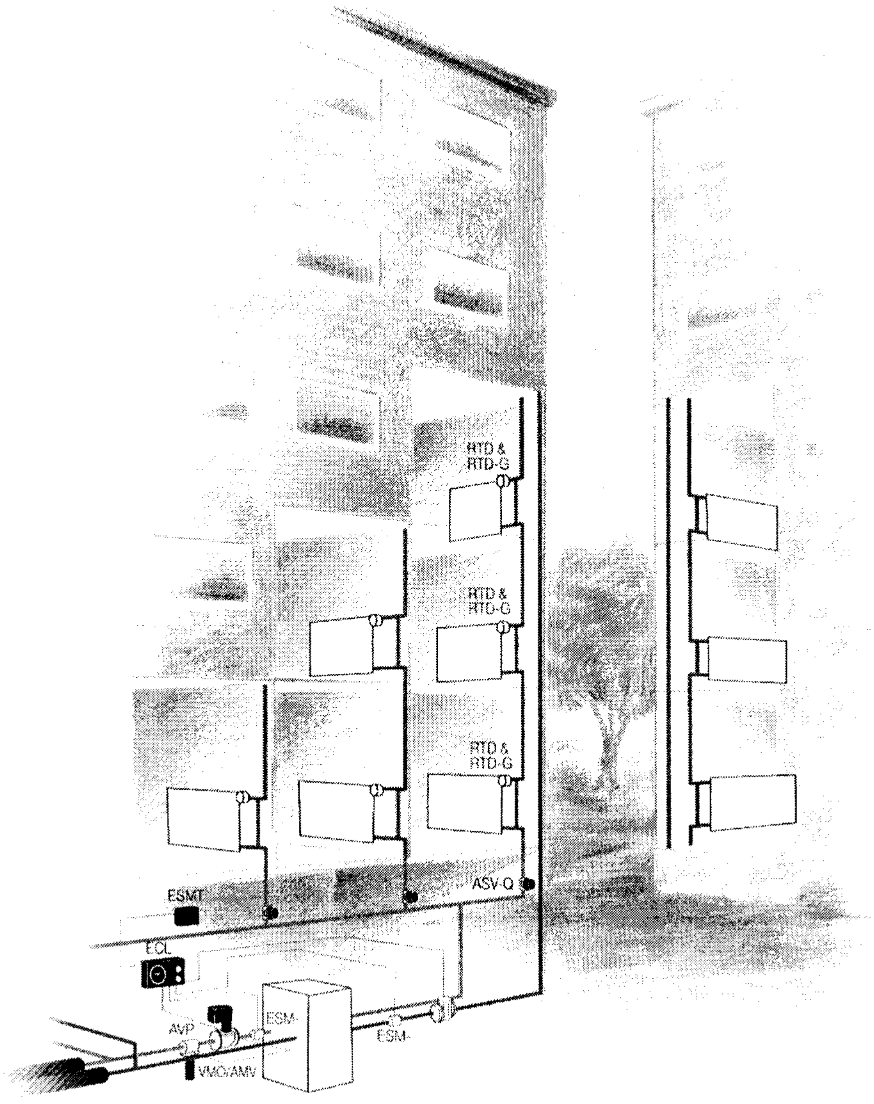
Design of Radiator/Convector Configurations in a One-pipe and a Two-pipe Installation

- including clarification of the consequences of direct renovation of existing one-pipe installations using radiator thermostats.



Contents

Design of Radiator/Convector Configurations .... p. 3

Conclusion .... p. 9

Addendum .... p. 10

Explanation of symbols .... p. 14

Appendices .... p. 15

Design of Radiator/Convector Configurations in a One-pipe and a Two-pipe Installation

In many countries, one-pipe water/heating installations have been used for many years. Often these installations provide no or only partial radiator bypass.

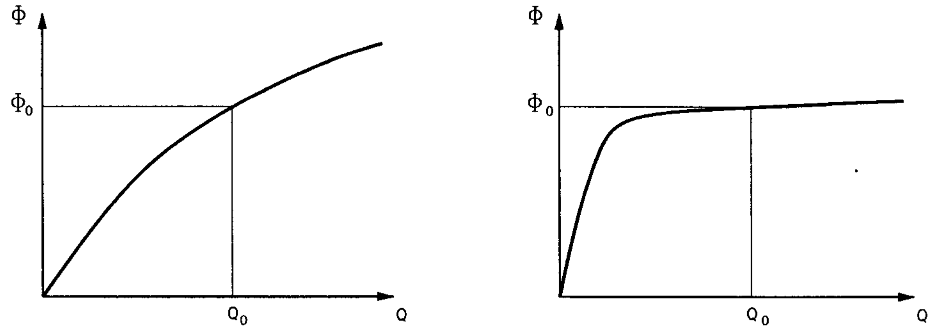
These types of installation were designed at times when energy and material consumption were not important, and when - because there were no good preset valves - it was difficult to make two-pipe installations, especially in high-rise buildings.

Today energy conservation is extremely important.

This has led to a strong trend away from one-pipe installations without a bypass towards two-pipe installations. However, it is likely that for practical reasons one-pipe installations with a bypass will continue to be made during a transition phase, since these installations can be automated using energy-saving radiator thermostats.

These statements are supported by developments in Western Europe, where two-pipe installations now reign almost supreme. Two-pipe installations have the following advantages over one-pipe installations:

- Full control of the entire water quantity in a two-pipe installation, while in a one-pipe installation it is not possible to control the bypass flow. This means that in a one-pipe installation there is always a heat loss from the bypass flow, while in the two-pipe installation there is no water flow when the radiator thermostat is turned off, which means that there is no heat loss either.
- Two-pipe installations are less sensitive to sizing errors than one-pipe installations, as can be seen from the figures below.



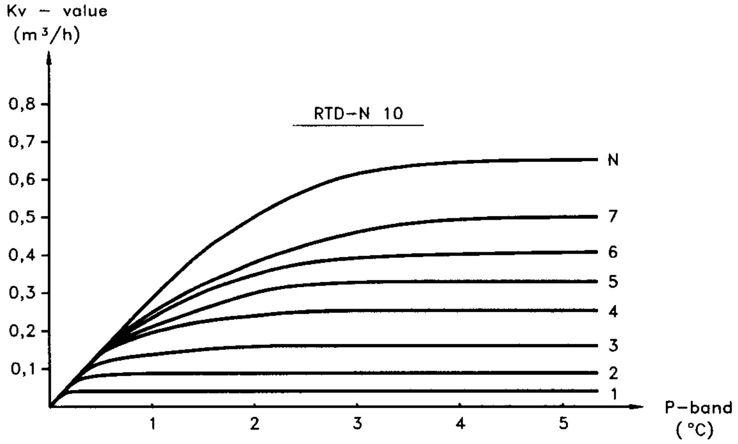
Radiator curve for two-pipe installation

Radiator curve for one-pipe installation

As can be seen, two-pipe installations offer a broad scope for regulation in the main regulation area (steep radiator curve), while one-pipe installations have a narrow scope for regulation in the main regulation area (flat radiator curve). This means that in a one-pipe installation extra water in addition to the sized volume does not really lead to any extra heat transmission, so in a one-pipe installation it is difficult to compensate for undersized radiators by increasing the water flow.

In a two-pipe installation, however, compensation for undersized radiators is easy, since extra water in addition to the sized water quantity will generate extra heat. This, however, means that in a two-pipe installation it is important to be able to control the water quantity, since otherwise an unbalance can easily arise in the installation. The most flexible control of the water quantity is presetting of the thermostatic radiator valve (e.g. Danfoss preset valves, type RTD-N).

Presetting RTD-N



- Less material consumption in a two-pipe installation than in a one-pipe installation. The total radiator surface, pipes and valves are often larger in a one-pipe installation than in a two-pipe installation. Larger pipes and valves may, at the same time, lead to an unintended, substantial loss of heat.

- In two-pipe installations, the radiator surfaces are nominally of equal size, while the radiator surfaces in a one-pipe installation need to increase across the system, since the flow temperature to the individual radiator decreases. Different sizes of radiators may be unpractical (the "Addendum" gives an example of the right way to size radiators for one-pipe installations).

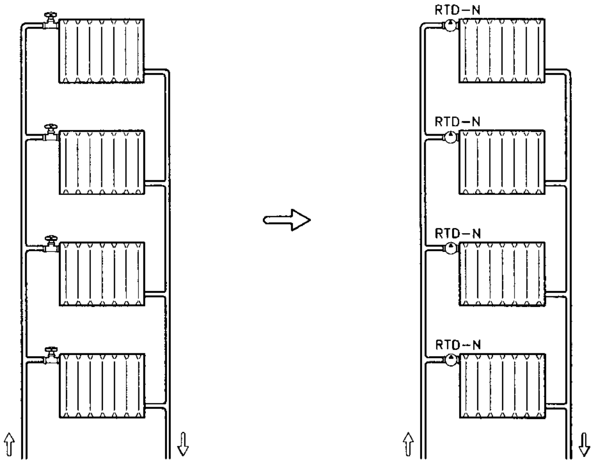
- In two-pipe installations a small heat load leads to high temperature drops, while a small heat load in a one-pipe installation involves small temperature drop, since all the water is led through the bypass. This means that the flow temperature in a one-pipe installation must generally be as low as possible - depending on local requirements - since otherwise the return temperature becomes too high, leading to excessive heat loss from the pipes. Regulation of a one-pipe installation thus requires the use of a highly accurate, central regulation valve, which in practice is very difficult because of different time constants. A two-pipe installation, on the other hand, has a positive feature in that if the flow temperature is too high, this simply results in the radiator thermostats regulating even faster and thus even more energy-economically.

In the light of this, it is necessary to distinguish between new construction work and renovation work when making future heating installations more energy-friendly, including the fitting of radiator thermostats in heating installations.

New construction work; renovation work

New construction work: Given the advantages of the two-pipe installation over the one-pipe installation, the best solution - in the case of a new construction - is a two-pipe installation combined with preset valves. To reduce the risk of noise in the installation, it is recommended to mount a Δp regulator on each pipe.

Two-pipe installation



If the change to a two-pipe installation is still premature and the one-pipe installation is to be continued, it is important to establish a bypass, since that facilitates subsequent automation.

Renovation:

For two-pipe installations: follow the procedure under "New construction work".

For one-pipe installations: Two configurations of radiator installations are relevant:

1) one-pipe installation with bypass;
2) one-pipe installation without bypass / partly without bypass.

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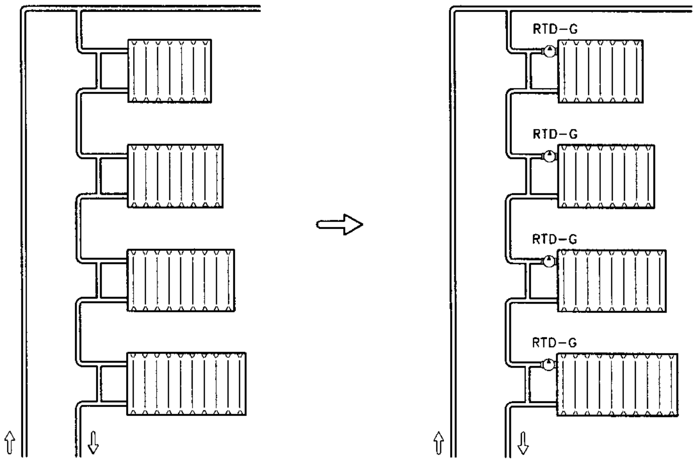
1) One-pipe installation with bypass

In this case, radiator thermostat valves, type RTD-G, with a high k_v-value can be mounted without any measures being taken. The k_v-value of these valves is so high that the limited resistance of the valve has no influence on the water flow to the radiator. To divide the heat between the pipes a volume limiter (e.g. Danfoss type ASV-Q) should be mounted on each pipe.

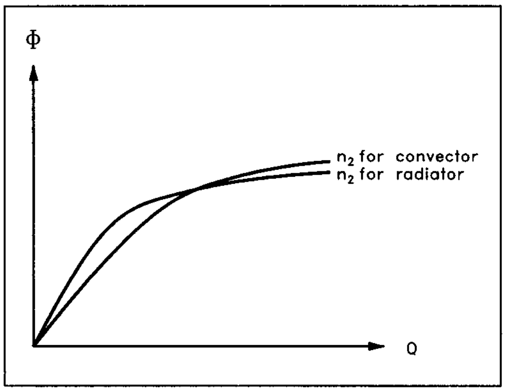
One-pipe installation with bypass



2) One pipe-installation without bypass / partly without bypass

Until now the general belief in the heating business has been that if an existing one-pipe installation is to be renovated *without* the use of a bypass, it is important to distinguish between radiators (plate iron and cast iron) on the one hand and convectors on the other. This view is based on the fact that the radiator exponent n_2 is higher for convectors than for radiators, i.e. it affects heat emission.

This view is entirely correct, as shown in the below figure.



The above figure makes it clear that in the case of small water quantities (= high temperature drop) the heat emission from convectors is *smaller* than the heat emitted by radiators. Also, it can be seen that in the case of large water quantities (= small temperature drop) - which is so characteristic of one-pipe installations - the heat emission from convectors is *greater* than the heat emission from radiators.

The reason why it was previously considered necessary to distinguish between convectors and radiators is that convectors were assumed to provide poorer heat emission than radiators. On the basis of the above figure, this can be seen to be entirely false!

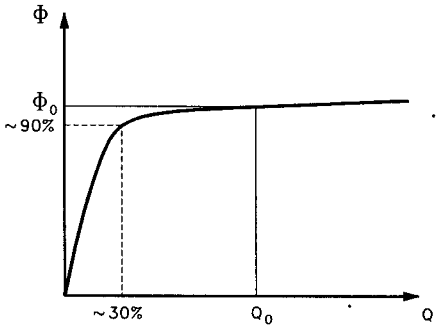
On the contrary, convectors in a one-pipe installation will generate *more* heat than radiators.

The heating business also believed that the k_v-value of a convector is so much smaller than the k_v-value of a radiator that capacity problems arise when installing a thermostatic radiator valve. Measurements made at Danfoss show that the k_v-value of a traditional Eastern European convector $k_v \sim 7.0\ m^3/h$, which is a magnitude that causes no problems whatsoever in the subsequent installation of radiator thermostats.

The overall conclusion is that it is not necessary to distinguish between radiators and convectors when renovating a one-pipe installation.

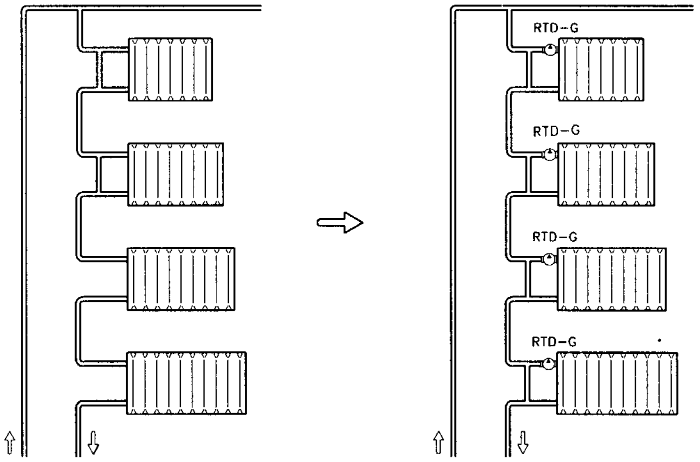
Renovation of one-pipe installations without a bypass has to start with the establishment of a bypass on all radiator elements. Establishing a bypass generates a higher k_v-value on the radiator elements, i.e. a lower pump resistance. When the radiator thermostat is closed, the resistance through the bypass circuit is slightly higher than the resistance through the radiator element before the bypass was established. However, the difference is so small that it is seldom necessary to establish extra pump pressure. This bypass must be sized one dimension smaller than the main pipe. Subsequently, a thermostatic radiator valve, type RTD-G, is mounted in the main pipe dimension in front of every radiator/convector. This results in a radiator share (water quantity) of ~ 30% of the previous value (calculations: see Addendum).

Radiator curve for a one-pipe installation



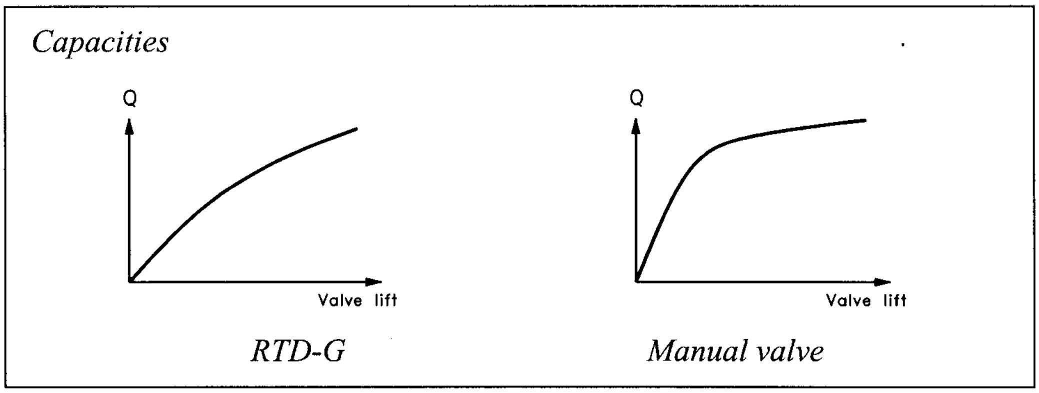
As can be seen from the graph, a water quantity of 30% of the previous level means that heat emission is reduced by ~ 10%. A reduction of 10% of the heat emission will give no problems in practice, since radiator surfaces are often oversized. In any case windows and doors should be weatherstripped, and subsequent insulation would reduce the heat requirement considerably. For the purpose of distributing the heat between the pipes, a volume limiter (e.g. Danfoss type ASV-Q) should be mounted.

One-pipe installation without bypass



Manual regulation

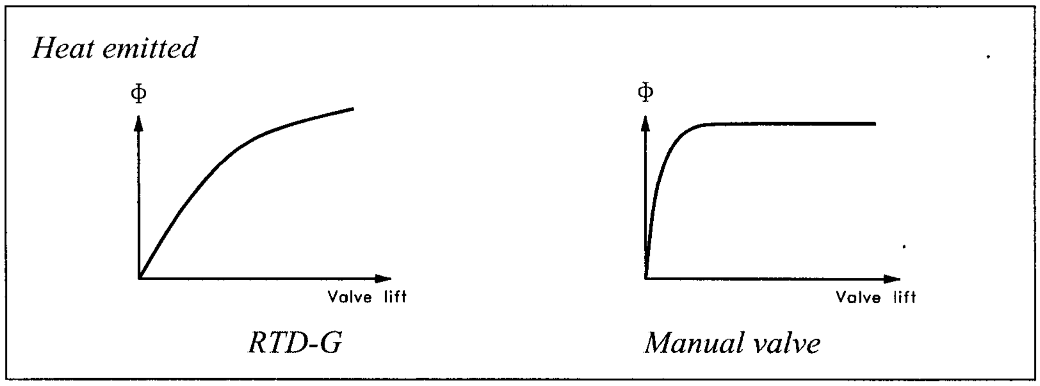
In the heating business some still advocate that manual regulation valves remain in the system. But the fact that the radiator graph of a one-pipe installation is steep around the closing position, after which it levels out, also means that manual regulation is almost impossible. Manual valves typically have a very steep valve characteristic in themselves in relation to thermostatic radiator valves.



Capacities

RTD-G *Manual valve*

The interaction between water quantity (Q) and heat emitted (Φ) is as follows: $\Phi \sim Q^n$.



Heat emitted

RTD-G *Manual valve*

As can be seen, manual regulation is in practice an on/off regulation, since even a modest opening of the valve generates a very substantial water quantity. In a one-pipe installation, the on/off effect will be stronger than in a two-pipe installation, since the radiator graph of a one-pipe installation is steeper than in a two-pipe installation around the closing position. In practice this means that manual regulation of a one-pipe installation is - to all intents and purposes - impossible. Manual regulation thus results in:

- no energy saving
- risk of poor comfort and poor hydraulic balance because of the above.

Conclusion

Danfoss has the right solution for all types of radiator installation - for new construction work and renovation work alike. It is Danfoss' belief that all new radiator installations should be two-pipe installations; however, the choice between a one-pipe and a two-pipe installation is often a matter of tradition. If a one-pipe installation is chosen, a bypass should, however, be mounted on every radiator - this facilitates subsequent fitting of thermostatic radiator valves on the radiators. Also, in such a case the radiators have been designed for the water quantity in question and thus have a fully adequate capacity.

Even if two-pipe installations are recommended rather than one-pipe installations, it must be pointed out that substantial energy savings can be achieved by mounting thermostatic radiator valves on a one-pipe installation. In particular if the job at hand is to renovate existing one-pipe installations, the required investment will pay off quickly, since the costs of such renovation are small.

Energy conservation is also enhanced by placing heat distribution meters on every radiator. This will induce the individual resident to make a deliberate effort to cut down on heating consumption, in addition to providing a fairer distribution key.

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Addendum

Example of renovation of one-pipe installation

Assumptions

- One-pipe installation with upper distribution;
- 6 storeys, 6 radiators;
- 2 top radiators have bypass, 4 bottom radiators have no bypass;
- No regulation.

Installation data

- Total heating requirement $\Sigma\Phi = 6000$ kcal/h;
- Heating requirement of each room $\Phi = 1000$ kcal/h;
- Total temperature drop 95/70 = 25 °C;
- Assumption: Water distribution on two top radiators is $\omega = 0.30$;
- Assumption: Same temperature drop across each radiator element.

$$\Delta t_n = \frac{\Delta t}{n} = \frac{25}{6} \simeq 4\ °C$$

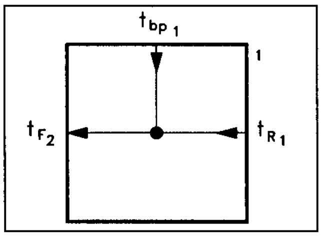
Temperature ratio and radiator surfaces can then be determined.

Data can be seen from Appendix 1.

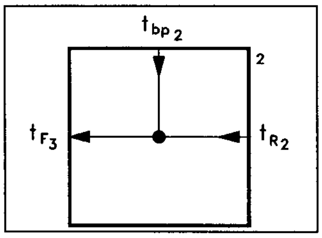
Calculation of temperatures

Calculation of total water quantity:

$$Q_{total} = \frac{\Sigma\Phi}{\Delta t} = \frac{6000}{25} = 240\ l/h$$



$$Q \times t_{F2} = Q(1 - \omega)\, t_{bp1} + Q \times \omega \times t_{R1;}$$
$$240 \times 91 = 240(1 - 0.3)\, 95 + 240 \times 0.3 \times t_{R1};$$
$$t_{R1} = 81.67\ °C.$$



$$Q \times t_{F3} = Q(1 - \omega)\, t_{bp2} + Q \times \omega \times t_{R2;}$$
$$240 \times 87 = 240(1 - 0.3)\, 91 + 240 \times 0.3 \times t_{R2};$$
$$t_{R2} = 77.67\ °C;$$

$$t_{R3} = t_{F4} \simeq 83\ °C;$$
$$t_{R4} = t_{F5} \simeq 79\ °C;$$
$$t_{R5} = t_{F6} \simeq 75\ °C;$$
$$t_{R6} = t_{F7} \simeq 70\ °C;$$

Calculation of radiator sizes

Assumption: Nominal temperature drop $t_{F0}/t_{R0} = 90/70 = 20$ °C. Calculation of radiator correction factor, K, on the basis of arithmetical temperature difference.

$$K_1 = \frac{\left(\frac{t_F + t_R}{2} - t_i\right)^{-1.3}}{\left(\frac{t_{F0} + t_{R0}}{2} - t_i\right)^{-1.3}} = \frac{\left(\frac{95 + 81.67}{2} - 20\right)^{-1.3}}{\left(\frac{90 + 70}{2} - 20\right)^{-1.3}}$$

$K_1 = 0.84$

$\Phi_{n1} = 0.84 \times \Phi_1 = 0.84 \times 1000 = 840$ kcal/h

$$K_2 = \frac{\left(\frac{91 + 77.67}{2} - 20\right)^{-1.3}}{\left(\frac{90 + 70}{2} - 20\right)^{-1.3}}$$

$K_2 = 0.91$

$\Phi_{n2} = 0.91 \times \Phi_2 = 0.91 \times 1000 = 910$ kcal/h

$$K_3 = \frac{\left(\frac{87 + 83}{2} - 20\right)^{-1.3}}{\left(\frac{90 + 70}{2} - 20\right)^{-1.3}}$$

$K_3 = 0.90$

$\Phi_{n3} = 0.90 \times \Phi_3 = 0.90 \times 1000 = 900$ kcal/h

$$K_4 = \frac{\left(\frac{83 + 79}{2} - 20\right)^{-1.3}}{\left(\frac{90 + 70}{2} - 20\right)^{-1.3}}$$

$K_4 = 0.98$

$\Phi_{n4} = 0.98 \times \Phi_4 = 0.98 \times 1000 = 980$ kcal/h

$$K_5 = \frac{\left(\frac{79+75}{2} - 20\right)^{-1.3}}{\left(\frac{90+70}{2} - 20\right)^{-1.3}}$$

$K_5 = 1.07$

$\Phi_{n5} = 1.07 \times \Phi_5 = 1.07 \times 1000 = 1070$ kcal/h

$$K_6 = \frac{\left(\frac{75+70}{2} - 20\right)^{-1.3}}{\left(\frac{90+70}{2} - 20\right)^{-1.3}}$$

$K_6 = 1.19$

$\Phi_{n6} = 1.19 \times \Phi_6 = 1.19 \times 1000 = 1190$ kcal/h

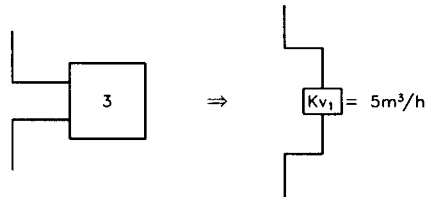
What happens then if thermostatic radiator valves are to be mounted on every radiator and a bypass is to be established on all the radiators?

Select bypass dimension, then calculate the new return temperatures from the different radiators. (Data can be seen from Appendix 2).

Selection of bypass

This is based on the assumption that the main pipe is DN 20 and that the bypass must be one dimension smaller (DN15). The intention is to obtain a radiator share (ω) of ~ 30% by establishing the bypass.

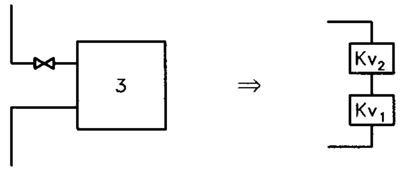
Before



A reasonable approximation of the k_v-value of a radiator incl. pipes is: $k_v \simeq 5$ m³/h.

Now insert a thermostatic radiator valve with a k_v-value = 1.80 m³/h (at Xp = 2 °K).

After mounting RTD-G 20



Total k_v-value after mounting of thermostatic radiator valve:

$$\frac{1}{k_v^2} = \frac{1}{k_{v1}^2} + \frac{1}{k_{v2}^2} \Rightarrow \frac{1}{5^2} + \frac{1}{1.8^2}$$

$k_v = 1.70$ m³/h

If the requirement is $\omega \sim 0.3 \Rightarrow$

$$\frac{1.7}{1.7+X} = 0.3 \Rightarrow 1.7 = 0.51 + 0.3X$$

$X \simeq 4 \Rightarrow$

$k_{v,\,bypass} \simeq 4$ m³/h

Sizing of bypass in <u>DN15</u>

1) $\xi_{branching} \sim 3$, $Q_{bp} = 0.7 \times 240 \sim 168$ l/h $\Rightarrow$ $P_d \sim 30$ Pa via nomogram

2) $\xi_{inlet} \sim 1.5$

3) $k_{v,\,pipe}$ 0.5 m long

<u>Re 1</u>

$\xi_{branching} \times p_d = 3 \times 30 = 90$ Pa

$$k_v = \frac{0.168}{\sqrt{90 \times 10^{-5}}} = 5.60 \text{ m}^3/\text{h}$$

Re 2

$\xi_{inlet} \times p_d = 1.5 \times 30 = 45$ Pa

$$k_{v,\,pipe} = \frac{0.168}{\sqrt{45 \times 10^{-5}}} = 7.92\ m^3/h$$

Re 3

$Q_{bp} = 0.7 \times 240 \sim 168$ l/h $\Rightarrow$ 65 Pa/m via nomogram for DN15.
With length 0.5 m: = 32.5 Pa

$$k_v = \frac{0.168}{\sqrt{32.5 \times 10^{-5}}} = 9.32\ m^3/h$$

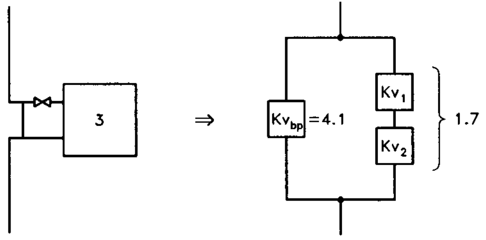
The total $k_{v,\ bypass}$ is calculated on the basis of the equation given below, since the bypass can be considered as three resistors connected in series:

$$\frac{1}{k_v^2} = \frac{1}{5.60^2} + \frac{1}{7.92^2} + \frac{1}{9.32^2}$$

$k_v \sim 4.10\ m^3/h$

This size fits in nicely with the assumption: $k_v \simeq 4\ m^3/h \Rightarrow$ ok!

After establishment of bypass in DN 15



$\Sigma k_v = 4.10 + 1.7 = 5.8\ m^3/h$

Assessment of new return temperatures

The calculation of the new return temperatures is rather complicated, since the return temperature cannot be isolated in the applicable formula equations.

On the other hand, the return temperatures can be read from a so-called radiator diagram (see Appendix 3).

The return temperatures for radiators 1 & 2 are unchanged.

Radiator 3

The radiator diagram reads $\frac{Q}{Q_0} \simeq 5.65$ for $t_F = 87$ °C & $\Delta t = 4$ °C (point 1 in Appendix 3).

At a reduction to 30% radiator share $\Rightarrow$ $\frac{Q}{Q_0} \simeq 1.90$. For $t_F = 87$ °C & $\frac{Q}{Q_0} \simeq 1.90$ the reading is $\Delta t \simeq 11$ °C (point 2 in Appendix 3).

The most important thing to note is that even if the water quantity has been reduced by 70%, the heat emission has only been reduced by ~ 8% (this can be seen by comparing the two values of Φ/Φ_0, item 1 & item 2. The radiator graph also shows that if the flow temperature at $Q/Q_0 \simeq 1.90$ is raised from the mentioned ~87°C to ~92°C, the same heat emission as previously is obtained.

Calculation of new flow temperature for radiator 4

$$Q \times t_{F4} = Q\,(1 - \omega)\,t_{bp3} + Q \times \omega \times t_{R3}$$

$$240 \times t_{F4} = 240 \times 0.7 \times 87 + 240 \times 0.3 \times (87 - 11)$$

$$t_{F4} \simeq 84\ ^\circ C$$

This means that the flow temperature to the individual radiator does not change noticeably after the establishment of a bypass. The only noticeable effect is that, as mentioned, the heat emission from the individual radiator is slightly reduced (~8%).

Conclusion

The establishment of a bypass in an existing one-pipe installation has only a small influence on the operating data of the installation. The insignificant reduction of the heat emission of the radiators or convectors can be compensated for by means of oversizing, as is in fact often done in practice, or by subsequent insulation.

Explanation of symbols

Φ = heat requirement (kcal/h)

Φ_n = rated radiator output (kcal/h)

Δt = total temperature drop (°C)

Δt_n = temperature drop across each radiator element = $\frac{\Delta t}{n}$

n = number of radiators

ω = radiator share = $\frac{Qrad}{Qtotal}$

t_i = indoor temperature

Example

t_{F2} = flow temperature to radiator 2

t_{bp1} = inlet temperature to bypass 1 (= t_{F1})

t_{R1} = return temperature from radiator 1

$\frac{\Phi}{\Phi_0}$ = relative heat emission

$\frac{Q}{Q_0}$ = relative water quantity

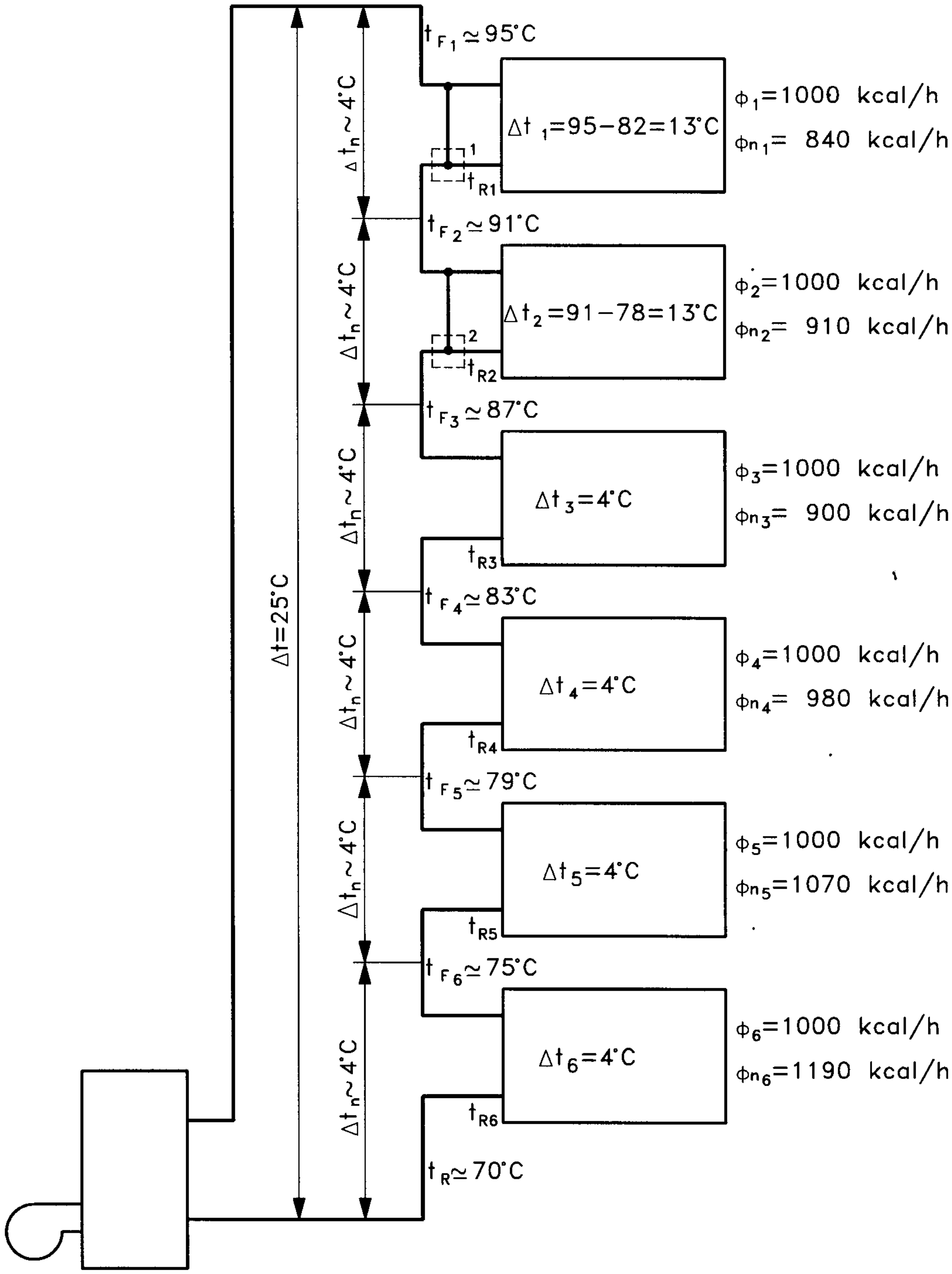
$k_v = \frac{Q}{\sqrt{\Delta p}}$ (m^3/h)

in which:

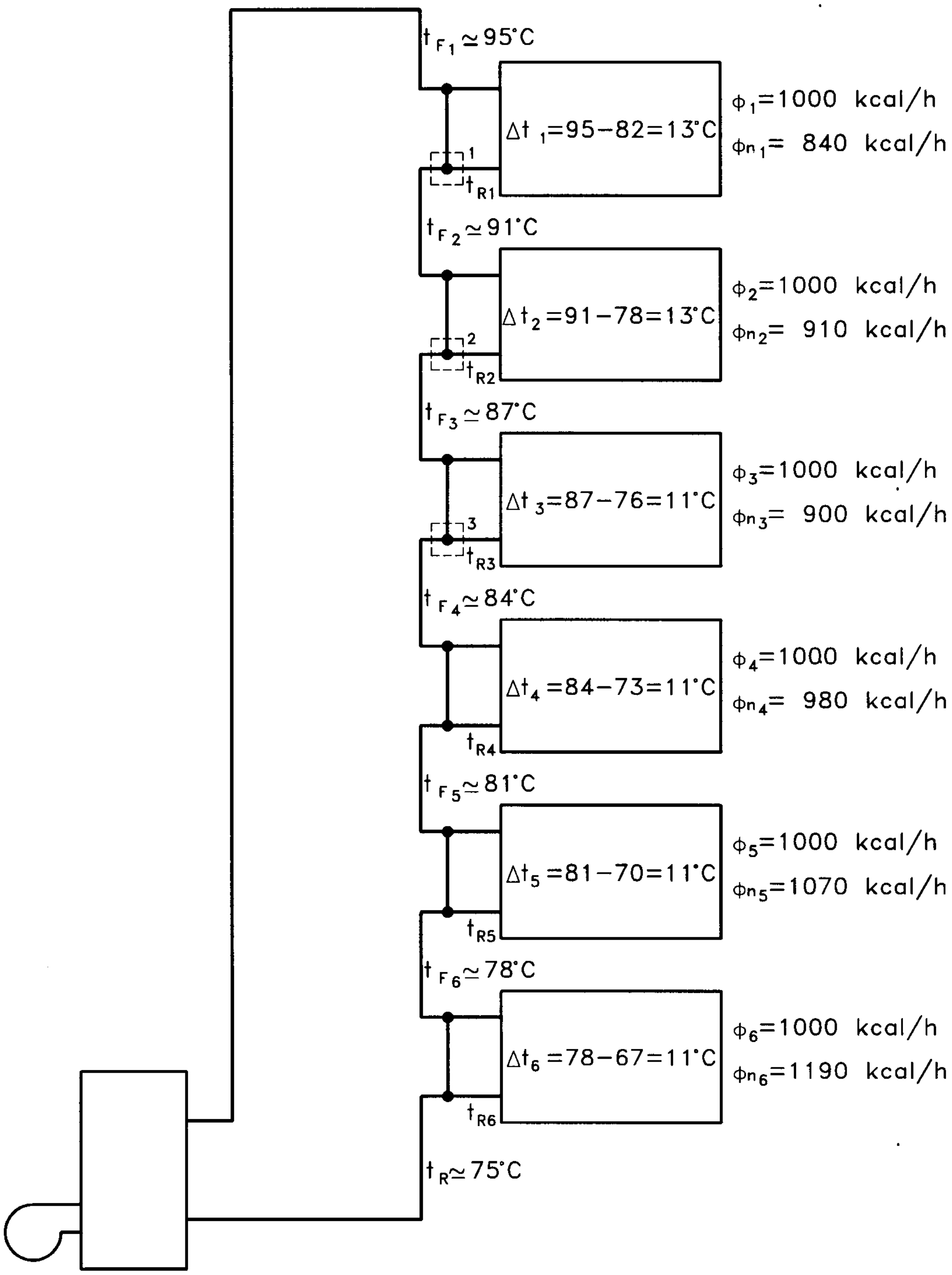
Q = water quantity (m^3/h)

Δp = differential pressure or pressure loss (bar).

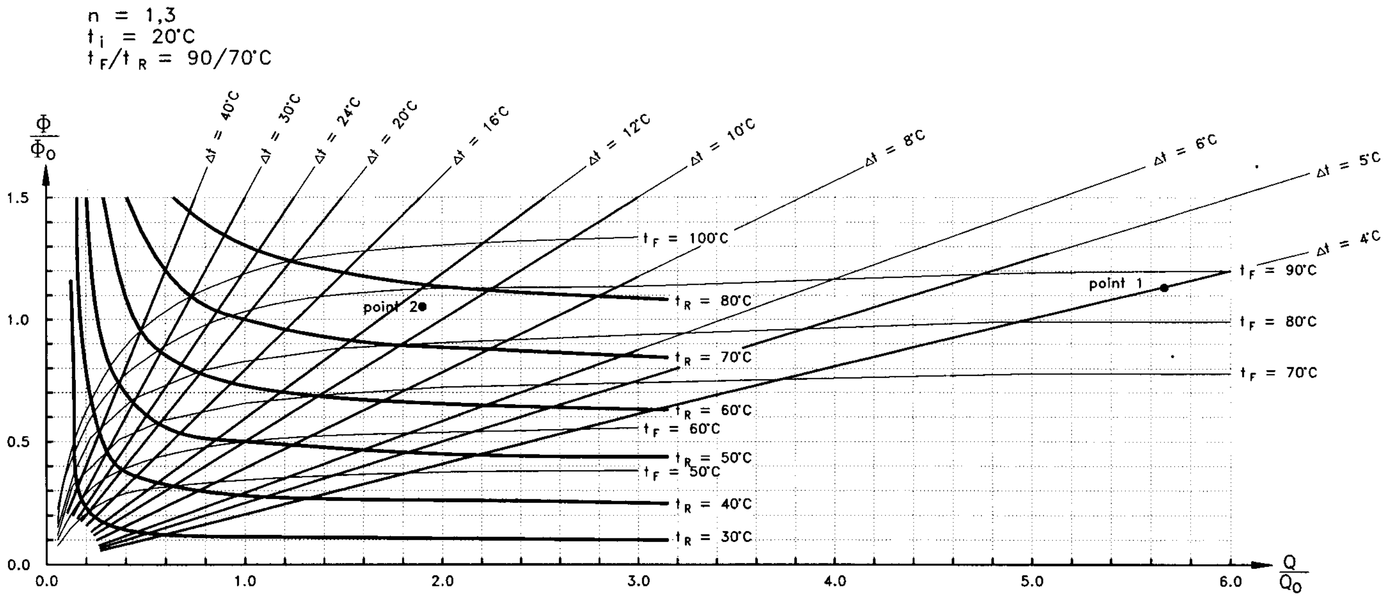
Appendix 1


t F1 ≃ 95°C
Δt 1=95−82=13°C
φ1=1000 kcal/h
φn1= 840 kcal/h
1
tR1
tF2 ≃ 91°C
Δt2 =91−78=13°C
φ2=1000 kcal/h
φn2= 910 kcal/h
2
tR2
tF3 ≃ 87°C
Δt3=4°C
φ3=1000 kcal/h
φn3= 900 kcal/h
tR3
t F4 ≃ 83°C
Δt4=4°C
φ4=1000 kcal/h
φn4= 980 kcal/h
tR4
t F5 ≃ 79°C
Δt5=4°C
φ5=1000 kcal/h
φn5=1070 kcal/h
tR5
t F6 ≃ 75°C
Δt6=4°C
φ6=1000 kcal/h
φn6=1190 kcal/h
tR6
tR ≃ 70°C
Δt=25°C
Δtn ~ 4°C
Δtn ~ 4°C
Δtn ~ 4°C
Δtn ~ 4°C
Δtn ~ 4°C
Δtn ~ 4°C

Appendix 2


$t_{F_1} \simeq 95°C$
$\Delta t_1 = 95-82 = 13°C$
$\phi_1 = 1000$ kcal/h
$\phi n_1 = 840$ kcal/h
1
t_{R1}
$t_{F_2} \simeq 91°C$
$\Delta t_2 = 91-78 = 13°C$
$\phi_2 = 1000$ kcal/h
$\phi n_2 = 910$ kcal/h
2
t_{R2}
$t_{F_3} \simeq 87°C$
$\Delta t_3 = 87-76 = 11°C$
$\phi_3 = 1000$ kcal/h
$\phi n_3 = 900$ kcal/h
3
t_{R3}
$t_{F_4} \simeq 84°C$
$\Delta t_4 = 84-73 = 11°C$
$\phi_4 = 1000$ kcal/h
$\phi n_4 = 980$ kcal/h
t_{R4}
$t_{F_5} \simeq 81°C$
$\Delta t_5 = 81-70 = 11°C$
$\phi_5 = 1000$ kcal/h
$\phi n_5 = 1070$ kcal/h
t_{R5}
$t_{F_6} \simeq 78°C$
$\Delta t_6 = 78-67 = 11°C$
$\phi_6 = 1000$ kcal/h
$\phi n_6 = 1190$ kcal/h
t_{R6}
$t_R \simeq 75°C$

Appendix 3


n = 1,3
t_i = 20°C
t_F/t_R = 90/70°C
Φ/Φo
Δt = 40°C
Δt = 30°C
Δt = 24°C
Δt = 20°C
Δt = 16°C
Δt = 12°C
Δt = 10°C
Δt = 8°C
Δt = 6°C
Δt = 5°C
Δt = 4°C
t_F = 100°C
t_F = 90°C
t_F = 80°C
t_F = 70°C
t_F = 60°C
t_F = 50°C
t_R = 80°C
t_R = 70°C
t_R = 60°C
t_R = 50°C
t_R = 40°C
t_R = 30°C
point 1
point 2
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Q/Qo