Technical Note

Summary The heat output from conventional hot water radiators falls as the return temperature is reduced. Experimental results show a much lower heat output from a pressed steel radiator than that calculated using the conventional formula based on the mean of flow and return water temperatures. The fall in output is especially marked when using bottom, opposite end water connections to the radiator, as in conventional British practice. This reduction in output has implications for the design of systems which are designed to operate at low flow rates.

Output of radiators at reduced flow rate

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List of symbols

B	radiator output constant	
n	temperature difference index	
m	flow index	
q	flow rate	$\mathrm{l\,h^{-1}}$
P	heat output	W
T_a	room temperature	°C
T_f	flow temperature (radiator entry)	°C
T_r	return temperature (radiator exit)	°C
ΔT_m	arithmetic mean temperature difference	K
ΔT_l	logarithmic mean temperature difference	K
ψ	flow correction factor	
ϕ	flow correction factor	
0	subscript: standard test condition	

1 Introduction

The conventional water filled radiator is probably the most widely used heat emitter in the UK. Some of the newer heat sources work more efficiently with low water return temperatures. This note examines the variation of heat output of radiators with reduction in return temperature.

2 Radiator output measurements

Standard test conditions for measuring the output of radiators are laid down in BS 3528[1] for measuring the output of radiators. The conditions have been standardised internationally, and are the same as those in ISO 3147, 3148 and 3150. The radiator is tested in a standard room at a controlled temperature of 20°C. Wall temperatures and mounting procedures are also laid down. Water connections to the radiator are made with top, bottom, opposite end (TBOE) connections unless otherwise specified. With a flow temperature of 90°C, the flow rate is adjusted to give a 20 K temperature drop across the radiator, i.e. a 70°C return temperature. This flow rate becomes the standard for subsequent measurements on that radiator. Output measurements are repeated at two more flow temperatures, maintaining the standard flow rate. Power output is expressed in the form

$$P = B(\Delta T_m)^n \tag{1}$$

where

$$\Delta T_m = \tfrac{1}{2}(T_f + T_r) - T_a \tag{2}$$

i.e. ΔT_m is the arithmetic mean temperature difference between radiator and room. The parameters B and n are found by a least squares regression of log B on log T_m.

The heat emission $P(W)$ of a radiator is given by

$$P = 1.16q(T_f - T_r) \tag{3}$$

where q is the water flow rate through the radiator. This equation is exact. Using the subscript 0 to denote standard test conditions, we can rewrite equation (1) as

$$P_0 = B\,[\tfrac{1}{2}(T_{f0} + T_{r0}) - T_a]^n$$

Hence the standard flow rate q_0 can be obtained from equation (3). The exponent n is measured during the British Standard test; it is found to be close to 1.3, and this is used as a general figure throughout this note. If the flow temperature is maintained at T_{f0} and the flow rate reduced

$$P/P_0 = (\Delta T_m/\Delta T_{m0})^n \tag{4}$$

If a value of reduced output P is selected, equation (4) can be solved for T_r, and then equation (3) for q. It is therefore possible to construct a set of curves relating the output, flow rate and return temperature.

Equation (4) is the conventional formula for calculating heat output of radiators, and is referred to in this paper as the AMTD method. It is quoted in the current CIBSE Guide[2] without qualification as to its range of application, and outputs are tabulated over a range of ΔT_m from 20 to over 100 K.

If the flow rate through the radiator is reduced, the dwell time of the water in the radiator increases, and the return

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temperature falls. At low flow rates, the mean surface temperature of the radiator is better approximated by the logarithmic mean temperature difference (LMTD), (Peach[3], Woodtli[4]).

$$\Delta T_l = \frac{(T_f - T_r)}{\ln[(T_f - T_a)/(T_r - T_a)]} \qquad (5)$$

in place of the AMTD ΔT_m in equation (4). The LMTD should be used in preference to the AMTD when

$$(T_r - T_a)/(T_f - T_a) < 0.7$$

However, more detailed examinations of flow in radiators by Peach[3] and Schlapmann[5] showed that the surface temperature of the hot end of the radiator is below the flow temperature, because the hot incoming water mixes with cooler water. Output from the radiator at low flow rate is therefore reduced below the value predicted by the logarithmic mean temperature difference. This reduction may be substantial.

3 Experimental

The heat output of radiators at low flow rates is not easily predicted by theoretical analysis, and it is necessary to turn to experimental measurements. Schlapmann[5] measured the output of several types of radiator over a range of temperature differences and flow rates. The radiators tested were a panel radiator, a narrow sectional radiator, and a radiator to DIN 4722; none have convection fins. He concluded that the output could be expressed for all the radiators by

$$P = \phi P_0 (\Delta T_m/60) \psi^n \qquad (6)$$

The exponent n has the usual value of 1.3. The factors ϕ and ψ depend on the flow rate and connection mode, but not on the type of radiator (among those tested). Schlapmann's graphs of ϕ and ψ are reproduced in Fig. 1 for the two main connection modes: top, bottom, opposite end (TBOE), as used in the BS test, and bottom, opposite end (BOE), which is the common connection mode used in the UK. Further results for top, bottom, same end (TBSE) and bottom, same end (BSE) are given in the original paper; TBSE gives outputs slightly higher than TBOE, and BSE gives outputs similar to BOE.

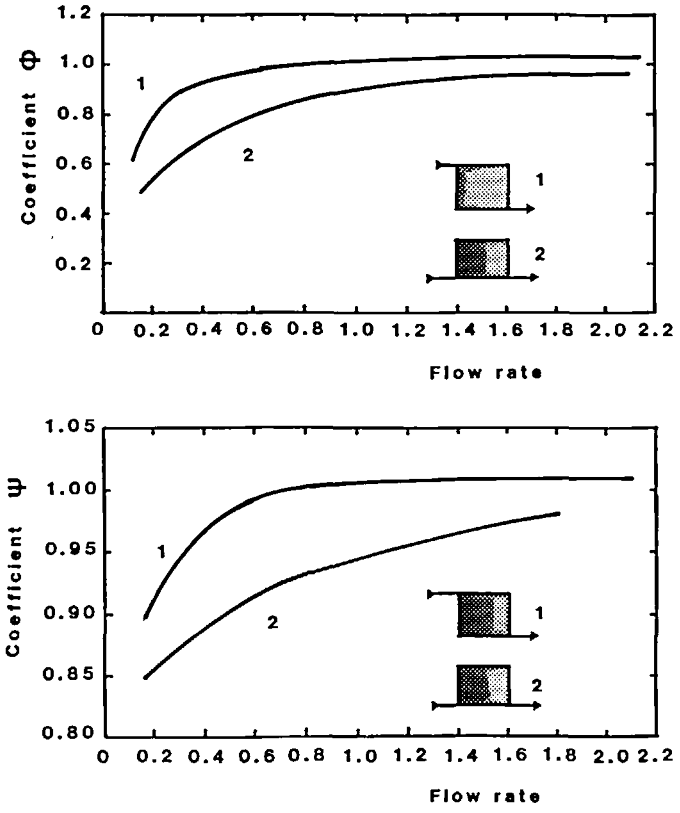

Fig. 1. Coefficients ϕ and ψ as a function of flow rate, taken from Schlapmann[5]. The flow rate is expressed as a fraction of the flow rate at standard test conditions. Radiator output is calculated using the universal equation (6).

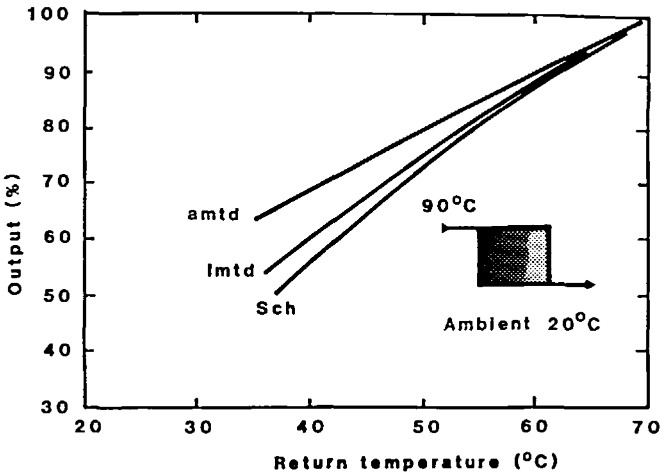

Fig. 2. Variation in output of a radiator as a function of return temperature, calculated by three different methods. Output is expressed as a percentage of that at standard test conditions of 90°C flow and 70°C return. The calculation methods are:
amtd–arithmetic mean temperature difference, equation (4);
lmtd–logarithmic mean temperature difference, equation (5);
Sch–Experimental results due to Schlapmann[5].

From the information given above, together with the coefficients shown in Fig. 1, it is possible to calculate the heat emission P of a radiator as a function of its measured emission P_0 under standard conditions, given any two of T_f, T_r and q. Fig. 2 shows the variation in heat emission of a radiator with TBOE connections, as a function of return temperature, calculated by the three methods.

The simple method based on AMTD consistently predicts the highest output of the three, and the experimentally based Schlapmann method the lowest output. The use of the logarithmic mean temperature difference predicts outputs higher than those of Schlapmann, but gives a much better approximation than the AMTD. All methods, of course, coincide at the standard conditions of test.

The discrepancy between the two methods is less at lower flow temperatures. Fig. 3 shows the variation in output as a function of return temperature for three flow temperatures. The discrepancy between the two calculation methods is much greater for BOE connections than for TBOE. Fig. 4 shows the output calculated for return temperatures of 90, 80 and 70°C. The curves calculated from the Schlapmann results show the surprising characteristic that the radiator output is virtually independent of flow temperature. This implies that the mean surface temperature of the radiator is also virtually independent of flow temperature, and supports the observation by Peach[3] that mean radiator temperature at low flow rates is near to the return temperature. It can be seen that there is a very large discrepancy between the two methods of predicting heat output of the radiator. At the worst case of 90°C flow and 40°C return temperatures, Schlapmann's results show an output only 50% of that predicted using the simple formula based on arithmetic mean temperature difference.

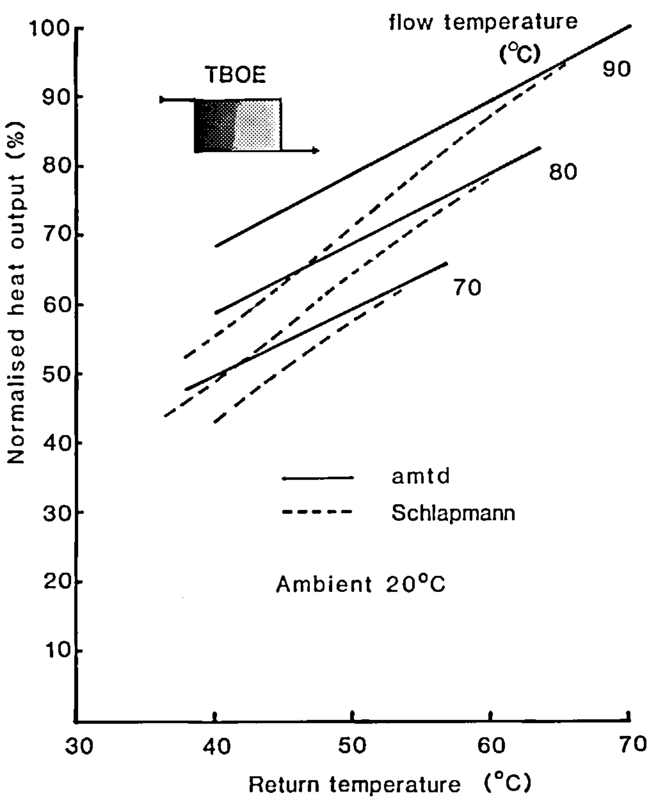

Fig. 3. Radiator output as a function of return temperature, calculated by two methods, for top, bottom, opposite end connection mode. Output is expressed as a percentage of the output at standard test conditions.

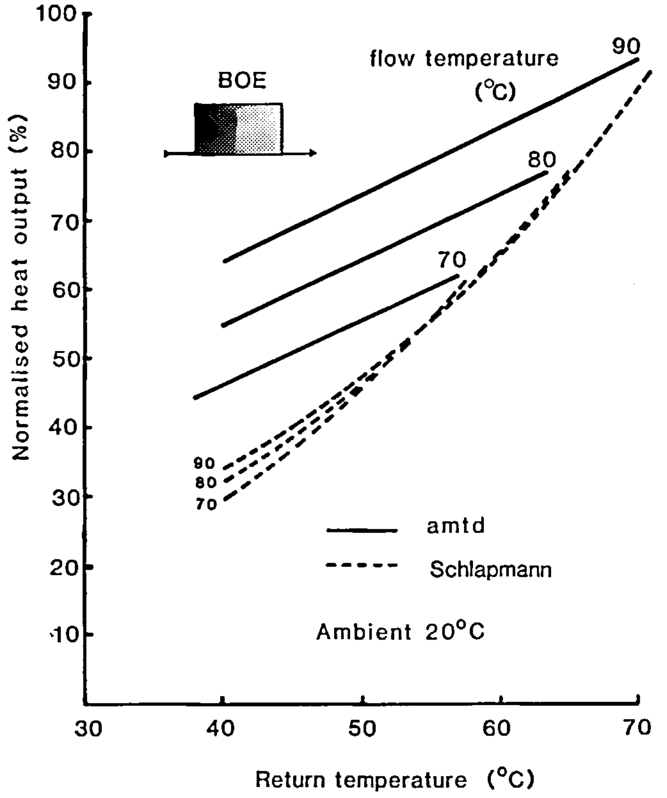

Fig. 4. Radiator output as a function of return temperature, calculated by two methods, for bottom, opposite end connection mode. Output is expressed as a percentage of the output at standard test conditions, which have TBOE connections.

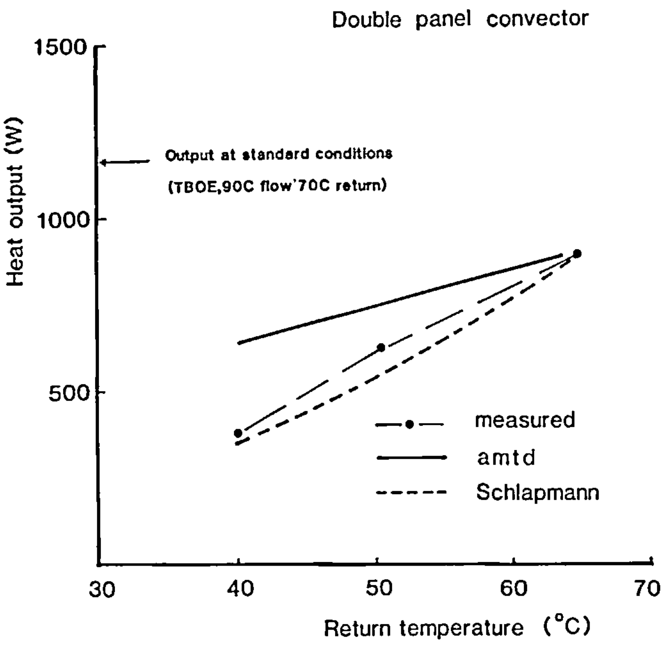

Fig. 5. Measured output from a British double panel convector radiator compared with two prediction methods. Measurements were made in a BS test room maintained at 20°C, with 80°C flow temperature using bottom opposite end connections. Both prediction methods take the measured output at standard conditions as a starting point for the calculations.

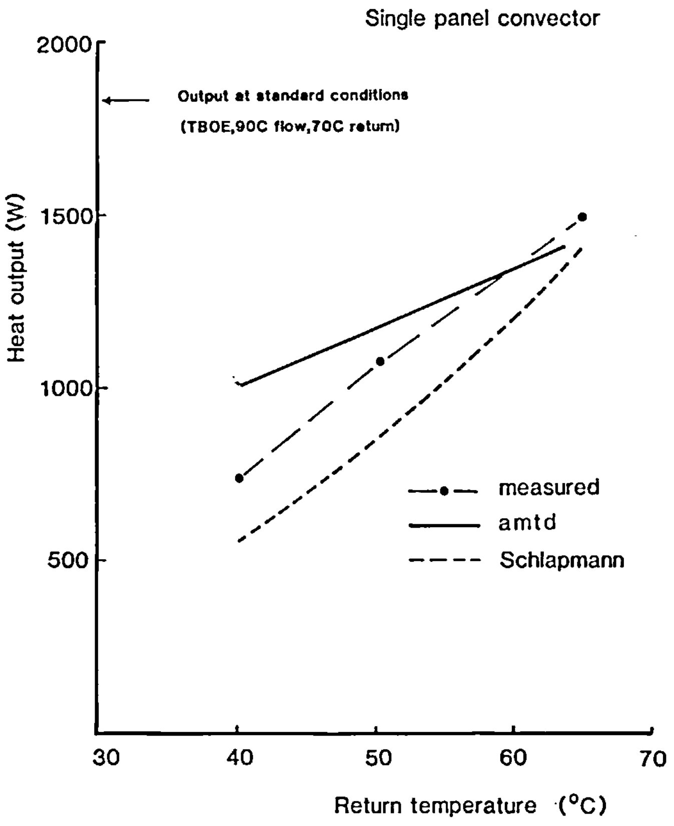

Fig. 6. Measured output from a British single panel convector radiator, compared with two prediction methods. Measurements were made in a BS test room maintained at 20°C, with 80°C flow temperature, using bottom opposite end (BOE) connections.

4 Experimental confirmation

The Electricity Council Research Centre commissioned measurements on two radiators to check whether the output curves shown in Figs. 3 and 4 apply to normal British radiators. Measurements were carried out at Portsmouth Polytechnic in their radiator test room. This is one of the three standard radiator test rooms in the United Kingdom, which are built and operated according to BS 3528: 1977. Measurements were made on two panel convector radiators of typical British design. Both had sheet metal fins added to increase the surface area for heat emission. The measurements were done using bottom opposite end connections; output from the radiator at standard test conditions had already been measured. The results are plotted in Figs. 5 and 6 together with the output curves predicted using the conventional (AMTD) method and the generalised results after Schlapmann. Fig. 5 shows good agreement between the three measured points and the predictions based on Schlapmann's figures. At a return temperature of 65°C, where the flow rate is relatively high, the two prediction curves and the experimentally measured point agree with each other. As the flow rate, and with it the return temperature falls, the measured output falls, following the prediction line due to Schlapmann. Results for the single panel radiator are shown in Fig. 6. While the slope of the measured output curve agrees very well with the slope of the prediction due to Schlapmann, it is displaced above it. The agreement between the two prediction methods and the measured result at the highest flow rate (65°C) return temperature) is not so good as in Fig. 5. This is probably because the reduction in heat output in going from TBOE to BOE is not a constant factor, as implied in Fig. 1, but is actually a function of the aspect ratio of the radiator. With BOE connections, after entering the radiator the hot water convects up to the top, while simultaneously flowing horizontally. The top corner above the entry is therefore cool, and with a short tall radiator the cool corner represents a larger fraction of the heat emitting surface than for a long low radiator. The ratio of output between BOE and TBOE has been measured by Arnold[6] to increase from 0.9 to 0.95 as the aspect ratio increases.

Taken together, the two sets of results show that Schlapmann's general equation (equation (6)) gives a much better prediction of the output of a radiator at low flow rates than does the conventional equation based on AMTD.

5 Conclusions

The generalised experimental results published by Schlapmann and confirmed by two sets of check measurements show that the output of a panel radiator, when operated with bottom opposite end connections and at low flow rates, can be very much lower than the output predicted by the conventional (AMTD) method. This has implications for the design of systems requiring low return temperatures. Where it is important to use accurate output figures for radiators, the generalised equation due to Schlapmann is recommended in preference to the conventional method.

References

1 BS 3528: 1977. Specification for convection type space heater operating with steam or hot water. (Equivalent to ISO 3147, ISO 3148, ISO 3150).

2 IHVE Guide Section B1, Heating. Institution of Heating and Ventilating Engineers, London (1970).

3 Peach, J., Radiators and other convectors. J.I.H.V.E., 39 (2), 239–253 (1972).

4 Woodtli, W., Low temperature operation of radiators. Heiz Luft Haustechnik, 29 (11), 434–436 (1978).

5 Schlapmann, D., Heat output and surface temperature of room heat emitters. Heiz. Luft Haustechnik, 27 (9), 317–321 (1976).

6 Arnold, J., Portsmouth Polytechnic, private communication (1985).

Acknowledgement

The radiator output measurements were carried out in the Portsmouth Polytechnic test room by J. Arnold, whose experience of radiator measurements contributed to this report.