Journal of Physics Special Topics

P4_3 Piping Hot!

D Starkey, J Nelms, D Roberts, S Thomas

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

November 7, 2012

Abstract
This paper estimates the temperature requirements of an under floor heating system for a room of equal dimensions as those stated in the 2011 paper, *Heating a Cold Room*. The temperature of the underwater piping required to maintain 25°C against heat loss through the walls is calculated explicitly. It is found that for the parameters stated in the paper, the piping must be maintained at 36.9°C . In contrast, the water temperature required to heat the room to the same conditions using 2 radiators is found to be 75°C.

Introduction
Energy bills represent a significant portion of most domestic budgets. As gas and electricity costs continue to rise, now more than ever, householders are concerned with using the most efficient methods to heat their homes. We investigate the temperature requirements of water-based under floor heating systems to maintain a steady floor temperature of 25°C, against an outside temperature T_0 of 10°C. The effect of heating time was investigated in a previous paper entitled *Heating a Cold Room*[1], which investigated the time taken to heat a room to 25°C using open fires and radiators (operating at 70°C). Included in our calculation are the effects of energy loss through the external walls.

Model - Under floor

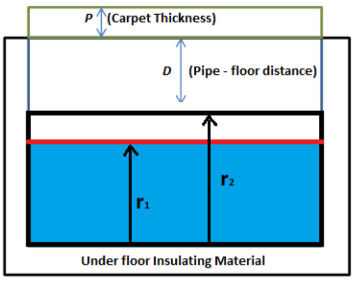

Figure 1: cross section of one pipe of the model room with the assumed parameters stated The pipe is assumed to have a width W.

The model room used throughout our calculation is shown in figure 1. The pipes (modelled as a slab) have inner and outer radii $r_1$and r_2, length *L* (assumed 30m) and width *B* modelled as 6.3cm (the equivalent circumference of a 10mm circular pipe). The pipes run a distance *D* (assumed to be 5cm) under the floor surface which is assumed to be well insulated by both artificial and natural means as a result of being beneath the surface. Therefore heat is only transferred upwards through the floor into the room. The carpet thickness is modelled as 2cm.

Model – Wall

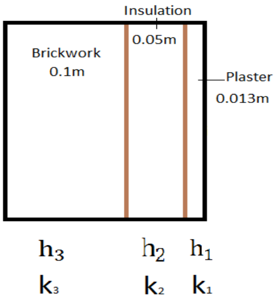

Figure 2: Diagram showing the model assumed for the wall. h and k indicate the thickness and thermal conductivities of each layer.

The model room is as described in figures 1 and 2 with the dimension stated, and thermal conductivities from [2], and [3]. The room is assumed as a cube with volume 85m^3 and area 85$^{2/3}$m^2.

Conduction through the Floor
Heat is provided to the surface of the concrete floor by conduction, heating the surface to a temperature *T.* Energy is then lost

by thermal conduction through the walls of the house (the radiative effects of heat loss are neglected in this article as they can be shown to be negligible by substitution into the Stefan-Boltzmann law). The net heat transfer from the water piping to the room, minus the thermal current out of the room per unit time $\left(\frac{dQ}{dt}\right)_{net}$ is then,

$$\left(\frac{dQ}{dt}\right)_{net} = \frac{T_p - T}{\frac{r_2 - r_1}{k_p BL} + \frac{D}{Ak_c} + \frac{p}{k_k A}} - \frac{NA(T - T_o)}{\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3}} \quad , \qquad (1)$$

where $\left(\frac{dQ}{dt}\right)_{net}$ is equal to zero if the room is maintained at constant *T*. The negative term represents that heat is conducted out through the exterior walls and the denominators of the first term on the right hand side of (1) represent the thermal resistances of the pipe casing, concrete and carpet. *N* represents the number of exterior walls of the room (approximated as 2), T_o and T_p are the outside and heating element temperatures respectively, and k represents the thermal conductivity. The subscripts *c*, *k*, *w* and *p* represent the values for concrete, carpet, wall insulation and copper respectively. These have been given the values 0.5, 0.48, 0.35 and 400 $Wm^{-2}K^{-1}$ [2]. $k_{1,2,3}$ are taken as 0.9, 0.35 and 0.5[3]. It is assumed that the floor and room have had sufficient time to reach equilibrium, so the floor temperature is equal to the room temperature (25°C). The left hand side of (1) is then set to zero and rearranged for T_p, to give the pipe temperature required to maintain a steady room temperature of 25°C ,

$$T_p = T + \frac{N(T - T_o)}{\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3}} \left(\frac{A(r_2 - r_1)}{k_p BL} + \frac{D}{k_c} + \frac{P}{k_k} \right). \qquad (2)$$

Inputting the appropriate parameters, and assuming an inner and outer pipe radius of 7mm and 10mm, we see maintaining a room temperature of 25°C requires a pipe temperature of the order 36.9°C.

Radiator Comparison

Heating a Cold Room stated a relation between the power produced by a radiator, with convective heat transfer coefficient *H* 13.1 $Wm^{-2}K^{-1}$ for water to air through copper) and the radiator water temperature T_w given by,

$$\frac{dQ}{dt} = HA_r(T_w - T), \qquad (3)$$

where A_r is the radiator area, set as 1m^2 [1]. Assuming that the radiator is in a room of equal dimensions and insulating properties as the previous calculation, equating (3) to the heat loss term from (1) and rearranging for T_W gives,

$$T_W - T = \frac{NA}{A_r H} \frac{1}{\left(\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3}\right)} (T - T_0) \ . \qquad (4)$$

It can be seen that when heat loss effects are considered, the radiator must be maintained at 124°C, higher than the room temperature at 149°C. Since this is higher than the boiling point of water in standard conditions, such a room would need to be heated by 2 radiators, so requiring a 62°C temperature difference assuming equal dimensions. The radiator water temperature would therefore be 75°C.

Conclusions

Investigated above are the required water temperatures of under floor and radiator heating systems for an environment with the conditions as in [1]. The results comparatively indicate that under floor heating can be kept at significantly lower temperatures than radiators to maintain a steady 25°C inside temperature against the effects of heat loss. Future investigations could improve on the model room used for these calculations, by including the effects of different methods of insulation.

References

[1] J. Sandhu et al, *A4_6 Heating a Cold Room*, PST **10**, (2011).
[2] P.A. Tipler and G. Mosca, *Physics for scientists and engineers: with modern physics* (W.H. Freeman and Company, 2008) sixth edition, page 676 - 678.
[3] http://moladi.com/images/Thermal%20Conductivity.htm accessed 03/11/2012