

The importance of hot water system design in the Passivhaus

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1 Introduction

This work is derived from an investigation of the carbon emissions associated with water use in dwellings in the UK [Clarke *et al* 2009]. This found that around 90% of the carbon emissions were from water use within the home. This is principally due to the heating of water, both in the domestic hot water system, and in appliances such as dishwashers.

Implications for Passivhaus

The default assumptions in PHPP [PHPP 2007] already put the energy demand for hot water higher than that for space heating. Our analysis of actual water use shows that in the UK hot water use is typically at least 30% higher per person than is assumed in PHPP. Also the losses associated with hot water generation are considerable, with a calculated 5kWh/(m².a) being the best achieved and over 10kWh/(m².a) more usual in modern low energy houses. Monitored data from completed low energy houses (at Stamford Brook) have shown higher losses than this in practice [Wingfield *et al* 2008]. So for occupancy levels assumed in PHPP (35m²/person) the total energy demand of the hot water system is usually at least 30kWh/(m².a), double the passivhaus heating demand of 15kWh(m².a).

PHPP doesn't include the full impact of hot water system losses on space heating demand. This is intentional to ensure that a poor hot water system isn't used to offset a poor building fabric, and the fixed internal gains figure of 2.1 W/m² is used when evaluating heating energy demand. Hot water system losses that contribute to heating are attributed to the heating system primary energy consumption. However the same 2.1 W/m² internal gains figure is used for summer overheating calculations. This overlooks the fact that summer hot water losses are not useful and are in fact a problem. As they may amount to more than 2 W/m² for the hot water system alone, this would double the effective internal gains that need to be considered for summer temperatures.

2 Measured hot water use

We would like to base our model of energy consumption for hot water on physical reality. For this we refer to measured datasets. Most of these only monitored incoming mains water supply and are poor at differentiating between hot and cold use. Martin's study for the Energy Saving Trust [Martin 2008] is specifically on hot water consumption. The

conclusions were that the mean household hot water use was 122 litres per day, and best modelled as 40 litres/day + 28 litres/day/person. The variation between individual households is large, from <25 litres/day to >300litres/day. Also, importantly, the average hot water delivery temperature was found to be 52°C, considerably less than the 60°C assumed in UK energy models and in PHPP.

In terms of hot water energy use for a household of average UK occupancy (2.4 people) the measured value for delivered hot water was 4.6kWh/day compared with the PHPP prediction of 3.5kWh/day.

3 The model

A spreadsheet provides a model for water and energy use within a dwelling. The primary input is the water use data which is standardised into litres/day/household for each end-use. The temperature at which the water is delivered and the percentage split of hot and cold give the energy demand of delivered hot water.

To analyse the energy use of the hot water system in detail, and to model the likely impact of varying say shower flow rate, or bath volume, we used a micro component model. This estimates the volume per use for each category, and daily frequency of use. The data available is limited, but in general we have taken use frequencies from measurements and estimated volume per use on the characteristics of the water use fitting, eg shower flowrate.

In our analysis we found that washing machines and dishwashers are responsible for a high proportion of primary energy from home water use. This is because they use electricity for most or all of their heat energy. As these appliances are generally cold-fill only we haven't considered them further in this paper.

The initial model assumes a hot water storage cylinder, heated by a separate boiler (typically gas-fired) which also provides space heating in one house. This is the usual arrangement in the UK, and the hot water distribution is not normally pumped, though we have included this as an option.

The hot water energy systems are modelled in detail to cover heat losses from distribution pipework, hot water cylinder & boiler primary circuits. These heat losses contribute to space heating, and are combined with the heating effect of hot-water in use (e.g. from showers) and the cooling of cold-water (e.g. in WC cisterns). The net offset to heating energy depends on the heating demand of the house. A utilisation factor is calculated as in PHPP for a house with an assumed 15kWh/(m².a) space heating demand.

The net heat demand on the boiler is then calculated, taking the delivered hot water energy and the losses minus the fraction that provides useful space heating.

Outputs

The primary output is the total energy use associated with water use in the house over the year. This is broken down into delivered hot water and losses in the system. These losses are reduced by the net useful heating they provide, as the system losses are generally specific to the system design rather than the water consumption. Where there are specific heat gains associated with end uses (e.g. showers warming the bathroom) these are included in calculating the particular end use energy consumption.

Details of the model

Measured data and model-predicted data are in the form of litres/day at various temperatures determined by the end use, e.g. showers 38°C. All these are converted to kWh per day. Here we used a micro-component model based on fittings specified in the AECB water standard [AECB 2009]. The house included in the model is a notional single-family Passivhaus dwelling of 84m², average 2.4 occupants.

Hot water storage and delivery

The model includes a hot water storage cylinder, and distribution pipework to the outlets. Heat loss is calculated for the cylinder based on size, insulation thickness and stored water temperature. We have not included for any additional heat loss due to conduction and natural circulation within connecting pipes [Suter 2003].

Heat loss from the distribution system is calculated as a continuous pipework heat loss from circulated systems and a “dead leg” heat loss from non-circulated hot water pipes. Here the heat loss is from the cooling down of the water and pipework after each use-period. The number of use-periods is estimated as in PHPP at three times per day per person. Various pipe diameters and lengths of pipework are modelled to explore the performance of different system design.

Boiler and primary circuit

The system being modelled has a separate heat source e.g. a gas fired boiler, operating as required to circulate water through a primary circuit to the hot water storage cylinder. The total energy requirement for hot water use and losses is compared with the boiler output to give an estimate for the boiler run time per day. For this period the heat loss from the primary circulation pipework can be calculated, however there is an additional loss when the boiler stops firing and the pipework cools down.

Measurement using heat meters at Stamford Brook [Wingfield *et al* 2008] showed that there was a step-change in energy consumption at the boiler depending on the number of times the boiler fired to re-heat the cylinder. This was found to be 1-3 times per day, depending on water usage and time control settings on the hot water programme for the boiler.

We have modelled the heat loss from pipe cool-down as for distribution pipework, and included as estimate for the water content and heat exchanger mass of the boiler. These losses will be utilised during the heating season. The number of reheats is estimated assuming 30% of the cylinder is drawn off before the boiler fires again.

Utilisation of losses for heating

These are calculated using the formula for PHPP annual method. A marginal utilisation is not used as in some cases the hot water system losses are too large for this method, so the utilisation is calculated based on the total gains, with a typical level of solar gain assumed. From this the actual level of space heating demand is derived once hot water losses are included and the useful percentage of hot water losses is the reduction in this heating demand.

We included some losses from hot water use, which are heat gains to the space, similarly as gains to cold water (e.g. WC cisterns) are a heat loss from the space. The contribution from hot water was estimated from temperature drop in use, based on some experiments by ourselves and others [Critchley and Phipps, 2007]. Further work is needed to identify what proportion of these gains leave the house as water vapour in exhaust air, where the heat of evaporation would be lost.

4 Results

Here we present some examples of the model output comparing different approaches to hot water system design, both our ideal specification and what we see installed in reality:

- insulation specifications for hot water cylinders;
- short and long primary pipework circuits, both insulated and uninsulated (a total circuit length of 28m uninsulated was reported by Wingfield [*op cit*] as actually installed);
- three basic designs for final distribution; traditional UK practice (22mm and 15mm pipework, uninsulated); micro-bore from a manifold; and pumped (20m long, well insulated, 6 W/m), 24h/d anticipating Legionella regulations.

	“best”	“good”	“EU basic”	“UK basic”
<i>Cylinder insulation</i>	150 mm	100 mm	50 mm	25 mm
kWh/(m².a)	2.2	2.8	4.6	7.4
<i>Primary circuit length</i>	2m, insulated	6m, insulated	14m, insulated	28m, bare
kWh/(m².a)	2.2	3.1	5.1	10.6
<i>Distribution</i>	Micro-bore	Pumped 6h/d	Pumped 24 h/d	UK normal
kWh/(m².a)	1.7	2.6	9.2	4.3
Total kWh/(m².a)	6.1	8.4	18.8	22.3

Table 1: calculated hot water system losses for a range of design approaches

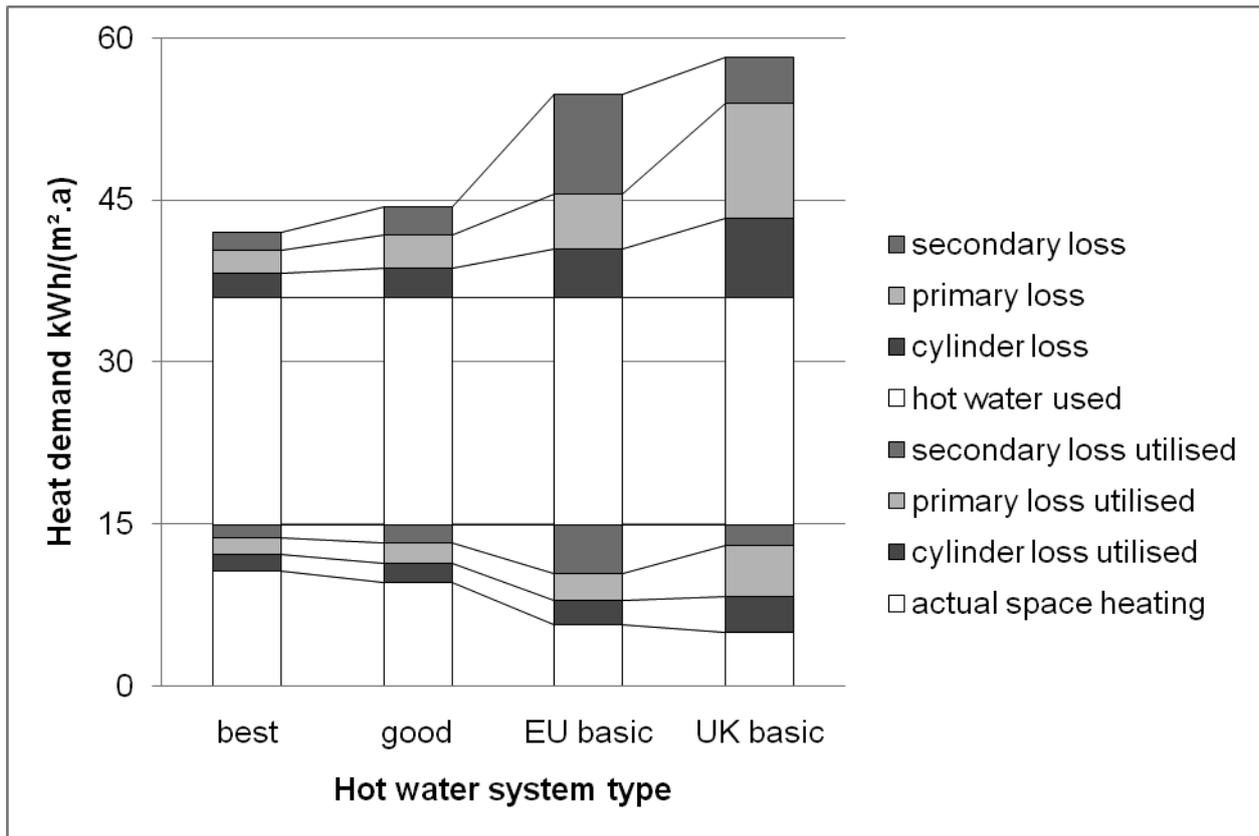


Figure 1: calculated combined heating and hot water annual energy demand

Observations

- poorly designed or installed hot water systems can have very high heat losses
- modelling actual heating demand allowing for gains from a poor hot water system, can lead to the conclusion that there is no need to insulate a house to Passivhaus standard.

5 Conclusions

In a Passivhaus dwelling the energy consumption for hot water at the taps is higher than the 15kWh/(m².a) heating demand.

Measured figures from the UK indicate that the PHPP assumptions on consumption are lower than average normal use. This is probably not significant given the large variation in individual household hot-water use. However in the case of compact systems the increased proportion of hot water that must come from direct electrical heating would adversely affect the seasonal performance factor.

Our modelling indicates that the energy consumption due to water system losses are largely independent of actual water consumption, but they are strongly influenced by house layout and hot water system design. These system losses are calculated to be 5-10kWh/(m².a) for good design, and can be considerably higher. Total heat demand for hot water ranged from 27kWh/(m².a) to over 40kWh/(m².a)

However good design can minimise these losses, and this effect is largely independent of actual water consumption. We would recommend that system losses are highlighted in PHPP so that they can be addressed by designers directly, instead of merely being included in the primary energy total.

PHPP takes a conservative view of the beneficial heating effect of hot water system losses, but does not correct the internal gains figure for summer overheating calculations, where the safe approach would be to include the calculated losses if they increase the default internal gains figure.

6 Acknowledgements

The model and original report 'Quantifying the energy and carbon effects of water saving' were commissioned by the UK Energy Saving Trust and the Environment Agency. www.energysavingtrust.org.uk/waterreport

The Authors would like to thank the AECB and Passnet for their assistance towards presenting this paper.

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