Internal heat gain assumptions in PHPP

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1 Introduction

One of the ways in which PHPP has closed the performance gap between modelling and reality is to assume low internal heat gains. The simplicity of a fixed W/m^2 internal gains figure for each building type is attractive, however in practice we have seen this lead to anomalies at extremes of building size and usage. One example of this is the “small house problem” where a design for a two person retirement dwelling of 40m^2 had no sensible design solution to meet the Passivhaus standard, yet Passivhaus components would clearly deliver a very low energy design with Passivhaus comfort levels.

Another case is the difference between schools in the UK and in Germany: occupancy in the UK is usually higher in terms of pupils per m^2, and the higher levels of internal heat gain mean the optimum building design is different.

In order to design comfortable and cost effective low energy buildings we need a useful estimate of internal heat gains. This estimate can never be accurate because the occupancy and technology associated with a building will vary over its lifetime. However there is potential to improve considerably on the current assumptions in PHPP in terms of accuracy, and in terms of delivering the most effective building design. As we will see, heat loss and internal gains are very non linear for small buildings.

2 The internal heat gain assumptions

As well as the blanket W/m^2 internal gain figure used for certification, PHPP also includes a detailed derivation of internal gains based on the various sources of heat and non-fabric losses such as evaporation and cold water for WC flushing.

Using the standard values for these gains included within PHPP, we separated out the gains per dwelling, per m^2 and per person. The per dwelling element comes from refrigeration and the base load of auxiliary energy for the heating system. The gains per m^2 in PHPP are for auxiliary energy. The rest is per person – metabolic, cooking, dishwashing, laundry, lights and consumer electronics. Cooling loads such as evaporation and incoming cold water are also per person.

For a typical single-family house with electrical appliances and a water based heating system these figures worked out in our example at 105 W/dwelling, 54 W/person and just 0.1 W/m^2.

However for certification PHPP assumes that internal gains are fixed at 2.1 W/m^2, and that occupancy is fixed at 35m^2/person. With gains largely proportional to occupancy, taking occupancy to be proportional to floor area leads to a conclusion that a constant W/m^2 is reasonable for larger dwellings. However for smaller dwellings the fixed element of gains predominates and the W/m^2 rises steeply as the building gets smaller:

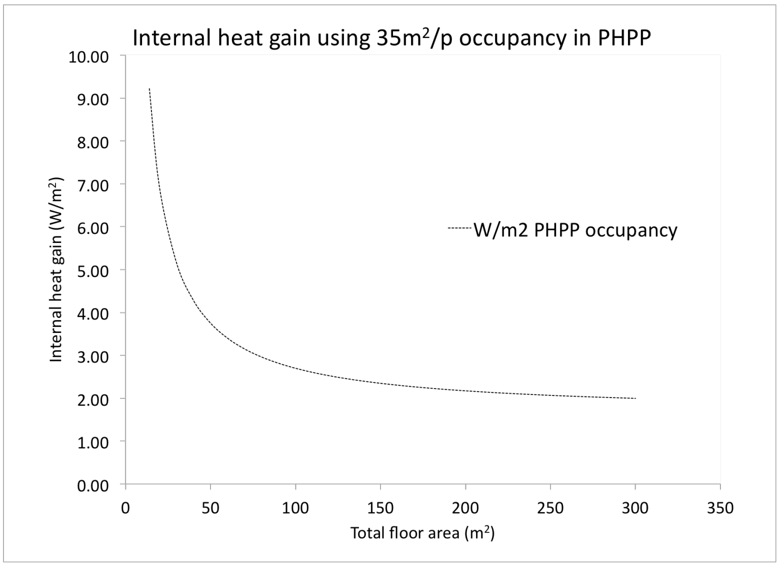


Figure 1. IHG calculated in PHPP for a range of floor areas based on 35m^2/p

Note that domestic hot water (DHW) also leads to significant internal gains but we have not counted these since DHW gains are dealt with differently than other gains in PHPP.

3 Occupancy per m^2

For two or more occupants the gains per person make up the majority of the total internal heat gain, so the question we have is whether the PHPP default figure of 35m^2/person is a good assumption. In our own practice we see a range of dwelling types. These include social housing with two and three occupants in 65m^2, and four in 85m^2; cohousing is similar, with two people in 55m^2 and three or four in 70m^2. Then larger private dwellings have two people in 130 or 170m^2, and families in houses 180m^2 – 420m^2. Overall we see occupancy rates between 20m^2/person and 140m^2/person. Is this an anomaly due to the small sample size?

To answer this we looked at the UK English Housing Survey and the occupancy data drawn from this by the BRE for use in the SAP energy model. The data covers 32,000 houses, with weightings to reflect the composition of the total UK housing stock. The raw data shows a wide variation in occupancy with no clear trend against floor area

BRE split the data into bands of 1000 houses, in order of increasing floor area, and looked at the average occupancy for each band. The interesting fact is that the average quickly rises to 2.5 people for 75m^2 and then levels off at 3 people however large the house is. We interpreted this data based on our anecdotal experience as the merging of two occupancy types – families, average 3 people, occupy houses mostly 80m^2 upwards. Couples and individuals occupy all sizes, but tend towards smaller dwellings. The net result is that the average for small dwellings is weighted towards non-families (one or two people), and for larger dwellings the average tends towards the family average occupancy.

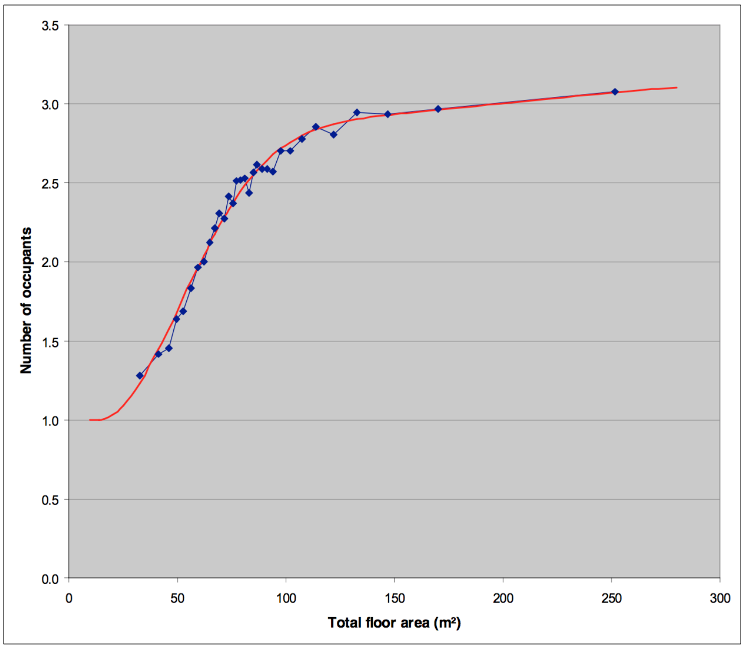


Figure 2. Graph of average occupancy against floor area for 32,000 homes [Henderson 2008]

For building modelling purposes BRE produced a curve fit to this data (mean occupancy for a particular building size) with the following equation, now used in the SAP model [Henderson 2008]:

Occupancy = $1+1.76(1-\exp(0.000349\ (TFA-13.9)^2) + 0.0013\ (TFA-13.9)$

This isn't a definite predictor of occupancy – a typical house could easily have anywhere between one and eight people living in it according to the data, but for optimising the building fabric for heating we have to use an average figure. On the other hand this data explains why building energy models have been so poor at predicting overall energy use including appliances, and provides a caution against giving any weight to the overall primary energy figures produced by PHPP. Also we need to be aware of the extremes concealed behind the average; a given house may be lightly occupied and in need of more space heating in winter, or it may be heavily occupied and prone to summer overheating.

It is interesting to note that the average occupancy in the UK is very close to the PHPP assumption of 35m^2/person. However we see from the distribution that smaller dwellings have higher occupancy/m^2 and larger dwellings have lower occupancy/m^2. This is also seen globally – countries with a small average dwelling size have higher occupancy/m^2 and larger dwellings have lower occupancy/m^2. So although adding data from more countries may lead to a more generalised equation for occupancy, it is more accurate to assume that specific occupancy is not fixed in terms of m^2/person, but varies according to dwelling size.

4 Results

Using the estimates derived from PHPP for internal gains based on dwelling, person and m^2, we applied the SAP occupancy formula to produce an internal gain figure in W/m^2 over a range of floor areas:

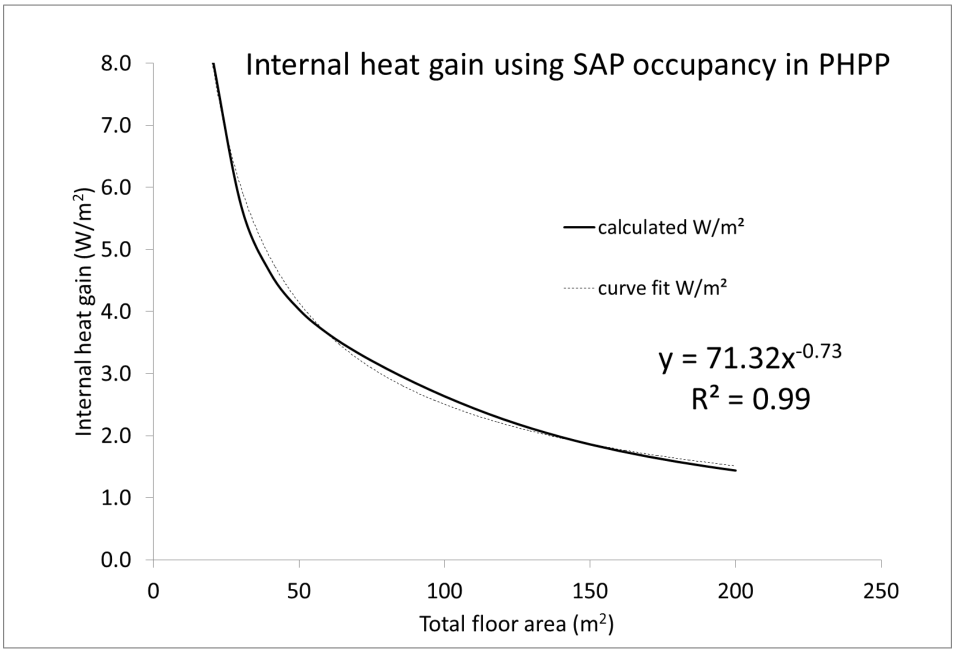


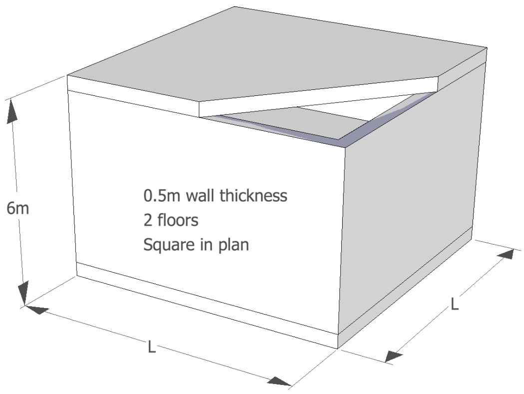
Figure 3. IHG calculated in PHPP for a range of floor areas based on SAP occupancy formula.

A simple power relationship approximates the curve reasonably well: IHG = 71($TFA^{-0.73}$). Mid sized houses still have internal heat gains around 2 W/m^2, in line with the PHPP default figure.

We propose that a formula such as this is worthwhile improvement to the PHPP algorithm: it is not complicated - a simple equation instead of a fixed figure – but offers a significantly better correlation between the internal heat gains we can expect and the size of a dwelling, which can only improve the optimisation of Passivhaus design. The details of what figures to take for current and future appliances, whether lighting should include a per m^2 element as well as per person, and what clothes drying we should assume are important and need to be resolved to give a working formula. Next we look at some implications of the principle.

5 The small house problem

A small building will have a higher external surface area for a given floor area and this has led to the use of extreme U values and additional areas of south glazing on what would otherwise be low cost modest dwellings. We find that the Passivhaus standard favours large dwellings as well as those with more efficient shapes. Interestingly the curve for heat form factor against floor area is similar to the internal gains curve above (here we arbitrarily assumed a square footprint but the trend will be familiar to any Passivhaus designer):



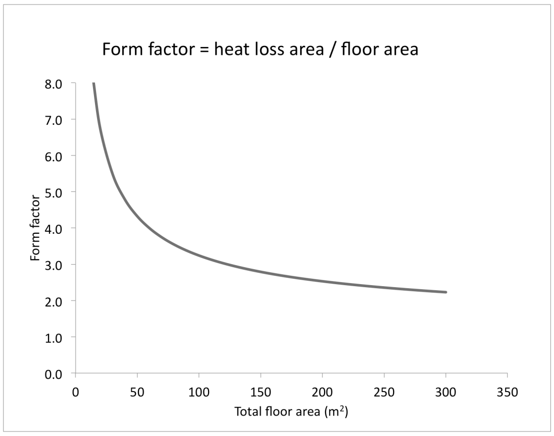


Figure 4 & 5. Form factor plotted against internal floor area for a square 2-storey building.

How does this relate to heating demand? For simplicity we assumed a reasonably good glazing design where gains equal loss:

Building form	Square in plan, 2 floors, 0.5m thick walls, 6m high
TFA	Gross internal floor area ignoring walls and stairs, 14-300m^2
Solar gain	10 kWh/(m^2.a)
Window heat loss	10 kWh/(m^2.a)
Fabric U values	0.10 W/m^2.K (chosen to achieve 15kWh/(m^2.a) at about 125m^2
G_t	70kKh/a (annual method)
Ventilation	Max of 30m^3/p and 0.3 ach with 90% HR efficiency
n_{50}	0.6 ach @ 50Pa
IHG	2.1 W/m^2 or 71(TFA$^{-0.73}$)

Table 1. Assumptions of energy model

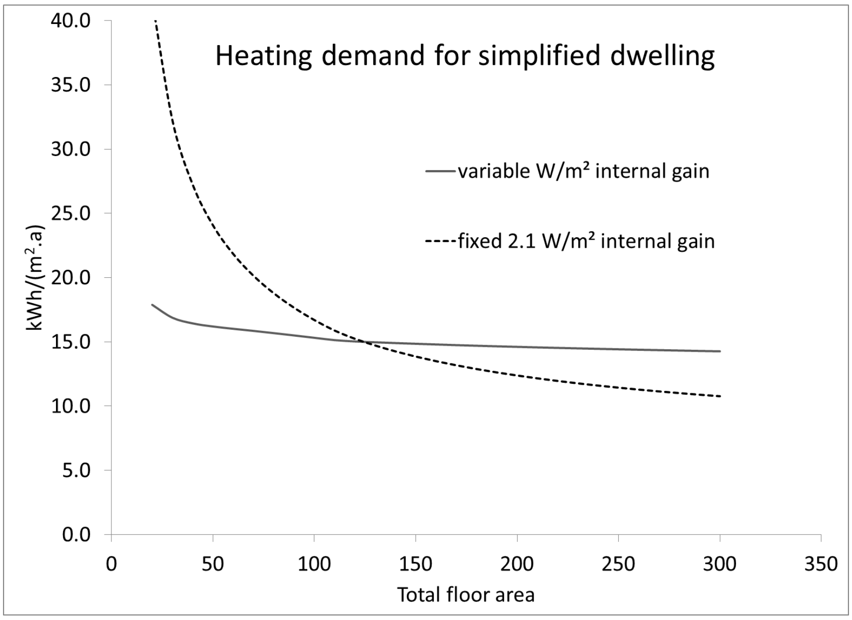


Figure 6. Annual heating demand calculated with the 2.1W/m^2 assumption and the proposed algorithm

For simplicity we have used gross internal floor area ignoring internal walls and stairs.

6 Discussion

The proposal for the rate of internal gains to be dependent on floor area in the domestic PHPP is not meant to be a “cheat” to get small houses through a loophole, it is simply a corollary of looking more carefully at the model and reality. PHPP has demonstrated the worth of assuming a realistic internal heat gain figure for making good predictions of heating demand. However as we have seen, basing IHG calculations purely on floor area leads to serious errors for small buildings. We propose that as PHPP is used for a wider range of building sizes and uses, that the basis for internal heat gain calculations is reviewed.

A simple adjustment to the assumptions of occupancy for a given house size based on measured data will lead to better optimised building designs at the extremes of small and large houses. There is no need to introduce special dispensations to the Passivhaus standard to deal with the small house problem if a realistic model of small house occupancy and internal gains is included in the PHPP calculation.

7 Schools and other non-domestic buildings

We have been involved in the design of four Passivhaus primary schools in the UK, and have noted that the average occupancy is 5.8m^2 per pupil for 30 hours/week, and around 10m^2/pupil for 25 hours/week in Germany. The difference purely in metabolic gains is nearly 1 W/m^2. This proves quite significant in terms of building design and the balance between winter solar gain and summer overheating. The results from the first three schools built to the PHPP default internal gains figures have actual heating demand lower than 15kWh/(m^2.a) but also require complicated ventilation strategies to maintain comfortable summer conditions. We consider an approach with allows for such difference in occupancy will lead to optimum building design both in terms of capital cost to deliver Passivhaus energy demands and in terms of summer comfort. A fuller exploration is beyond the scope of this short paper.

8 Conclusions

“All models are wrong, some are useful” George Box

- Absolute IHG assumptions can never be correct over the life of a building
- PHPP can better reflect the non-linear relationship between TFA and IHG.
- The refined PHPP model shows that in reality, even tiny Passivhaus buildings should be no more difficult to achieve than large ones.

9 References

[Henderson 2008] Henderson, John, A review of the relationship between floor area and occupancy in SAP.

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