EuroPHit

T2.4.2 Balancing tool for step-by-step energy efficient refurbishment incl. RES

Report_Optimisation of the PHPP for old buildings with high energy consumption

INTELLIGENT ENERGY – EUROPE II

Energy efficiency and renewable energy in buildings

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EuroPHit

[Improving the energy performance of step-by-step refurbishment and integration of renewable energies]

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Abstract

The Passive House Planning Package (PHPP) is a easy to use, reliable and well-proven design tool for highly efficient buildings such as Passive Houses or NZEBs. The purpose of the present study was to investigate its validity for existing buildings with a high energy demand, in order to make sure that it is suitable for calculating the effects of step-by-step renovation. A comparison of PHPP results with results from dynamic simulations revealed that, although some algorithms were developed with highly efficient, well-insulated buildings in mind, the PHPP can be used for this purpose with sufficient accuracy. No need for changes was detected.

Cover page of the current PHPP 9,
released in 2015 and updated with features for step-by-step retrofits in 2016

1 Introduction

1.1 The PHPP and its validity

The first version of the Passive House Planning Package (PHPP) was published in the late 1990ies. The energy balance calculation tool is an Excel spreadsheet that – in the current version – calculates e.g. the annual heating and cooling demand, peak heating and cooling load, frequency of overheating in summer, and primary energy demands. It is based partly on established standards, e.g. EN 13790 for the heating and cooling demand, partly on methods that have been developed specifically for the design of Passive Houses.

The calculation algorithms have been compared to field measurements in realised, inhabited buildings in the past. The results were very satisfactory, usually the calculated and measured data agree within the limits of uncertainty (cf. e.g. [Ebel 2003], [Feist 2000], [Peper 2002], [Reiß 2003], [Schnieders 2001], [Treberspurg 2010]).

To date, however, it was not clear to what extent the PHPP would also be suitable to predict the performance of existing buildings, and which possible adaptations would be required. This investigation is the purpose of the present paper.

1.2 Method

The PHPP contains relatively simple calculation procedures which have the great advantage that they are fast and easy to use. In many cases the law of conservation of energy forms the basis of the algorithms, but nevertheless the program is far from physical first principles. As a reference for checking the validity of any simplified algorithm we use a detailed dynamic thermal simulation based on hourly values, in this case the DYNBIL program.

DYNBIL is a dynamic thermal building simulation program developed at the Passive House Institute. The DYNBIL room model works with one air node and one radiation node, clearly separated from one another. Heat transmitted to interior surfaces is calculated depending on the location in the room and the actual temperature difference; for exterior surfaces, the complete solar and infrared radiation balance and the influence of wind speed are taken into account. U and g-values are calculated for windows depending on the current temperature and solar radiation in each time step. The wall model uses not transfer functions but a forward difference method, thereby fulfilling the conservation of energy principle even over long periods of time. The program was validated against measured data from a number of construction projects.

In the following, the DYNBIL results for certain characteristic values, e.g. annual heating demand or frequency of overheating, are calculated for different cases and compared to the corresponding PHPP results. If the two methods lead to similar results, within certain error margins, it is concluded that the simplified algorithms of the PHPP can be used with confidence.

2 Validity of some calculation procedures in the PHPP for existing buildings

In this section we compare the results of several PHPP algorithms with the results of dynamic simulations carried out with DYNBIL. This is done for two different buildings, both with the same geometry of a small, semi-detached, two-storey home with 120 m² of living area.

Figure 1: Photo of the Passive Houses in Hannover-Kronsberg built in 1998 (south façade). The geometry of the simulation model is based on an end-of-terrace house of this settlement.

The first type of building represents the type of building the PHPP has been developed for. The U-value of the walls is 0.2 W/(m²K), the roof has a U-value of 0.14 W/(m²K). Triple glazing with U = 0.72 W/(m²K), g = 53% is installed, the ventilation system has 85% heat recovery. In the following, this building is referred to as a Passive House, although it may not necessarily meet Passive House requirements in the respective climate.

The second type of building represents the building stock, with U-values of 2,0 W/(m²K) for the walls, 1.68 W/(m²K) for the roof, no ventilation heat recovery, and double clear glazing with U = 2.8 W/(m²K), g = 76%.

Both buildings were moved to the climates of Frankfurt/Main, Stockholm, Madrid, Sofia, Rome, Dublin, and Paris, and calculation results were determined both by DYNBIL and the PHPP.

Figure 2: PHPP results and dynamic simulation were compared for 7 different European climates

2.1 Annual heating demand

The principle of the calculation procedure for the annual heating demand in the PHPP follows the monthly method of EN 13790. A comparison with the dynamic simulation under identical boundary conditions (Figure 3) results in a small overestimation by the PHPP, typically by 1 kWh/(m²a). This behaviour is desirable for simplified procedures like the one in the PHPP.

For the Existing Buildings a certain *under*estimation of the heating demand is typical. In absolute terms the difference can reach nearly 10 kWh/(m²a), much more than for the Passive Houses.

One possible reason is the different incidence angle of the sun on the south facade during different seasons. While DYNBIL calculates the reduction due to non-perpendicular incidence angles in detail hour by hour, the PHPP uses a global reduction factor, in the case of heating 0.85. Figure 4 shows the effects for the particular example building used here, which has mostly south-oriented glazing. In the coldest months, when most of the heating demand in a Passive House occurs, the gains according to the PHPP are underestimated because of the nearly perpendicular direct solar radiation. At higher angles of the sun, outside the heating period of the Passive House, the underestimation of solar gains becomes smaller, thus reducing the heating demand of the Existing Building only.

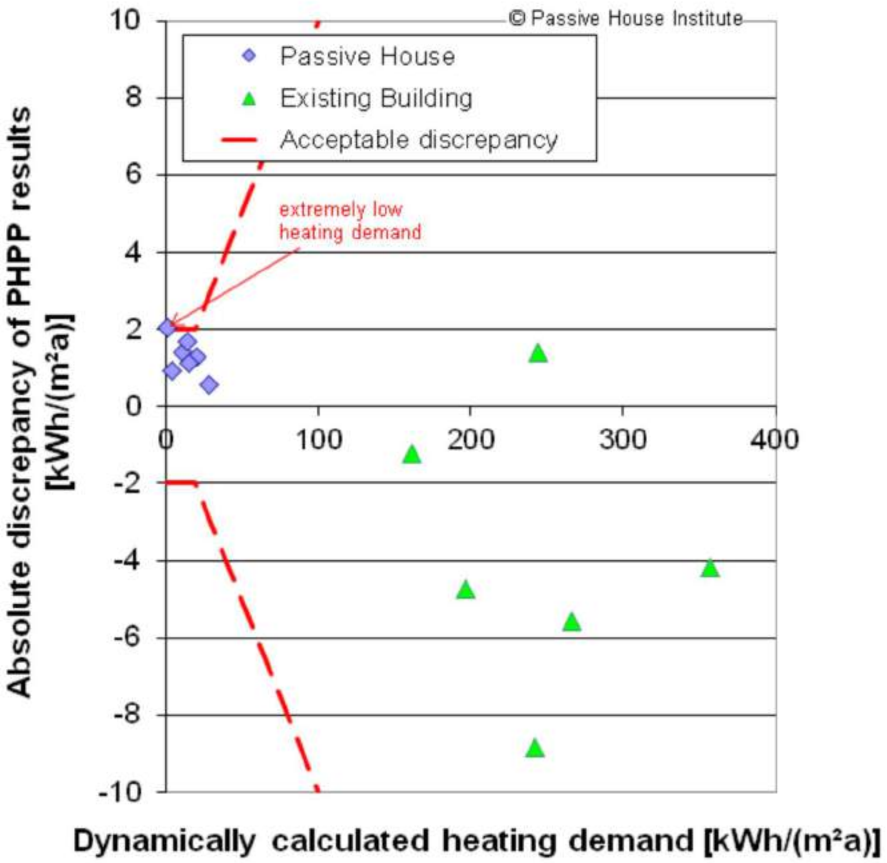

Figure 3: Comparison of annual heating demand from PHPP calculation and DYNBIL simulation

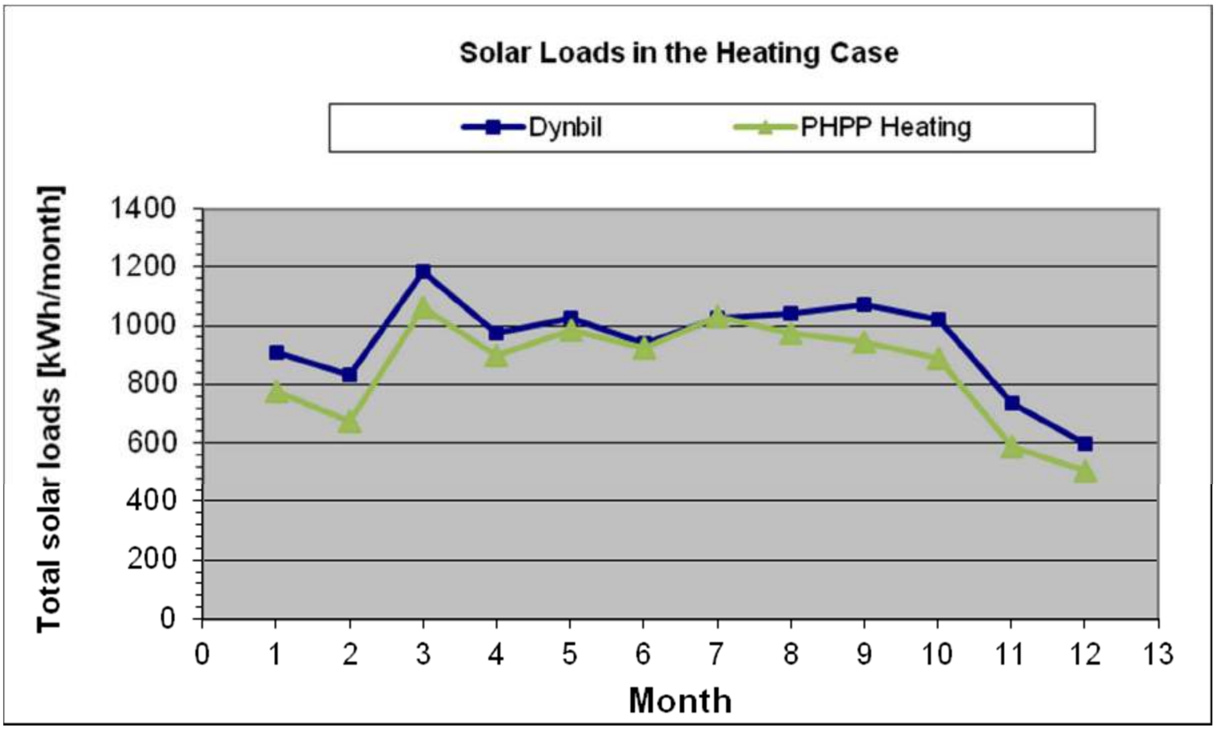

Figure 4: Sum of solar gains for each month according to the PHPP and DYNBIL. The PHPP estmates solar gains on the safe side.

It should be noted that the exact dependence of solar gains on the incidence angle is usually not known in everyday practice, so that the standard reduction factor of the PHPP simplifies the planning process considerably.

The relative discrepancy between PHPP and DYNBIL for the Existing Buildings does not exceed 4% for any of the climates considered and is thus totally acceptable. The higher accuracy for Existing Buildings is easy to understand: In Passive Houses internal and solar loads play an important part. These contributions are more difficult to assess because they occur irregularly and may lead to temporarily higher room temperatures, thereby rendering the utilisation factor for free heat more important. In addition, solar gains are by themselves more difficult to assess in simplified procedures. In Existing Buildings the heating demand is mostly determined by transmission and ventilation heat losses, which can easily be summed up over the period of one month.

It can be concluded that no changes are required to allow for the calculation of the annual heating demand of poorly insulated, existing buildings in the PHPP.

2.2 Heating Load

The heating load of Passive Houses, contrary to existing buildings, is significantly influenced by internal and solar heat gains. An accurate calculation of the heating load is therefore more demanding than for existing buildings, where the heating load is dominated by transmission and ventilation losses. In order to avoid unnecessary investments it is desirable to calculate a sufficiently high, but not overly cautious heating load.

The heating load procedure in the PHPP uses two separate design periods: a cold period, which in most climates corresponds to clear skies and relatively high levels of solar radiation, and an overcast period with milder temperatures. Due to the high time constant of Passive Houses it is sufficient to consider daily average heating loads only.

Although the calculation in the PHPP itself is a simple power balance, the design data for temperature and solar radiation are determined by an hourly dynamic simulation which includes internal and solar heat gains. The method first determines a time series of the heating power required by a typical Passive House. The design periods can be determined by using different window fractions on the south façade, which typically makes the peak load switch to another day. The effective boundary conditions for the design periods can then be determined by observing the changes in heating power caused by small changes in the specific heat losses or the solar aperture, respectively. Depending on the climatic data source certain safety margins may be applied to account e.g. for changes in the weather of different years. The method is described in detail in [Bisanz 1999]. A validation using field measurements can be found in [Feist 2005].

For the 7 climatic data sets used here, heating load data were determined following this procedure for the year 2005. To allow for a better comparison the PHPP's usual safety margin for internal heat gains of 0.5 W/m² was *not* applied.

Figure 5 shows a comparison of the PHPP results and the DYNBIL simulation. The discrepancy always lies within the limits of acceptability: For the Passive Houses, differences of no more than 2 W/m² are observed. For the Existing Buildings the discrepancy never exceeds 10% of the heating load.

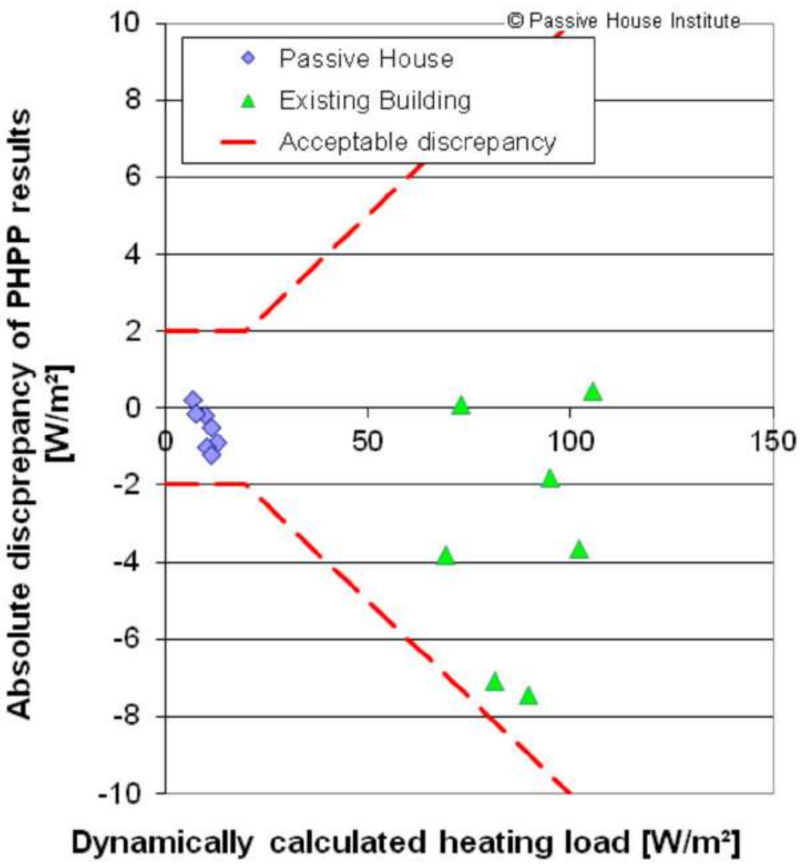

Figure 5: Comparison of peak daily average heating load from PHPP calculation and DYNBIL simulation

It should be noted that the heating load as calculated by the PHPP is generally smaller than in the simulation. Consequently, if the heating system is dimensioned exactly to the PHPP values, the indoor temperature will occasionally drop below the setpoint. It is not so much the difference in heating power itself but this undertemperature that is decisive for the assessment of the heating load procedure.

By limiting the available heating power in the dynamic simulation to the value calculated by the PHPP, the respective undertemperatures were determined. In Figure 6 it can be seen that for the Passive Houses the temperature drop is less than 0.1 K. Here, the PHPP provides exactly the desired result of a sufficient, but not overdimensioned heating load. Even for the Existing Buildings the temperature drops below the setpoint by less than 0.5 K, a difference that would be very hard to detect in field measurements.

It can be concluded that the heating load procedure from the PHPP can also be applied for existing buildings. No changes to the PHPP procedure are required.

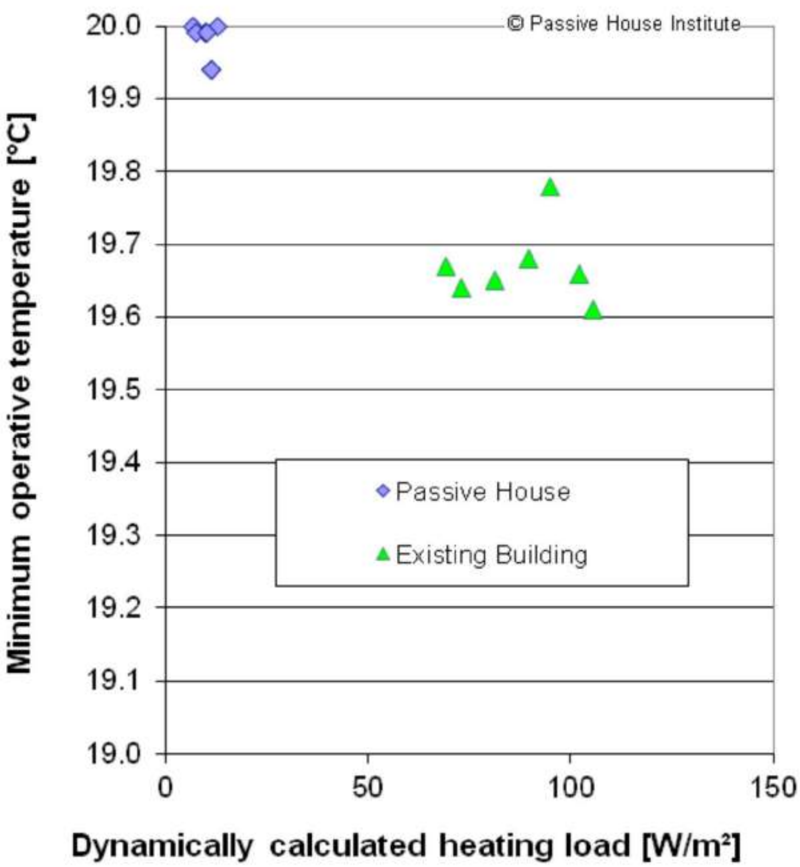

Figure 6: Lowest operative temperature (hourly values) if the heating power is limited to the value resulting from the PHPP calculation. Temperature setpoint 20 °C, usual safety margin for internal gains not applied

2.3 Annual cooling demand

The PHPP procedure for calculation of the annual cooling demand roughly follows EN 13790. Starting from the first PHPP implementation, some small modifications have been applied in order to improve the accuracy for small cooling demands: In climates with mild summers the periods where active cooling is required may be rather short, possibly only few days. To account for this possibility the PHPP splits the month of July into 4 parts of different lengths, one of them being a one-day period with the cooling load data.

The discrepancy between PHPP and simulation is shown in Figure 7. While the Passive Houses show no systematic deviation, there is a tendency for the cooling demand of the Existing Buildings to be slightly overestimated. In general, however, the agreement is very satisfactory, with only one deviation above 2 kWh/(m²a).

Conclusion: No revisions to the cooling demand calculation are required.

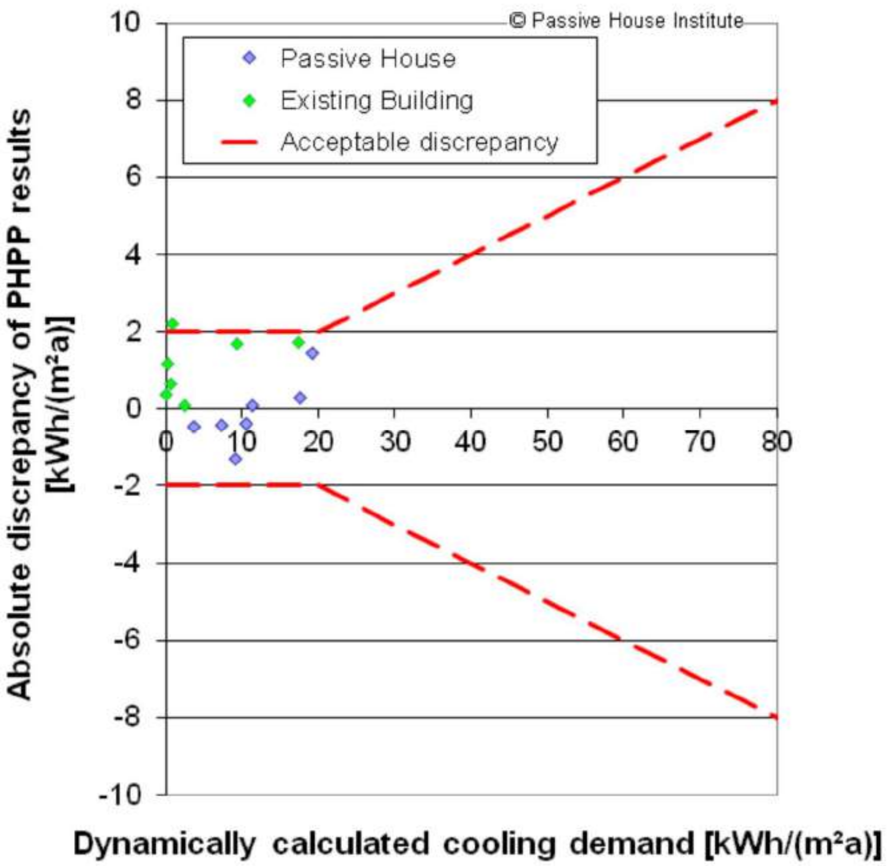

Figure 7: Comparison of annual cooling demand from PHPP calculation and DYNBIL simulation

2.4 Cooling load

The PHPP contains an algorithm for the calculation of a building's peak cooling load for the case that an active cooling system is installed. In a manner similar to the calculation of the heating load the procedure calculates a daily average load. Due to the small power required to cool a Passive House it is not necessary to consider cooling loads on a smaller time scale, e.g. hour by hour. Should a higher hourly cooling power be required during the most critical hours of the year it can be covered by increasing the temperature of the building's heat capacity.

The algorithm itself appears to be rather simple: An energy balance is set up based on design values for ambient temperature, solar radiation and internal heat loads at the design indoor temperature. The design data are, however, the crucial point in this procedure. To provide a sufficiently conservative estimate of the cooling load they are usually determined from the highest daily average temperatures combined with the highest daily average solar radiation levels in the data set. If climatic data for longer time periods, e.g. 20 years, are available, appropriate quantiles are chosen which allow for occasional excessive indoor temperatures, on average once every two years.

Similarly to the heating load calculation two design periods are considered, namely with higher or lower paths of the sun in the sky (‘declination’). Similarly to VDI 2078 this approach would detect a cooling load that occurs at moderate ambient temperatures, but high solar radiation levels on the South facade, e.g. in September.

A comparison of dynamic simulation results and PHPP calculations (Figure 8) shows that cooling loads which have been determined by this procedure are rather conservative, approximately 2 W/m² too high. This is true for both the Passive House and the Existing Building case. For Passive Houses, a similar result had already been found in [Schnieders 2012].

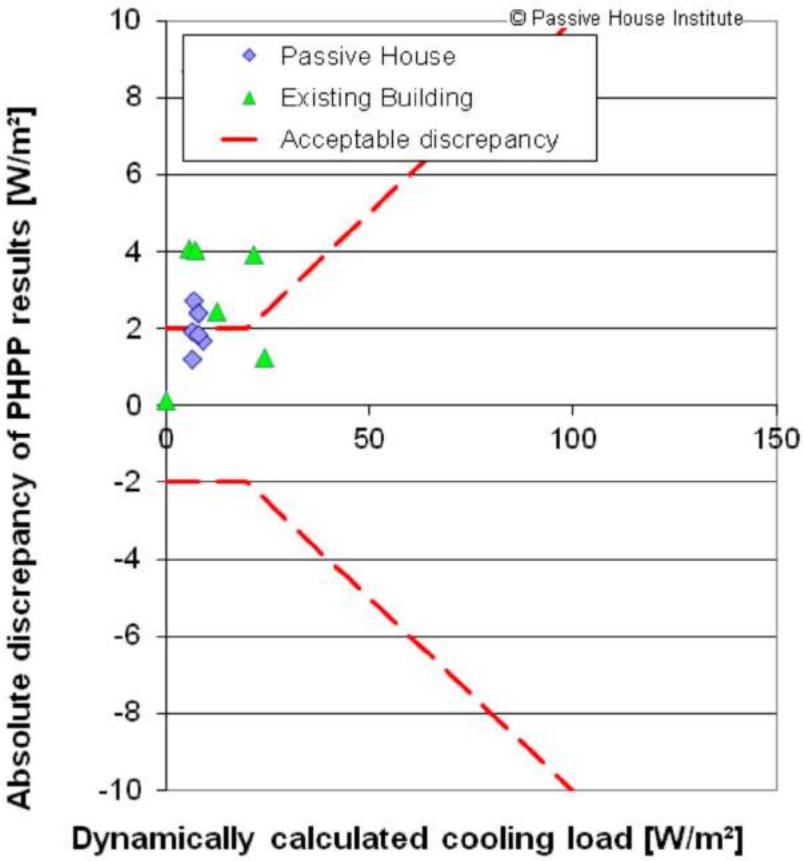

Figure 8: Comparison of peak daily average cooling load from PHPP calculation and DYNBIL simulation (existing procedure for determination of cooling load data)

Motivated by this result, the procedure for the determination of the cooling load data was reconsidered. Following a similar procedure as for the heating load data (cf. section 2.2) the cooling load data are now determined from dynamic simulations. As can be seen in Figure 9 this results in an excellent agreement of the daily average cooling loads for the Passive Houses. For the Existing Buildings, however, this procedure leads to a considerable underestimation of the daily average cooling load by up to 8 W/m². The reason is that the high time constant of the Passive Houses has entered into the cooling load data.

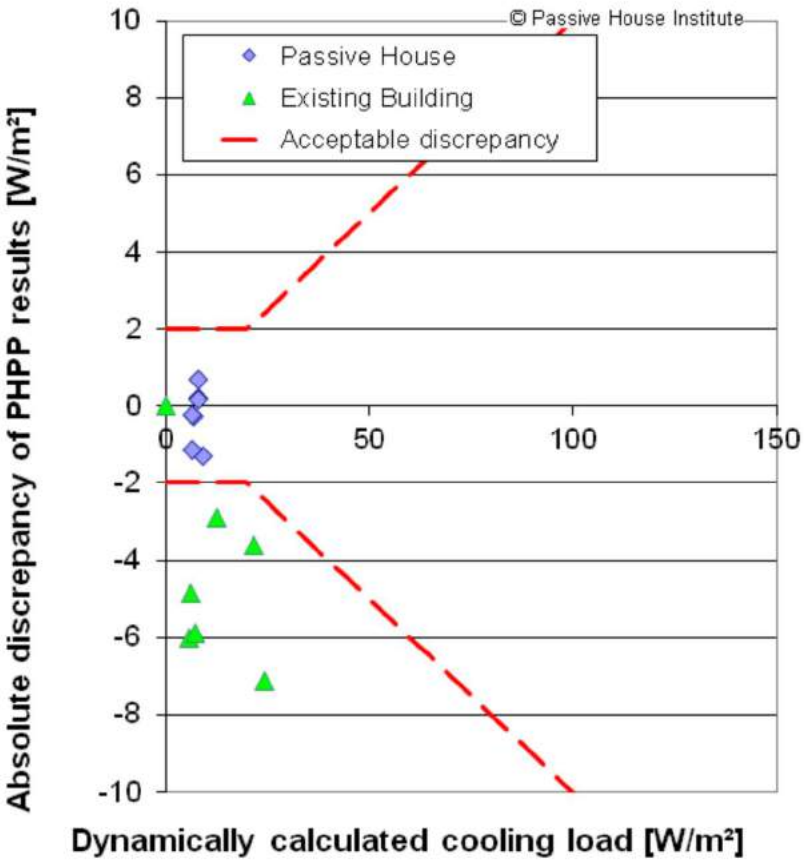

Figure 9: Comparison of peak daily average cooling load from PHPP calculation and DYNBIL simulation (alternative, dynamic procedure for determination of cooling load data)

The peak temperatures at a cooling power that is limited to the PHPP result can be seen in Figure 10. In the Passive House case the overtemperatures are always less than 1 K, which is within the acceptable range. For the Existing Buildings, probably also due to the underestimation of the daily average cooling load itself, the temperature difference may reach 2 K. In principle this means that the adjusted procedure cannot be applied to buildings with low levels of insulation and solar protection and that the algorithm would require some further adjustment, depending on the building type. However, such an adjustment would render the procedure rather complicated. This does not appear justified because cooling systems in old buildings usually do not run continuously, so that some extra cooling power for reducing the temperature at the beginning of the utilisation period will have to be foreseen anyway. Therefore it appears more appropriate to design cooling systems for existing buildings with some buffer in the available cooling power anyway.

It can be concluded that modifications of the PHPP cooling load algorithms would not be justified.

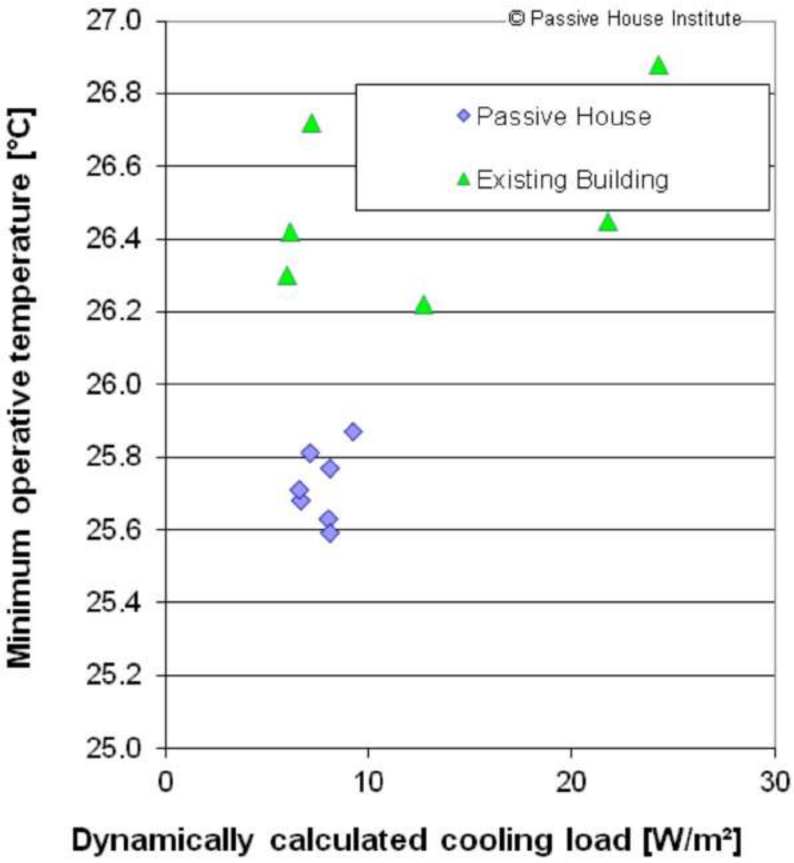

Figure 10: Highest operative temperature (hourly values) if the cooling power is limited to the value resulting from the PHPP calculation. Temperature setpoint 25 °C.

2.5 Frequency of overheating

An accurate prediction of indoor temperatures in a free-running building is very difficult. Overheating frequency is influenced by shading and ventilation and their respective patterns of use, but also by the weather. A hot summer, as compared to a typical one, may increase the overheating frequency by more than 10 percentage points (cf. [Schnieders 2012]). This means that it is fully sufficient to distinguish between a limited number of summer comfort levels in buildings without active cooling, e.g. excellent (overheating for 0-2% of an average year), good (2-5%), acceptable (5-10%), bad (10-15%), very bad (above 15%). Accordingly, the accuracy of the calculation need not be higher than 3 percentage points for low overheating frequencies and about 5 percentage points at 20% overheating.

A comparison of the results for overheating frequency from the PHPP summer worksheet and from dynamic simulation is shown in Figure 11. In order to bring the majority of the buildings into the interesting range of less than 20% overheating, a heat recovery bypass and an additional summer ventilation of 480 m³/h were assumed. With one exception, the accuracy of the PHPP calculation is fully sufficient, both for the Passive House and Existing Building cases.

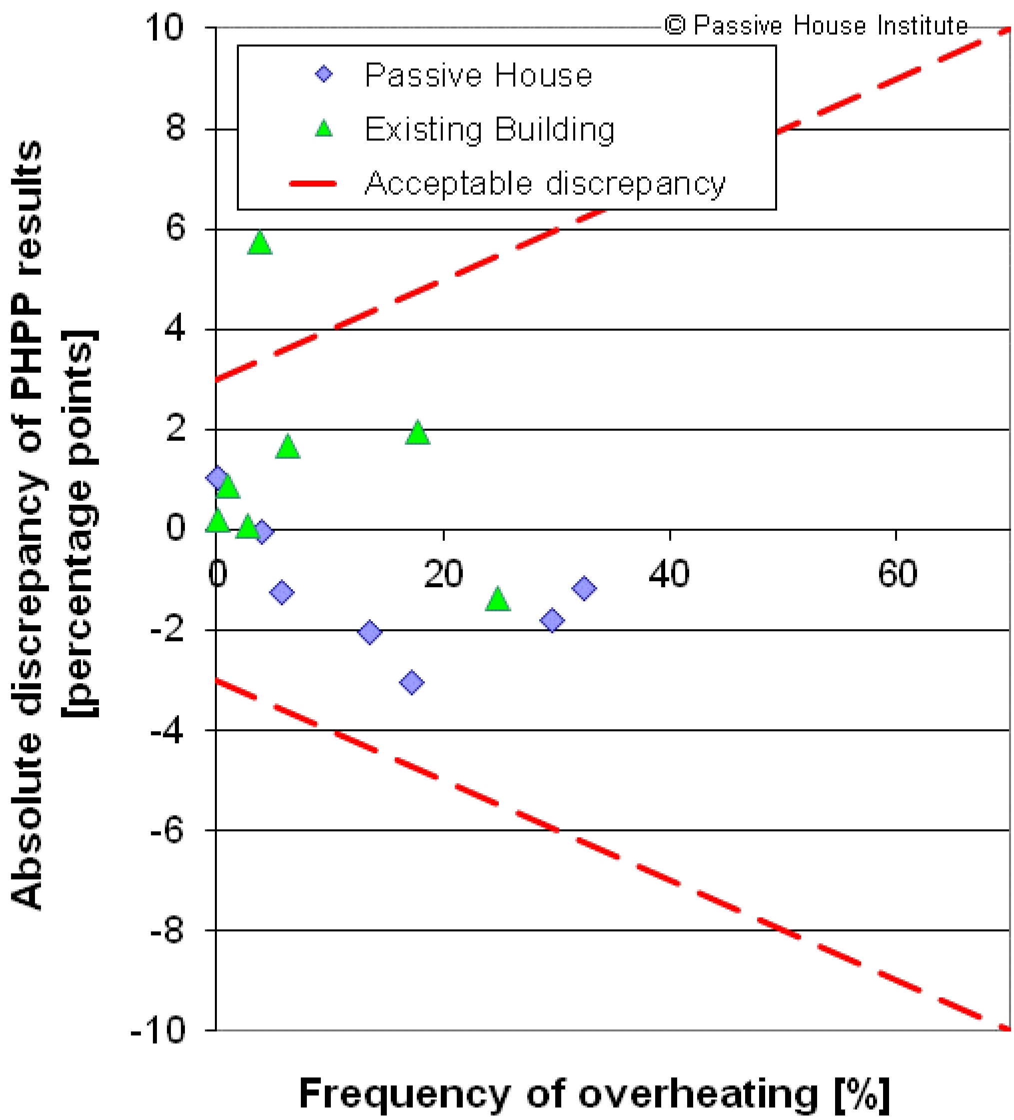

Figure 11: Comparison of overheating frequency over 25 °C

Again, it can be concluded that no particular changes to the summer overheating calculation are required in order to account for uninsulated buildings.

3 Heat losses through the ground in the calculation of the time constant

When determining the annual heating demand, the time constant of the building is one of the inputs for the calculation of what fraction of the internal and solar heat gains becomes useful in the energy balance. Similarly, the time constant determines which fraction of the heat losses becomes effective to reduce the annual cooling demand. The influence of the time constant is relatively small, and EN 13790 therefore states that “a relative uncertainty ten times higher than that of the heat loss is acceptable”.

The time constant of a building is calculated from its heat losses and its heat capacity. Higher heat losses would result in a faster reaction of the building to changes in the boundary conditions, thus reducing the time constant and the utilisation factor. In the past, the PHPP calculated the time constant from all the U-values and areas of the external building elements, neglecting possible changes of the time constant due to the adjacent ground. This latter effect is indeed negligible for well-insulated buildings, it typically reduces the heating demand by less than 0.1 %.

On rare occasions this influence may become greater, particularly if the floor slab is not insulated at all, but the rest of the building is. This can sometimes happen in case of refurbishments, depending on climate or refurbishment concept, or also in step-by-step refurbishments, where only façade and roof might be renovated in a first step but not the floor. In such cases effects up to an order of 1 kWh/(m²a) may be observed. Therefore, the calculation of the time constant in the PHPP was adapted in order to better represent the effects of the adjacent ground also for uninsulated buildings. It should be noted that the calculation of the heat losses through the ground did not require any adaptations; the change only affects the utilisation factor.

4 Standard values for internal heat gains

Up to PHPP 8, internal heat gains (IHG) for residential buildings were assumed to be 2.1 W/m² living area. Although this value lead to good agreement with monitoring results in many projects (cf. section 1.1), [Grant 2014] pointed out that the value is likely to be higher for smaller dwelling units, and possibly lower for very large units. This is due to the fact that smaller dwellings tend, on average, to have a higher occupancy, with all per-person IHGs becoming higher in a per-square-meter reference frame, and that some appliances exist in every apartment, even if it only has a small living area. Given that existing buildings often have smaller dwelling units, the effects f higher heat gains become particularly relevant in the field of refurbishment.

Proceeding from these considerations, an approach for occupancy rates and internal heat gains was devised. Statistical correlations between the floor area of a dwelling unit and the number of occupants could be found (cf. Figure 12).

Assuming highly efficient household appliances as well as heating and DHW systems that are suitable for a future, all-renewable energy supply, typical values for IHG depending on the size of the dwelling unit could be derived. The correlation follows the function

$$IHG = 2.1\frac{W}{m^2} + \frac{50\,W}{A_{DU}}$$

Figure 13 shows a graphic representation. For reasons of consistency with other applications and uses in the PHPP, the standard IHGs were restricted to an intervall of 2.1 to 4.1 W/m². The model below the equation could actually give higher or lower values than that (cf. the line

'Model' in the Figure), but the validity of the underlying assumptions becomes questionable in such extreme cases.

Details about the IHG model can be found in [Passipedia]. For very special applications it may still be advisable to carry out an individual calculation of the IHGs in order to provide a sound basis for design decisions.

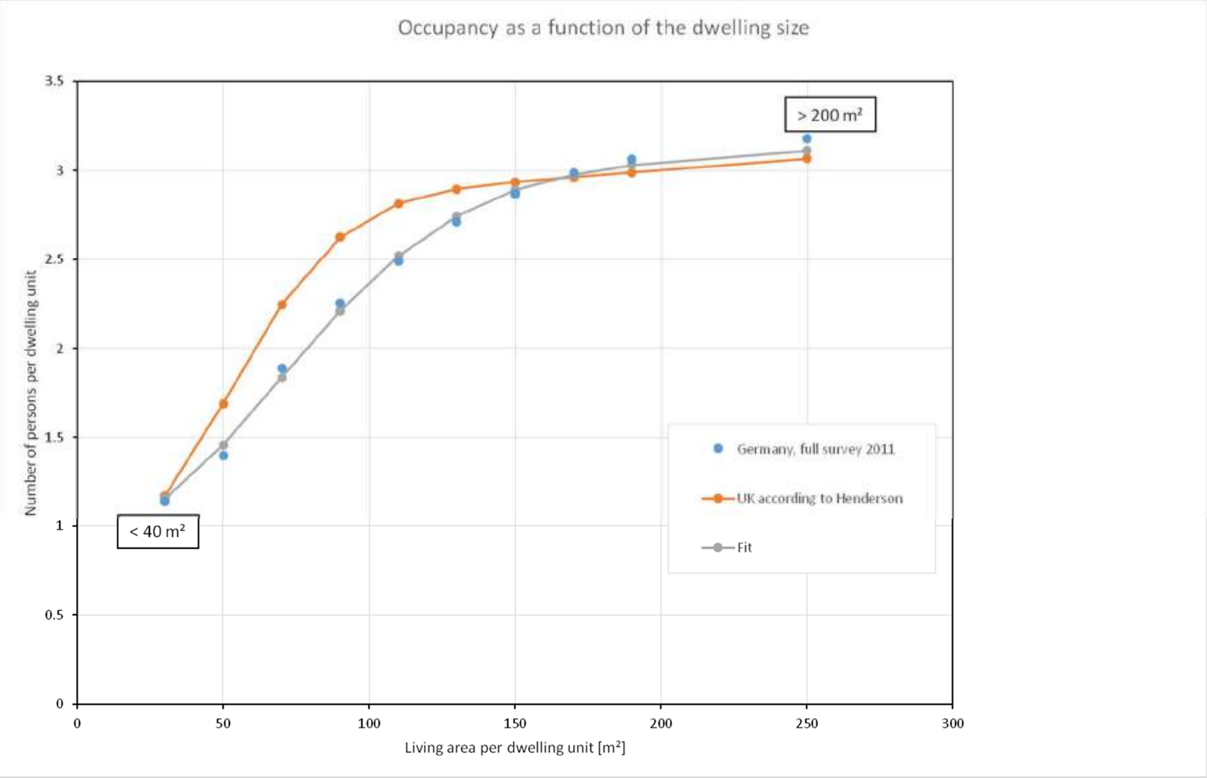

Figure 12: Average occupancy as a function of the living area

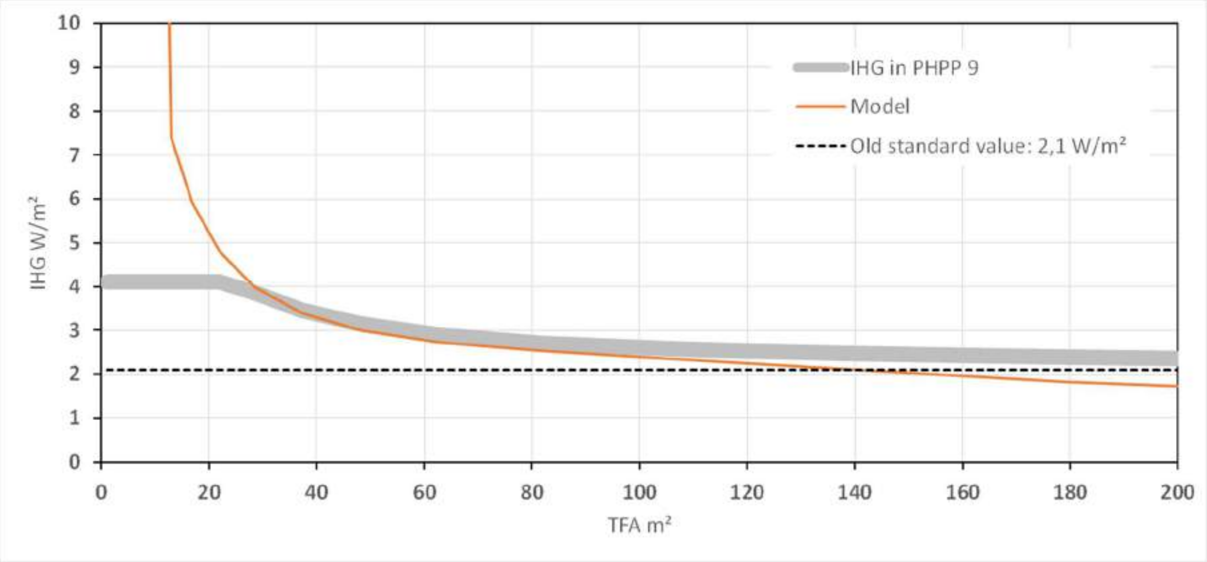

Figure 13: IHG depending on the living area, as used in the PHPP 9

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5 Conclusions

The Passive House Planning Package (PHPP) was originally developed for the design of Passive Houses, which have good thermal insulation and high time constants. Its validity for old buildings is of particular interest for the prediction of savings achieved with step-by-step refurbishments. This question was therefore investigated in the present study.

It turned out that, in general, the predictions of the PHPP agree very well with those of more complex and time-consuming dynamic simulations, both for old and new buildings. Small adaptations were applied in the calculation of the building time constant, with relevant effects only for well-insulated buildings with uninsulated floor slabs. In addition it was found that the internal heat gains of residential buildings depend, on average, on the size of the dwelling unit. A correlation reflecting this fact was implemented in the current version 9 of the PHPP.

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