Monthly Balance Based Method Versus Transient Whole Building Energy Simulation for Passive House Design

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Abstract

For the design of the so called passive houses a monthly balance based method, is used. This paper compares the balance based method of the Passive House Planning Package (PHPP) with the results of an easy to use whole building energy simulation software based on a simplified black-box model. The different calculation methods for all heat flows influencing the energy performance are compared. Shortcomings and advantages of the different methods are discussed. It is shown that both methods can produce similar results when transient effects are neglected. It can be concluded, that the time demand to set-up a complete calculation in each of the tools is approximately the same. The amount of information and possible improvement strategies regarding energy demand and comfort that can be achieved are higher with the transient simulation.

Keywords – passive house;dynamic building simulation; monthly balanced method, WUFI®Passive, PHPP

1. Introduction

A significant part of global energy consumption is caused by households. In Germany for example the domestic consumption in 2008 counted for 27% of the total energy uses [1].

Energy-efficient building standards can help to reduce this fraction. In Germany an ordinary building consumes 220 $\frac{\mathrm{kWh}}{\mathrm{m^2\,year}}$ only for heating [2]. For comparison, a typical house build in 2002 requires only 70$\frac{\mathrm{kWh}}{\mathrm{m^2\,year}}$ for heating [2]. The certification criteria for a Passive House is much lower with 15 $\frac{\mathrm{kWh}}{\mathrm{m^2\,year}}$. This illustrates how the use of energy efficient technologies can significantly undercut the current state of standardization.

The Passive House concept was developed in the mid 80´s from a low-energy standard for new buildings in the Nordic countries [3]. The concept is based on the following principles: excellent thermal protection, avoidance of thermal bridges, airtightness of the building envelope, well insulated windows, and a controlled ventilation system [3]. The heating should be realized via the already required ventilation system. By building without a separate heating system, investment costs will be reduced, this limits the additional financial burden.

2. Methodology

For the design of such a building the PHPP from the Passive House Institute (PHI) could be used. The PHPP is using Excel© as its program base and calculates the annual heating demand by monthly heat balances [4]. In this method the internal- and solar heat gains are weighted by an utilization factor and subtracted from the heat losses. The required heating power in the PHPP method is calculated by (1) following [4].

$$\mathrm{Q_H} = (Q_T + Q_V) - (Q_S + Q_I) \cdot \eta \qquad (1)$$

where:

Q_H – heating demand $[\frac{\mathrm{kWh}}{\mathrm{a}}]$

Q_T- transmission heat losses $[\frac{\mathrm{kWh}}{\mathrm{a}}]$

Q_V - ventilation heat losses $[\frac{\mathrm{kWh}}{\mathrm{a}}]$

Q_S – solar heat gains $[\frac{\mathrm{kWh}}{\mathrm{a}}]$

Q_I - internal heat gains $[\frac{\mathrm{kWh}}{\mathrm{a}}]$

η – utilization factor

In the PHPP, the period under review for the annual heating demand depends on the monthly difference between the heat losses and the heat gains. If this difference is greater than 0.1kWh the month will be considered in the calculation. The result is a variable period under observation depending on the ambient climate and the thermal performance of the building.

For an estimation of the annual heating demand the monthly method is adequate. It is assumed that the monthly method is validated with a transient calibration simulation [4].

The Passive house concept was reviewed within the European project *Cost Efficient Passive Houses as European Standards* (CEPHEUS). As a result this project illustrates that the specific annual heating demand calculated with the PHPP is slightly below the measured heating demand [5]. Among other things this is due to the drying of the built in moisture of the construction [5]. Furthermore the calculated heating demand for each month is not directly comparable to the result of a dynamic simulation; the discrepancy is due to the disregarding of seasonal heat storage effects [4].

A stronger temporal discretization than a monthly one and a combined calculation of heat – and moisture flows could solve these problems. It can also improve the assessment of thermal comfort, e.g. through the calculation of the *Predicted Percentage of Dissatisfied People* (PPD) in accordance to the ISO 7730:2005-11. Another additional option is the mold growth prediction. For other climate zones than the North and Central European ones, the importance of this features rises.

A higher degree of discretization could be reached by using dynamic building simulation software e.g. WUFI®Passive. WUFI®Passive combines the hygrothermal component simulation with the energetic whole building simulation. The coupled heat- and moisture transport in the building envelope is documented in [6]. The physical background for indoor climate simulation is the heat balance equation. In one zone the heat balance can be written as (2) in accordance to [7].

$$\rho \cdot c \cdot V \cdot \frac{d\vartheta_i}{dt} = \sum_j A_j \alpha_j (\vartheta_j - \vartheta_i) + \dot{Q}_{sol} + \dot{Q}_{IHS} + n \cdot V \cdot \rho \cdot c \cdot (\vartheta_a - \vartheta_i) + \dot{Q}_{HVAC} \quad (2)$$

with:

$\rho =$ density of air $\left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]$
$\alpha_j =$ heat transfer coefficient $\left[\frac{\mathrm{W}}{\mathrm{m}^2\,\mathrm{K}}\right]$ following [8]
$\vartheta_a =$ exterior air temperature [°C]
$\vartheta_i =$ interior air temperature [°C]
$\vartheta_j =$ temperature of the envelope [°C]
$t =$ time [s]
$A_j =$ area of the envelope [m^2]
$c =$ specific heat capacity $\left[\frac{\mathrm{J}}{\mathrm{kg}\,\mathrm{K}}\right]$
$n =$ air change rate $\left[\frac{1}{\mathrm{h}}\right]$
$V =$ room volume [m^3]
$\dot{Q}_{sol} =$ direct solar irradiance [W]
$\dot{Q}_{IHS} =$ internal heat sources [W]
$\dot{Q}_{HVAC} =$ heat flux through the ventilation system [W]

For the detailed comparison of the individual heat flows a very simple “black-box” as shown in Figure 1 was designed.

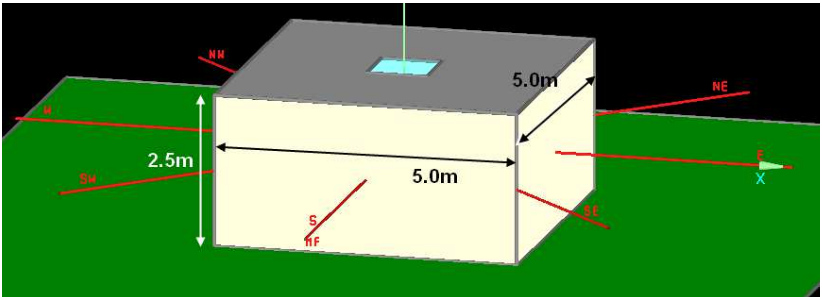

Fig. 1 “black-box” for the comparison

The components are assumed to be solid concrete with an exterior expanded polystyrene (EPS) insulation to reach passive house criteria and a roof light in the flat roof. For the comparison the ambient climate of the Hohenpeissenberg, Germany was chosen.

In order to create the same initial conditions for both calculations, the climate data was taken from the climate database METEONORM. The residual difference between both datasets is due to the adverse resolution [monthly average value (PHPP), vs. hourly values (WUFI®Passive)]. The heating degree hours for WUFI®Passive, based on 20°C indoor temperature, are slightly higher. This means that WUFI®Passive will slightly overestimate the transmission losses. Furthermore it should be noted that the calculation of solar irradiance on vertically oriented surfaces is different between METEONORM and WUFI®Passive. The horizontal global radiation is the same for both programs.

In the first step each of the four heat fluxes (transmission-, ventilation losses, solar- , and internal gains) is compared in detail. In the next step, the annual heating demand should be investigated. For this comparison the original steady state PHPP heating demand calculation was step by step replaced with the transient interim results from WUFI®Passive.

This approach was chosen to detect deviations between the two programs at an early stage. The individual factors considered were: the specific heat capacity of air, the heat flow calculation method, and the calculation of the annual heating demand. On example, in the first step the PHPP calculation was repeated with the simulated ventilation heat flux from WUFI®Passive. The result of this calculation was set into relation to the original PHPP calculation and illustrates the influence of the different calculation methods [volume-(PHPP) vs. mass-flow (WUFI®Passive)].

For the evaluation of the results it is important to define an interval of acceptance for the deviation. For this work the +/-0.1K criteria based on [9] is used. This is based on the assumption, that a temperature could be measured only within an accuracy of ±0.1K over a long period of time. On example this means for a calculation period of one year (8760h) a fluctuation of ±0.876kKh for the heating degree hours. Finally the annual heating demand is in a good agreement between both programs if the deviance is less than the discrepancy caused by a variation of the heating degree hours by 0.876kKh.

For an accurate comparison between WUFI®Passive and PHPP it is necessary to limit the heat storage effects in the components. By keeping a constant indoor temperature of 20°C these effects can be reduced.

3. Comparison

1. Transmission

One of the biggest heat losses even in well insulated buildings is the transmission heat loss through the surrounding opaque components. The heat flow through a component could be determined from the heat flow density. The heat flow density is the product of the heat transfer coefficient (α) and the difference between ambient (θ_a) and surface temperature (θ_s), as shown in (3).

$$\boldsymbol{q} = \boldsymbol{\alpha} \cdot (\boldsymbol{\vartheta_a} - \boldsymbol{\vartheta_s}) \qquad (3)$$

where:

q – heat flow density $[\frac{W}{m^2}]$

α – heat transfer coefficient $[\frac{W}{m^2K}]$ following [8]

ϑ_a – ambient temperature [°C]

ϑ_s – surface temperature [°C]

The heat transfer coefficient includes convection and radiation heat exchange and is defined in accordance to [8]. For the first comparison of the transmission losses the radiation heat exchange (absorption and emission) of the opaque partitions is unaccounted. The results are summarized in Table 1.

Table 1. Compared transmission losses

component	*WUFI®Passive [kWh/a]*	*PHPP [kWh/a]*	*deviation [%]*
exterior wall	573.2	573.3	-0.0
bottom plate	235.4	235.7	-0.1
flat roof	287.3	286.0	+0.5
total	1096	1095	+0.1

The next step is the additional consideration of the radiation heat exchange. For the PHPP the radiation exchange in Central Europe has no influence on the annual heating demand [4]. WUFI®Passive can handle the radiation heat exchange, the effect for different ambient climates is listed in Table 2.

Table 2. Effect of the radiation exchange on the heating demand

ambient climate	*WUFI®Passive [kWh/a]*	*Fraction of the total heating demand [%]*
Hohenpeissenberg	75	6.9
Holzkirchen	89	8.2
Freiburg	-6	-0.7
Brussels	-43	-5.0

2. Ventilation

For the regarded “blackbox” the second largest heat flow is the heat loss due to ventilation. In order to create the same conditions the energetic equivalent air change rate from the PHPP was used for the WUFI®Passive simulation. The energetic equivalent air change rate describes the air exchange without heat recovery. The ventilation heat flows are calculated with both programs in two different ambient climates the results are shown in Figure 2.

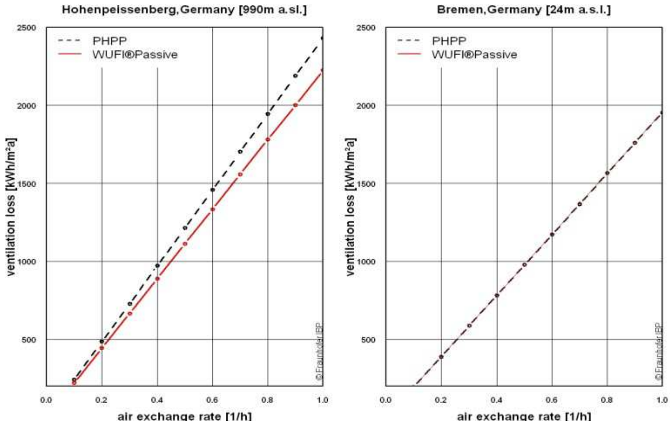

Fig. 2 ventilation heat flows depending on air change rates

For the case with 990m a.s.l. the WUFI®Passive findings are ca. 8% lower than the PHPP ones. For the case near sea level the findings are nearly equal.

3. Solar gains

In the case of the solar heat gains it is necessary to differ between gains from absorption of short wave radiation of opaque partitions and solar gains through windows. In this chapter the solar gains through windows are considered.

In both programs a horizontally oriented window was used with a *solar heat gain coefficient* (SHGC) of 0.7. The global shading factor was varied between 10% and 90%. The added solar gains for each shading factor are diagrammed in Figure 3.

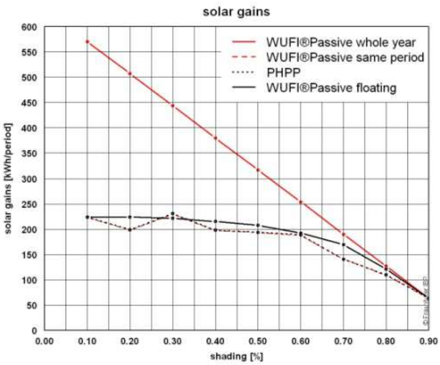

Fig. 3 Distribution of the solar gains

The graph "floating heating period" refers to the period which is under review (defined in chapter 2). For this graph, the period under observation was the whole year. During the year the solar gains were only considered if there is a heating demand at the same time. This proceeding is only possible in WUFI®Passive and unassignable to the PHPP calculation.

4. Internal gains

The second part of the heat gains are the internal gains. Internal heat gains are e.g. people or electrical machinery which is located within the thermal envelope.

The internal gains are calculated as the product of the heating days, the internal heat load, and the treated floor area [4]. If the period under observation and the boundary conditions are equal in both programs the results are also suitable.

5. Annual heating demand

As shown in equation (1) the annual heating demand in the PHPP is the difference between the heat losses and the heat gains. The utilization factor in (1) reflects how well the occurrence of the solar gains matches with the occurrence of a heating demand. For the cases considered so far, this factor was round about one.

All compared heat flows lead to the calculation of the annual heating demand. The main focus is now the evaluation of the annual heating demand. The computation was done as described in chapter 2 [equations (1) & (2)]. The findings are summarized in Table 3.

Table 3. Annual heating demand

<table>
<tr><th>PHPP origin</th><th>Heat capacity</th><th>Heat Flow</th><th>Heating Demand</th><th colspan="2">Reliance based on column 2</th></tr>
<tr><td rowspan="2">658.7</td><td rowspan="2">640.5</td><td rowspan="2">637.4</td><td rowspan="2">637.0</td><td>+ 0.1K</td><td>648.7</td></tr>
<tr><td>- 0.1K</td><td>632.4</td></tr>
</table>

From the left to the right the influence of, the specific heat capacity of air, the heat flow calculation and the heating demand calculation is represented.

If the monthly heating demands are compared between both programs there is a difference due to the seasonal heat storage effect as described in [4]. For the considered “black-box” in the ambient climate of Passau, Germany, this effect is highlighted in Figure 4.

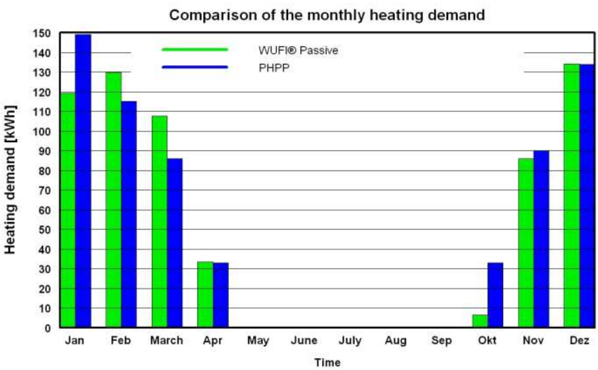

Fig. 4 Comparison of the monthly heating demand for the exemplary building in the ambient climate of Passau, Germany

4. Discussion

In Table 1 it became clear, that the WUFI®Passive results are immaterial higher than the PHPP ones, the deviation is well within the before defined reliance. Therefor it can be stated that, as long as the material parameters are the same and constant over the time and heat storage effects could be neglected, both programs provide nearly the same results.

In contrast to the PHPP the radiation exchange of opaque partitions has an effect on the WUFI®Passive heating demand (cf. Table 2). Depending on the ambient climate the effect could be positive or negative.

The consideration of the ventilation losses in chapter 3.b indicates a clear difference between both programs. The PHPP on the one hand calculates a volume flow with a constant value for the specific heat capacity of air, WUFI®Passive on the other hand calculates a mass flow with a height dependent heat capacity. The magnitude of the difference depends on the height of the building site. As Figure 3 shows for the case near sea level both programs agree very well. For the subsequent comparison this means, that the programs provide identical ventilation losses only for climates which are close to sea level.

For the solar gains the findings for both programs are the same if the period under observation is equal. The trend of the PHPP graph in Figure 3 shows some special effects, e.g. if the shading rises from 20 % to 30 %, the solar gains are increasing too. This effect is due to the longer period used for the assessment of the heating demand. With increased shading, heating is required for a longer period of time. Through this larger observation period the solar gains increase as well.

With the simulation variation “floating heating period” it was possible to smooth this effect.

Chapter 3.e is focused on the calculation of the annual heating demand. As shown in Table 3 the strongest effect is due to the different calculation of the specific heat capacity. The deviation in this case is clearly outside the reliance of the original PHPP calculation. Beside this the deviation due to the calculation of the heat fluxes and the heating demand is very small. The remaining difference compared to the original PHPP calculation method is caused by the utilization factor. For the monthly heating demand the statement from [4] could be verified. As Figure 4 showed the PHPP overestimates the heating demand in the beginning of the heating period and underestimates it in the end.

The required time to feed in the building data is relatively the same for both programs. Due to the better visualization of the building, the troubleshooting in WUFI®Passive is much easier.

5. Conclusions

The previous chapters have shown that for the considered example WUFI®Passive and the PHPP method provide comparable results. For the considered “black-box”, both the individual heat flows as well as the heating demand can be replicated with a high accuracy. It should be noted that this is only possible through the limitation of heat storage effects and the adaption of the observation period. For other types of construction as well as for more complex buildings the findings from both programs could differ.

The PHPP calculation method allows a fast assessment of the annual heating demand. The transient simulation of WUFI®Passive allows a more detailed evaluation of the heating demand, the thermal comfort and additional analysis e.g. mold grow prediction.

6. Outlook

This work highlighted the differences and the similarities between both calculation methods. Possible further analysis could be the detailed assessment of the heat storage effects (e.g. in the field of summer comfort), the hygrothermal assessment of passive house components in other climate zones, the influence of multi zonal simulation and the comparison of real already built passive houses.

7. Acknowledgment

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