Evaluation of a versatile energy auditing tool

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ABSTRACT
Energy auditing can be an important contribution for identification and assessment of energy conservation measures (ECMs) in buildings. Numerous tools and software have been developed, with varying degree of precision and complexity and different areas of use.

This paper evaluates PHPP as a versatile, easy-to-use energy auditing tool and gives examples of how it has been compared to a dynamic simulation tool, within the EU-project iNSPiRe. PHPP is a monthly balance energy calculation tool based on EN13790. It is intended for assisting the design of Passive Houses and energy renovation projects and as guidance in the choice of appropriate ECMs.

PHPP was compared against the transient simulation software TRNSYS for a single family house and a multi-family house. It should be mentioned that dynamic building simulations might strongly depend on the model assumptions and simplifications compared to reality, such as ideal heating or real heat emission system. Setting common boundary conditions for both PHPP and TRNSYS, the ideal heating and cooling loads and demands were compared on monthly and annual basis for seven European locations and buildings with different floor area, S/V ratio, U-values and glazed area of the external walls.

The results show that PHPP can be used to assess the heating demand of single-zone buildings and the reduction of heating demand with ECMs with good precision. The estimation of cooling demand is also acceptable if an appropriate shading factor is applied in PHPP. In general, PHPP intentionally overestimates heating and cooling loads, to be on the safe side for system sizing. Overall, the agreement with TRNSYS is better in cases with higher quality of the envelope as in cold climates and for good energy standards. As an energy auditing tool intended for pre-design it is a good, versatile and easy-to-use alternative to more complex simulation tools.

KEYWORDS
Energy auditing tool, energy conservation, building simulation, PHPP, TRNSYS

INTRODUCTION
Accounting for 40% of the total energy use in Europe, the building sector is very important in the work towards more efficient use of energy and resources (EC, 2008, EC, 2010). As a part in that work, energy auditing can be an effective way to identify and assess energy conservation measures (ECMs) in buildings. While the extent of an energy audit can vary, it typically includes data collection and review, system survey and measurements, observation and review of operating practices and data analysis (Krarti, 2010). An energy audit is normally done using

one of the many available computer software or calculation tools. A comprehensive review of existing software for energy auditing, certification, calculation and simulation was done within the iNSPiRe project (Gustafsson et al., 2015), identifying more than 200 tools with varying scopes and levels of detail. A lot of the tools in the survey had limitations in terms of area of use, restricted modification rights, high level of knowledge required or not being available in English.

PHPP was developed by Passive House Institute in Germany as an easy-to-use planning tool for energy efficient buildings, intended for architects and planning experts (PHl, 1998). Heating and cooling demand is calculated according to EN ISO 13790 (ISO, 2008) as a monthly energy balance. Heating load is calculated using an approach considering two days (one cold and sunny and one milder but overcast) (Bisanz, 1999) and a similar method is used also for cooling load (Schneiders, 2012). Both are estimated with a safety margin for designing purposes without taking building dynamics into account. Other features include calculation of heating and cooling load, active components (heat pumps, boilers, air heat recovery, solar thermal, PV), passive components (opaque, transparent, frame, thermal bridge), shading, ground losses and DHW losses (distribution/storage). Being a monthly balance calculation tool, PHPP has some limitation compared to dynamic simulation tools, as complex control of systems is not possible. Furthermore, the building, regardless of size, is modelled as a single zone.

Many features and components of PHPP have been validated in previous studies, including the solar thermal (Siegele et al., 2015) and heat pump (Dermentzis et al., 2014) applications. Gustafsson, Dermentzis et al. (Gustafsson et al., 2014) compared the heating demand of low-energy and passive single family houses in PHPP and TRNSYS for seven European climates. Ochs, Dermentzis et al. (Ochs et al., 2013) performed a parametric study with 44 renovation variants of a multi-family house with four apartments and compared heating demands and heat loads to TRNSYS and MATLAB/Simulink results. For larger buildings and for cooling, however, there is more work to be done.

In this paper, PHPP is assessed as an energy auditing tool for single- and multi-family houses through comparison against TRNSYS 17 (Klein et al., 2011). The study focuses on calculation of heating and cooling demand, heating and cooling load, heat losses and heat gains. Buildings of different energy standard, from typical levels of existing buildings down to a heating demand of 25 kWh/(m²·a), were included, and climate data for seven European locations were used.

METHOD

Calculation results from PHPP were compared against results for a full year simulation with TRNSYS 17, a dynamic simulation tool for buildings and energy systems (Klein et al., 2011). Identical boundary conditions and building models, a 97 m² single family house (designed by EURAC (Birchall et al., 2014)) and a multi-family house (designed by UIBK (Birchall et al., 2014)) of 1950 m², were defined and implemented in PHPP and in TRNSYS. Both houses were modelled as single-zone buildings in TRNSYS, which is always the case in PHPP. The comparison included heating and cooling loads and demands, heat losses and heat gains, and was done for seven European locations, defined in the iNSPiRe project to represent regions with similar numbers of heating and cooling degree days (Birchall et al., 2014). The locations used were: Stockholm, Sweden; Gdansk, Poland; London, UK; Stuttgart, Germany; Lyon, France; Madrid, Spain; and Rome, Italy. The houses were modelled in their existing state (denoted “EX”), with construction data for typical buildings from the period 1945-1970 in the respective climate (Birchall et al., 2014), and with ECMs applied to achieve annual heating demand levels of 45 kWh/(m²·a) (denoted “45”) and 25 kWh/(m²·a) (denoted “25”), respectively. The ECMs included mechanical ventilation with heat recovery (MVHR), new windows and insulation in walls, roof and ground floor layers, and were defined to achieve the chosen heating demand in PHPP. For the single family house, a comparison was done between using the convective and the operative temperature for controlling the heating and cooling in TRNSYS, while for the multi-family house the operative temperature was used throughout. PHPP does not distinguish between convective and operative temperature. Boundary conditions regarding shading, ventilation and internal gains were based on IEA/SHC Task 44 (IEA, 2012) and are described in detail in iNSPiRe project reports (Birchall et al., 2014, Gustafsson et al., 2015).

The reader should keep in mind that results of dynamic building simulations might strongly depend on the model assumptions and simplifications, such as ideal heating or real heat emission system, heat emission to convective or radiative node, control with respect to radiative or operative temperature, sky model, zoning or ground coupling etc. Also the choice of the physical model (e.g. star-node or 2-star, transfer function or R-C-wall) might influence the results.

RESULTS

Single family house

Figure 1 shows the heating demand for all variations of the single family house as simulated with TRNSYS and calculated with PHPP, as well as the absolute difference between TRNSYS and PHPP. For the renovated cases the deviations are below 5 kWh/($m^2 \cdot a$), except for the “45” house in the warmest climates of Madrid and Rome. For Rome “45” there was a different behavior in TRNSYS with respect to ground losses. For the existing cases the absolute deviations are generally higher, but in relative numbers they are below 7%. The difference between using convective or operative temperature for heating control in TRNSYS is negligible for the renovated cases, while for the existing cases the heating demand is considerably higher if the operative temperature is used.

When it comes to the maximum daily heating load, the deviations are also small in absolute terms – 6 W/m^2 or less for the renovated cases. For the non-renovated houses in Gdansk, London and Stuttgart, the agreement is also very good. PHPP calculations give slightly higher heating loads than TRNSYS for all cases apart from STO_EX (5.5 W/m^2 higher or 9%).

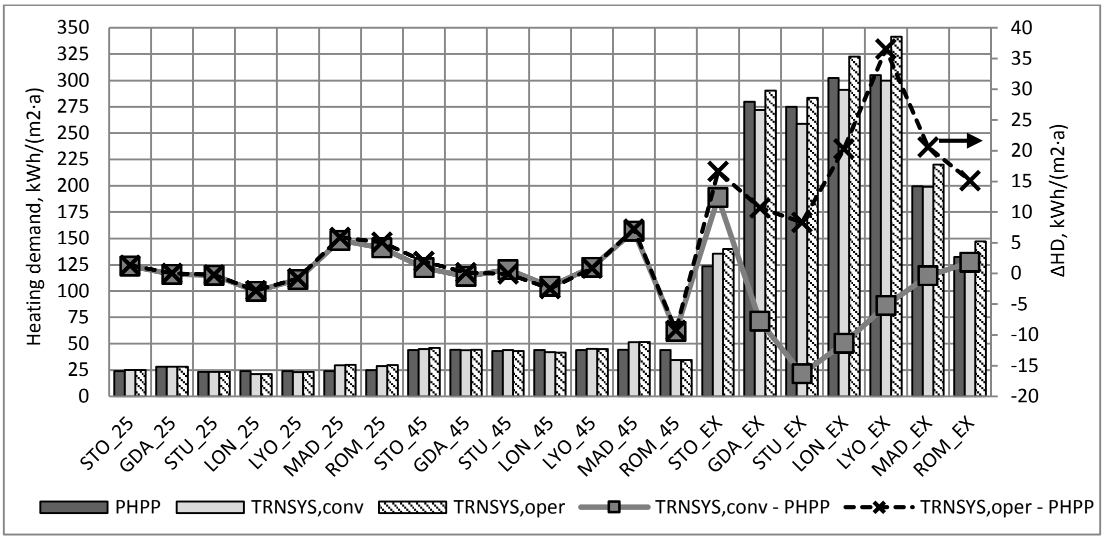

Figure 1. Heating demand (left axis) and absolute deviation (right axis) between TRNSYS (convective/operative temperature control) and PHPP for the single family house model for all climates and renovation levels.

Figure 2 shows the results from TRNSYS and PHPP for the cooling demand of the single family house, with absolute deviation between TRNSYS and PHPP. For the climates of Lyon, Madrid and Rome, which have the highest cooling demands, the relative deviations are within ±27%. The absolute deviations for these climates are below 4.3 kWh/(m²·a), except for ROM_45 with 6 kWh/(m²·a), where there was the same issue with the ground losses as for the heating comparison. Generally, the agreement is acceptable, although not as good as for the heating demand. The difference between using convective or operative temperature in TRNSYS was noteworthy only for the warmer climates, although still not larger than 1 – 8 kWh/(m²·a).

The cooling loads are, similar to the heating loads, higher in PHPP than in TRNSYS (equal for LYO_25 and ROM_45). The agreement for the cooling loads is better for renovated buildings, with deviations below 5 W/m^2 for all cases, while for the existing cases the deviations are above 10 W/m^2 for Lyon, Madrid and Rome.

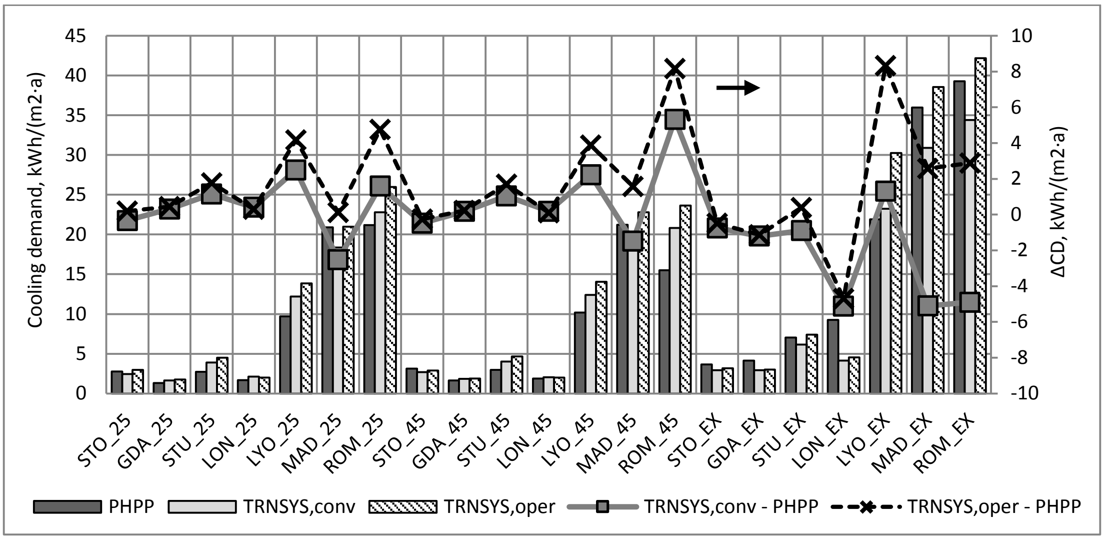

Figure 2. Cooling demand (left axis) and absolute deviation (right axis) between TRNSYS (convective/operative temperature control) and PHPP for the single family house model for all climates and renovation levels.

Multi-family house

Results for the heating demand of the multi-family house are shown in Figure 3, with absolute deviation between TRNSYS and PHPP. Contrary to what is seen for the single family house, PHPP produces slightly lower results than TRNSYS for all cases. The agreement is good though, within 1 – 6 kWh/(m²·a) for almost all renovated cases in the colder climates: Stockholm, Gdansk, Stuttgart, London and even Lyon. For non-renovated cases and warmer climates the absolute deviations are larger, although not so high in relative terms.

The heating loads are in most cases higher in PHPP than in TRNSYS, around 1 – 5 W/m^2, with exception for the existing buildings in Gdansk, Stuttgart, London, Lyon and Madrid and the 45 kWh/(m²·a) house in Gdansk and Madrid, where TRNSYS gives 1 – 4 W/m^2 higher results.

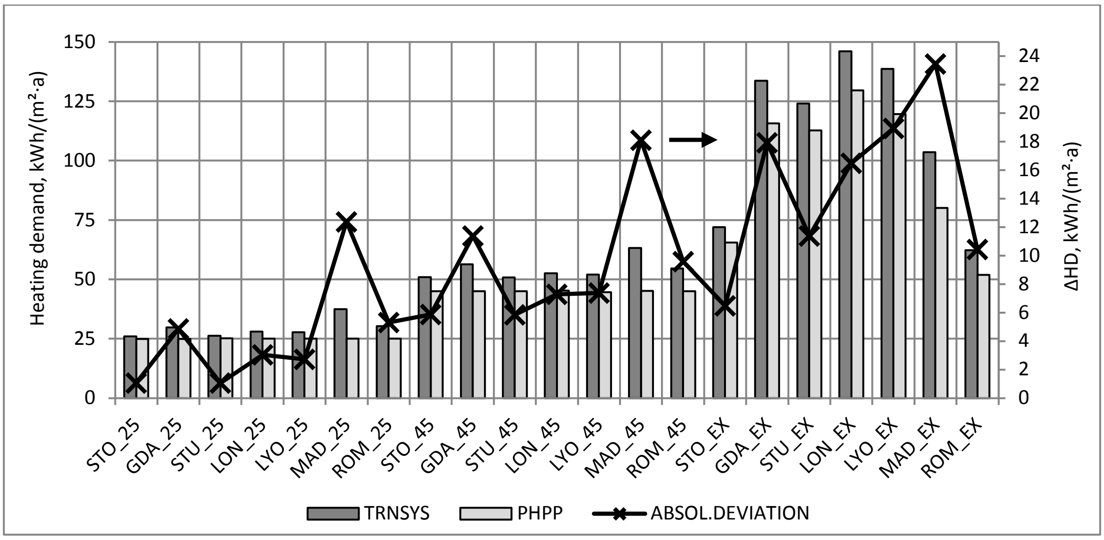

Figure 3. Heating demand (left axis) and absolute deviation (right axis) in TRNSYS and PHPP for the multi-family house model for all climates and renovation levels.

Figure 4 shows the cooling demand for all variations of the multi-family house in TRNSYS and PHPP, with absolute deviations between the two tools. TRNSYS gives slightly higher results than PHPP, 1 – 8 kWh/(m²·a), for all cases except Lyon. The agreement is equally good for renovated and existing houses.

The cooling loads of the multi-family house are higher in PHPP than in TRNSYS for all cases, with a difference of 1 – 7 W/m^2.

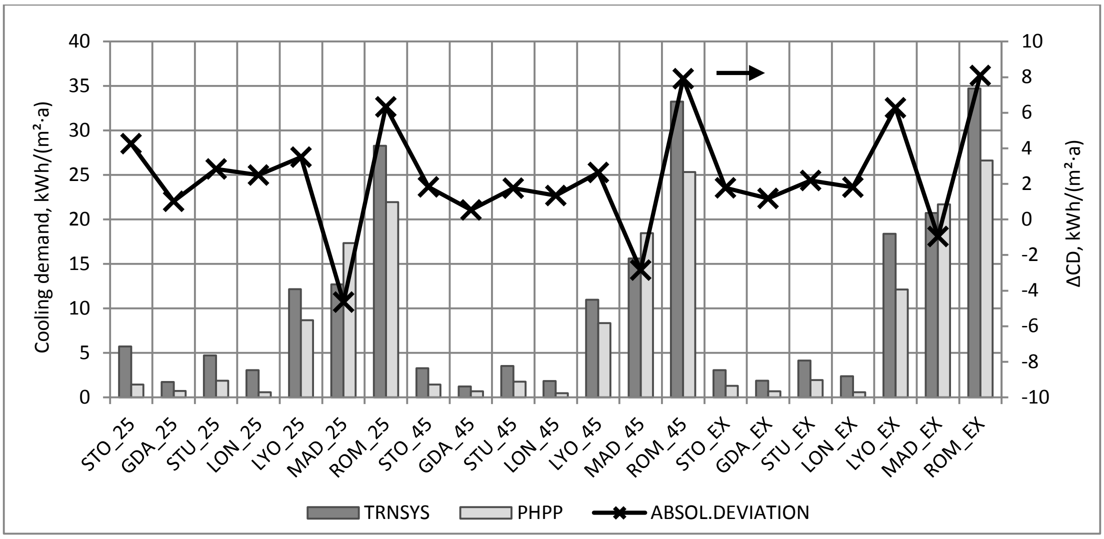

Figure 4. Cooling demand (left axis) and absolute deviation (right axis) in TRNSYS and PHPP for the multi-family house model for all climates and renovation levels.

DISCUSSION

In general, the agreement between PHPP and TRNSYS is good. The comparison is a bit better for heating than for cooling. It is also better for houses with good quality of the building envelope, i.e. better for renovated buildings than existing and better in cold climates than in warm climates. It should be noted that for the colder climates of Stockholm, Gdansk, Stuttgart and London, the cooling demand is too small to make a meaningful comparison. Heating and cooling loads are in most cases estimated to be higher in PHPP than in TRNSYS. This overestimation, however, is intentional, to be on the safe side for system design.

In PHPP, the internal temperature was assumed to be 20 °C in the winter season and 25 °C and in summer season; no transition season exists in PHPP. Thus, in cases where there are periods with cooling demand and heating demand at the same time there is a disagreement between the internal temperature of TRNSYS and PHPP, resulting in the deviations of the transmission and ventilation losses. The influence on the total heating and cooling demand is, however, negligible.

For the multi-family houses, heating demands were higher in TRNSYS than in PHPP. This happened mainly for two reasons: 1) The set point temperature in TRNSYS was controlled according to the operative instead of convective. As a consequence, the convective temperature will often be higher than 20 °C, thus increasing the heating demand; 2) In PHPP, unlike TRNSYS, there is a fully separated algorithm for heating and cooling calculations. The parameters controlling shading and bypass of MVHR should therefore work only in non-heating period, while in TRNSYS these two parameters may influence also the heating period.

CONCLUSIONS

This paper evaluates PHPP as an energy auditing tool for residential buildings by comparing calculations of heating and cooling demands and loads to the dynamic simulation tool TRNSYS. The comparison includes renovated and existing single- and multi-family houses in seven European climates.

The investigations show that PHPP can be used to assess the heating demand of residential buildings and the reduction of heating demand with energy conservation measures. The prediction of the cooling demand is also acceptable. Generally, the results are better in cases of good energy standards and with higher quality of the envelope (e.g. as in cold compared to warm climates). The predictability is more difficult for lower envelope qualities due to the increasing influence of the boundary conditions. However, setting the boundary conditions correctly in a simulation requires more information, which might not be available in many cases, thereby be based on assumptions as well.

As an energy auditing tool intended for pre-design, PHPP is an easy-to-use, versatile and accurate alternative to more complex simulation tools. In addition to what was shown here, it is also possible to perform parametric studies, including comparison of economics of different energy conservation measures.

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