Comparison Between the EN ISO 52016-1 Hourly Calculation Method and a Fully Detailed Dynamic Simulation

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Comparison Between the EN ISO 52016-1 Hourly Calculation Method and a Fully Detailed Dynamic Simulation

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Abstract

The present research proposes a preliminary investigation of the new hourly method for the assessment of building energy needs for heating and cooling introduced by the EN ISO 52016-1 standard. It was applied to a case study and compared with a fully detailed dynamic model (EnergyPlus). The comparison was performed considering two building operation modes: in a free-floating condition, the hourly differences between the indoor operative temperatures were analysed considering the different contributions to the heat balance; in an ideal heating and cooling system operation, the heating and cooling energy needs were compared on a monthly basis. The discrepancies between the calculation methods, both in the indoor operative temperature and in the thermal energy needs, were investigated and the causes of the deviations were identified.

1. Introduction

As indicated in the recast of European directive 2010/31/EU (European Commission, 2010), buildings are responsible for approximately 40% of overall energy consumption in the European Union. Energy efficiency of buildings plays a crucial role in reducing global energy consumption. To this purpose, it is vital to assess energy performance accurately (Wang et al., 2012). The past decade has seen the rapid development of standards for the assessment of the overall energy performance of buildings (EPB). However, different calculation methods do not provide the same level of details, transparency, reproducibility, etc. The use of simplified models is preferable for verifying the EPB requirements since detailed dynamic simulations introduce a large number of choices, details and complexities that reduce the reproducibility and transparency of the model (van Dijk, 2018). Thus, the accuracy of simplified models as compared to detailed dynamic models should be investigated and increased.

The new EN ISO 52016-1 standard (European Committee for Standardization, 2017) specifies a new Simplified Hourly Calculation Method (SHCM) for the calculation of the (sensible) energy need for heating and cooling and the (latent) energy need for (de)humidification, the internal temperatures and the heating and cooling loads. The SHCM takes time variations into account by considering hourly time intervals and daily alterations such as changing weather conditions are therefore not neglected. Furthermore, the amount of required input data for this method does not significantly exceed that required for the monthly method. The use of the new EN ISO 52016-1 hourly method, which replaced the simple hourly method of EN ISO 13790 (European Committee for Standardization, 2008), has not yet been investigated sufficiently in literature. Siva Kamaraj (2018) compared the new standard with the TRNSYS model for six BESTEST cases, using the weather file of Milan (Italy), Palermo (Italy), Denver (USA), and Colorado (USA). Results showed a range of difference between 10% to 30% in the heating needs, and between 25% to 40% in cooling needs for various cases (heavyweight, lightweight, etc.). A similar study was carried out for Croatian reference buildings for a wide range of building uses, envelope properties, climates, and heating/cooling needs (Zakula et al., 2019). The study concluded that the new standard results are acceptable in some cases, although there is a certain level of inconsistency between the two calculation methods in other cases.

Recently, Ballarini et al. (2019) investigated the hourly model of EN ISO 52016-1 by comparing it to the simplified hourly model of EN ISO 13790 and the detailed dynamic model of EnergyPlus. All methods were applied to a two-story single-family house in order to calculate the heating and cooling needs. It was found that the results generated using the new method were more similar to the results obtained using EnergyPlus than those using the simplified model of EN ISO 13790. However, this conclusion is reliable for the assessment of simple case studies and there is a need for further study with more complex buildings.
The literature reveals the need to broaden current knowledge of the newly proposed standard EN ISO 52016-1. This study sets out to assess the accuracy of the new method in predicting the building thermal behaviour. The present study attempts to validate the new hourly method by comparing it with a detailed dynamic simulation applied in the framework of the energy audit of an existing building located in Turin (northern Italy). Both calculation methods were implemented by means of two software applications: Open Studio platform, which implements the EnergyPlus modelling engine, and an Italian commercial tool, which implements the new hourly calculation model, in compliance with the EN ISO 52016-1 standard. The analysis was carried out through the comparison and discussion of the operative temperature and heating and cooling energy needs. In addition, this study also investigates the building model calibration procedure performed through the simplified hourly calculation model.

2. Methodology

2.1 Steps of Analysis

A case-study approach was used to facilitate the achievement of the research goals. The procedure applied is based on a first phase, consisting of the case-study energy model calibration, and a second phase in which the calculation model comparison was performed. As regards the first phase, initial data processing was performed to extrapolate the heating energy needs from the overall energy consumption (for heating and domestic hot water production). The energy model calibration was performed by means of the new EN ISO 52016-1 hourly calculation model, implemented using an Italian commercial tool. In the second phase, the calibrated energy model was then modelled with EnergyPlus to perform the model comparison. A set of consistency options was applied to both models to make their results comparable. The comparison was performed based on the hourly profile of the indoor operative temperature (in a free-floating condition), and the thermal needs of the building for heating and cooling.

2.2 Case Study

The analysed case study is one of the eighteen existing building blocks (named “Pavilion I”) of the military base “Riberi” sited in Turin (northern Italy). It was built between 1903 and 1913 and a major restoration of the building was performed in 2006 with the aim of accommodating more than a thousand journalists during the Turin 2006 Winter Olympics. It is currently used as a military guest house.
The pavilion is a three-story building (a representative story plan is shown in Fig. 1) with a gross conditioned volume of 10 261 m^3, a net conditioned floor area of 1 633 m^2 and a compactness factor of 0.29 m^{-1}.

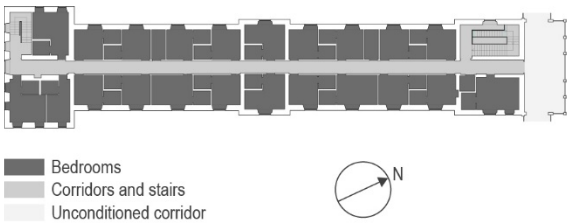

Fig. 1 – Representative building story and thermal zoning

The building envelope is characterized by uninsulated load-bearing brick exterior walls (finished with a layer of plaster), reinforced concrete slabs and double-glazed windows with wooden frames and roller shutters (used only at night-time from 8 p.m. to 8 a.m.), while no solar shading devices are installed in the building. The windows are mainly South-East and North-West oriented. The bottom floor borders on a ventilated crawl space (built on the existing floor), while the upper floor adjoins an unconditioned attic. Table 1 shows the thermal properties of the envelope. Standard values, derived from the UNI/TR 11522 technical report abacus (Ente Italiano di Normazione, 2014), were adopted for the opaque building envelope due to the lack of reliable information, while actual construction data were considered for the transparent envelope.

Table 1 – Building envelope thermal properties

Envelope component	*U*-value [W m^{-2} K^{-1}]
External walls	1.04
Windows	1.86
Bottom floor (vs. ground)	0.62
Upper floor (vs. unconditioned attic)	0.48

Standardized user behaviour, related to occupancy, heat gains, natural ventilation and lighting, was considered. The internal gain values and hourly schedules were derived from the ISO 18523-1 technical standard (International Organization for Standardization, 2016). An additional heat gain due to the presence of an indoor hot water storage was taken into account and calculated according to UNI/TS 11300-2 (Ente Nazionale di Normazione, 2019). Considering all the internal heat sources, the daily average value of internal gains was assumed to be equal to 9.5 W m^{-2}. In the first-stage simulation, a constant ventilation rate (0.25 h^{-1}) was adopted.

All the pavilions are supplied by district heating, which provides thermal energy both for space heating and domestic hot water. The heat exchange substation that serves the eighteen pavilions is composed of four single heat exchangers with a total power of 3 600 kW. The distribution system is characterized by uninsulated underground water pipes. Each room is equipped with a fan-coil, with no heating control systems. Due to the lack of data and the high indoor temperatures encountered during the site inspections, a 22 °C heating set-point was assumed in the first-stage simulations.

3. Energy Model Calibration

3.1 Energy Consumption Data Processing

The actual energy consumptions for space heating and domestic hot water production were analysed in order to extrapolate the energy needs for space heating. In this way, the heating needs can be compared with the outcomes of the hourly calculation method provided by the EN ISO 52016-1 technical standard. The extrapolation was performed through an energy signature based on the actual energy consumption of three heating seasons (monitored on a one-week basis starting from May 2017) and the actual average outdoor temperature in the same period, provided by the Regional Agency for the Protection of the Environment of Piedmont (ARPA Piemonte). The sequence below was followed:

1. Pattern recognition for domestic hot water energy consumption (black dots in Fig. 2);
2. Identification of an energy consumption benchmark, related to the heating system heat losses;
3. Final computation of the energy needs for space heating by subtracting the energy consumption identified in the previous phases from the heating energy consumptions (grey dots in Fig. 2).

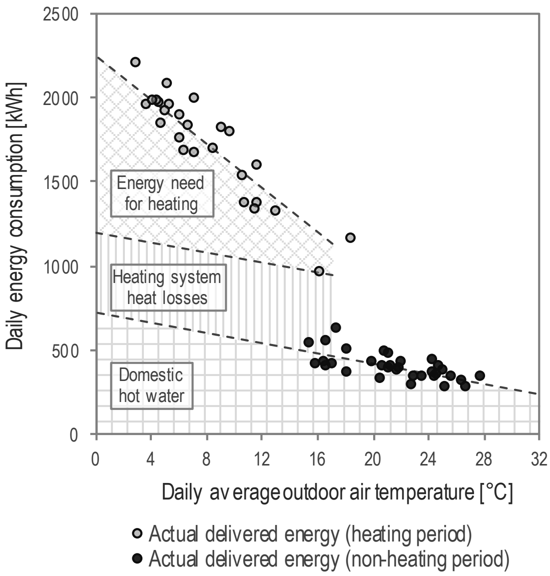

Fig. 2 – Extrapolation of the energy needs of the building for heating from overall energy consumption

3.2 Model Calibration Results

The calibration of the model was performed by means of a graphical comparison technique (Fig. 3): the grey dots in Fig. 2 represent the actual energy need; the black dots, by comparison, refer to the results of the simulation with the EN ISO 52016-1 hourly method and relate to the calibrated model.

The first-stage simulation was characterized by an overestimation of the calculated heating energy needs with respect to actual needs, and a larger slope in the line representing the simulated energy needs. To correct the slope, the parameters affected by the outdoor–indoor air temperature difference were calibrated. As mentioned above, due to the lack of reliable information, it was not possible, in calibrating the model, to consider the thermal properties of the opaque building envelope. Thus, the ventilation air changes were reduced during the unoccupied hours (0.12 h^{-1}) so as to accurately represent the actual opening of the windows while ensuring the infiltration air flow rate. Moreover, due to the fact that the opaque building envelope was uninsulated, only the thermal bridge between the external walls and the windows was considered. On the other hand, due to the uncertainty related to the absence of heating control systems, the heating set point was lowered to 20 °C (with a continuous operation) to reduce the gap between the actual and simulated lines.

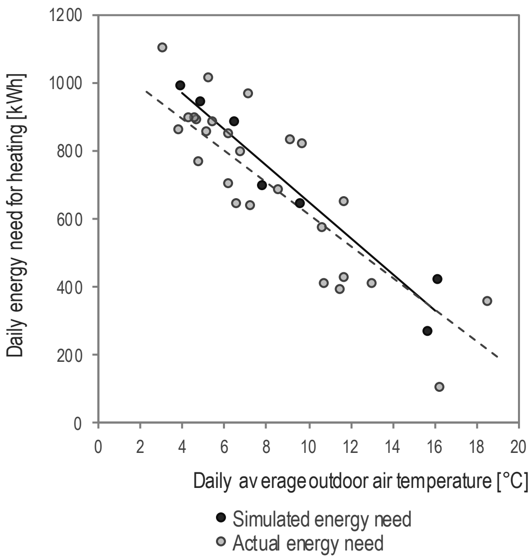

Fig. 3 – Results of the calibration procedure

4. Comparison of the Calculation Models

4.1 Consistency Options

The investigation of the reliability of the new hourly calculation method in predicting the indoor temperatures and the heating and cooling needs was based on its comparison with the detailed dynamic model. The comparison was developed using two different analyses, as outlined above, considering indoor operative temperatures and both the heating and cooling needs. Some consistency options were applied to the two models to make their results comparable. The options, applied to the calibrated model (and in addition to the boundary conditions, geometrical data and thermal properties of the building envelope, and the user behaviour parameters) are as follows:

1. Ground temperature. A constant ground surface temperature of 18 °C was assumed;
2. Heating and cooling set-point temperatures. The set-points referred to the operative temperatures, and were set at 20 °C and 26 °C for heating and cooling operation respectively;
3. Convective and radiative fractions of internal heat sources. The heat flow was assumed to be 40% convective and 60% radiative;
4. Fully convective heating and cooling systems. In both models, the heat supplied by the heating and cooling systems was assumed to be completely convective;
5. Furniture heat capacity applied to the air node. The standard value indicated in the EN ISO 52016-1 (10 000 J m^{-2} K^{-1}) was modelled in the EnergyPlus tool by means of the “zone sensible heat capacity multiplier parameter”.

Standard hourly weather data (test reference year for the city of Turin) were provided by the Italian Thermo-technical Committee and used in the comparison between the two calculation models.

Regarding solar heat gains, the convective fraction of the solar radiation was assumed to be equal to 0.1 in the simplified model, and a “FullExterior” algorithm for the solar distribution was adopted in the EnergyPlus simulations.

As far as thermal capacity assessment of the building is concerned, the finite difference heat conduction model was applied to the EnergyPlus model. In the EN ISO 52016-1, the heat capacity of envelope components was applied to the external surface node or assumed to be equally distributed (external walls).

4.2 Internal Operative Temperature

The operative temperature comparison was performed on an annual basis, considering a free-floating condition (the heating and cooling systems were assumed to be switched off), by applying the principle of superposition of effects. This principle was applied to investigate the reason for the discrepancy between the models, based on the deviation of the resulting internal temperature profile. Thus, the effects of each driving force on the air heat balance in the indoor environment were identified. To this purpose, the considered driving forces were added in four different simulations (identified by a simulation-ID), as follows:

1. In the first simulation (ID: EnvTr), ventilation (both natural ventilation and infiltrations), solar radiation and internal heat sources were removed, so that the only driving force considered was the heat transmission through the building envelope components due to the outdoor air temperature;
2. In the second simulation (ID: VenTr), the effect of ventilation due to the outdoor air temperature was added by considering the correct values for the air change rates;
3. In the third simulation (ID: IntG), the effects of the internal heat sources were considered, by introducing the correct values for the internal heat gains;
4. Finally, the fourth simulation (ID: SolG) was a complete simulation, in which the effect of the solar radiation was considered by adding the contribution of the solar radiation incident on the opaque and transparent envelope.

For each of the aforementioned simulations, the analysis was performed by considering the hourly difference between the indoor operative temperatures calculated through the EN ISO 52016-1 and the EnergyPlus methods, as described in equation (1), for a typical winter and summer week.

$$\Delta\theta_\mathrm{i} = \theta_{\mathrm{EN\ ISO\ 52016\text{-}1},i} - \theta_{\mathrm{EnergyPlus},i} \qquad (1)$$

where $\theta_{\mathrm{EN\ ISO\ 52016\text{-}1},i}$ and $\theta_{\mathrm{EnergyPlus},i}$ are the indoor operative temperatures from EN ISO 52016-1 and EnergyPlus respectively, at time step i. The results of the indoor operative temperature comparison are presented in Fig. 4 for two representative thermal zones, the bedrooms on the ground floor (GF) and on the second floor (SF) respectively. In Fig. 4, a negative difference means an overestimation in the calculation of the operative temperatures in the detailed dynamic tool, while a positive difference means an underestimation. The results are presented for one typical winter week (from January 17th to 23rd) and one summer week (from June 12nd to 18th).

The main result that can be seen in Fig. 4 is the strong influence of solar radiation compared to the other driving forces, which results in an underestimation of the prediction of the internal temperature by the EN ISO 52016-1 model, compared to the prediction obtained using the EnergyPlus model. Considering the first three simulations and their relative driving forces, the temperature trends are consistent between the two models, mainly in the typical summer week, with temperature differences lower than ±1 °C. If the simplified hourly method gives consistent results in terms of free-floating operative temperatures for the second-floor thermal zone both in cold and hot weeks, a negative influence of the heat transfer through the ground on the energy behaviour of the ground floor is registered in the winter week. The EN ISO 52016-1 model calculates higher temperatures than EnergyPlus, even though the ground temperature was made consistent between the two models. The difference is therefore strictly related to the ground heat transfer solving models. On the other hand, a negligible deviation between the two models is reported during the typical summer week, as can be seen in the chart on the top right of Fig. 4.

The introduction of the contribution of the solar radiation on the opaque and transparent envelope affects the amplitude of the temperature difference, both in the winter and the summer season. On the ground floor, solar radiation leads to an increase in the predicted temperature in the detailed dynamic simulation (of around 2 and 4 °C), even though the ground floor is only slightly influenced by solar radiation due to the shading of the surrounding buildings. The wide exposure of the 2nd floor to solar radiation, the orientation of the windows and the absence of any solar shading devices lead to significant discrepancies in the free-floating operative temperatures: a difference of 2 °C is registered in the winter week, while the operative temperature rises by 6 °C in the summer week. However, the lack of outputs in the commercial tool did not allow for the reasons for this deviation to be investigated in more depth.

This analysis was performed, as previously mentioned, for two typical winter and summer weeks. However, the identified trends were also demonstrated in the numerical evaluation of the reliability of the models in predicting the operative temperatures, conducted by means of the Root Mean Square Error (*RMSE*) calculation on an annual basis, as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N_i}\left(\theta_{\mathrm{EN\,ISO\,52016\text{-}1},i} - \theta_{\mathrm{EnergyPlus},i}\right)^2}{N_i}} \qquad (2)$$

where $\theta_{\mathrm{EN\ ISO\ 52016\text{-}1},i}$ and $\theta_{\mathrm{EnergyPlus},i}$ is the indoor operative temperature from the EN ISO 52016-1 and EnergyPlus respectively, at time step i, and N_i is the number of the considered time steps (8 760 time steps). Table 2 summarizes the annual *RMSE* values for the four simulations; for the first three steps, the *RMSE* values remain within acceptable values (1 °C). The introduction of solar radiation (fourth simulation, ID: SolG) causes the *RMSE* to rise by 2.35 and 4.19 °C for the ground and the second floor bedroom thermal zones respectively.

Table 2 – Annual *RMSE* [°C] related to each driving force

Thermal zone	EnvTr	VenTr	IntG	SolG
Bedrooms GF	1.01	0.94	0.79	2.35
Bedrooms SF	0.80	0.81	0.97	4.19

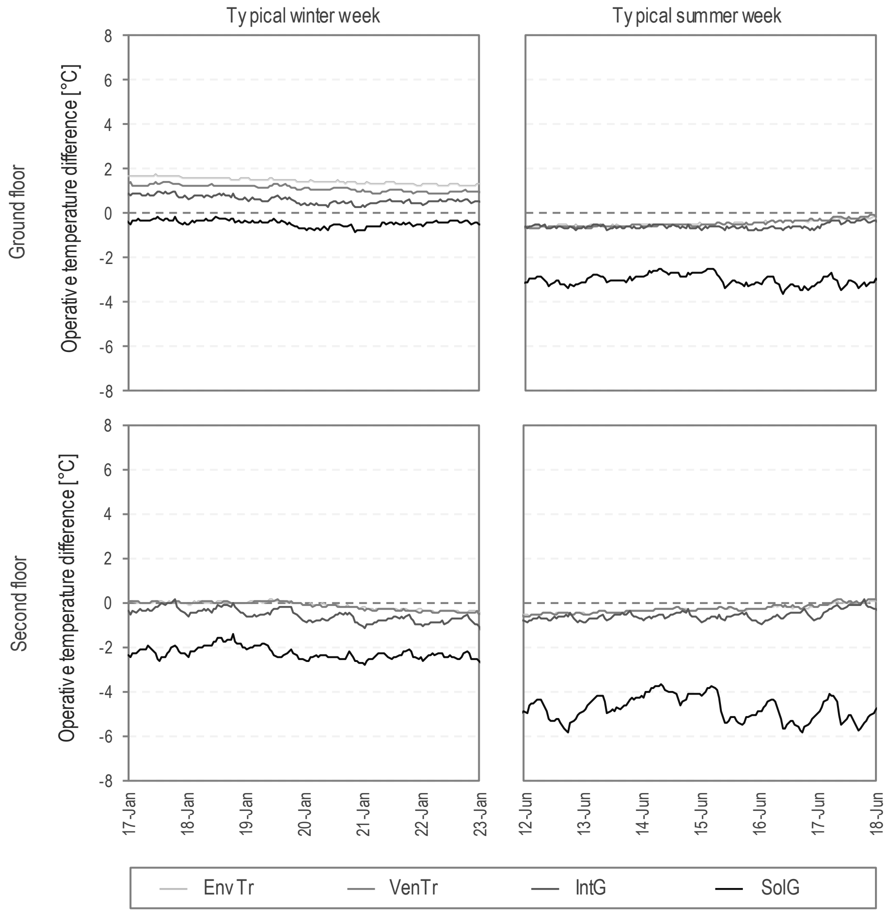

Fig. 4 – Operative temperature comparison for two thermal zones (ground and second floor bedrooms) for typical winter and summer weeks

4.3 Building Thermal Needs

The operative temperature comparison made it possible to better understand the results of the comparison between the thermal needs of the building predicted by the two considered calculation models. In the present analysis, the EN ISO 52016-1 "basic" heating/cooling energy need calculation and the EnergyPlus "ideal load" system were assumed. For both calculation models, a continuous operation and no power restriction for the heating/cooling system were assumed, as well as a purely convective emission. The monthly thermal energy needs for the whole building are shown in Fig. 5.

Interesting results, which confirm the results previously discussed, can be derived from this analysis. Generally, the hourly method introduced by the new EN ISO 52016-1 tends to slightly overestimate the heating energy needs with respect to the detailed dynamic calculation model. Despite the overestimation, the discrepancy between the two models does not exceed 5% on a monthly basis. On the other hand, in 'mid-season' months (e.g. March, April and October), the prediction of heating energy needs shows significant discrepancies (e.g. the EN ISO 52016-1 model overestimates the heating energy needs in March by 21.5%). As highlighted in the analysis previously presented, the influence of the solar radiation driving force may be the reason for such differences. However, it should be noted that the EnergyPlus model produces a remarkable underestimation of energy needs for heating in mid-season months (specifically in April and October) for an uninsulated building sited in a heating dominated climatic context.

The critical discrepancy in the operative temperatures due to the solar radiation driving force presented in the previous analysis translates into large differences in the calculation of the cooling energy needs. In this instance, the EnergyPlus model calculates cooling energy needs consistently higher than the EN ISO 52016-1 model (the discrepancy ranges from 52.9 to 74.3%).

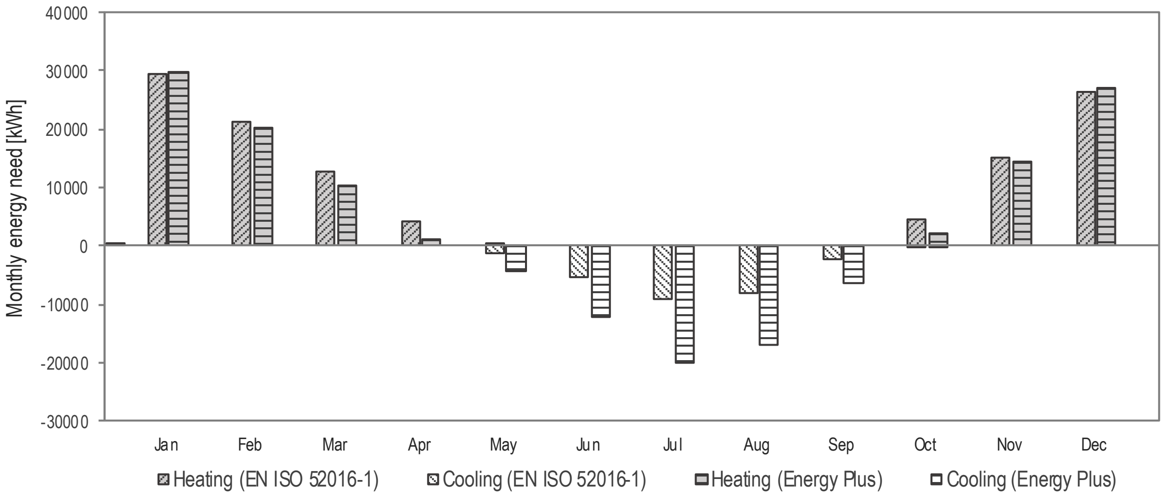

Fig. 5 – Comparison between the monthly heating and cooling energy need

5. Discussion and Conclusion

A number of conclusions can be drawn from the analysis presented in this paper. Firstly, the extrapolation of the heating energy need made it possible to calibrate a model independently from the modelling of the technical building system. However, the lack of reliable information on building use, user behaviour and, particularly on the building envelope – considering that the building is uninsulated – made it impossible to reach a more acceptable model calibration. Nevertheless, the new hourly method introduced by EN ISO 52016-1 proved to be a suitable tool for the calibration of the energy models for the building.

As regards the investigation of the accuracy of the new hourly method in comparison with a detailed dynamic one, two different behaviours can be pointed out. First, negligible deviations between temperatures and thermal energy needs were registered in the winter months. Second, the results of the performed analysis showed a remarkable deviation in mid-season and summer months. Deriving from the evaluation of the effect of the different driving forces on the air heat balance, solar radiation was identified as the main cause of the highlighted discrepancy. However, the explanation should not be limited to the different modelling of the solar gains through windows, as it is also related to the modelling of the thermal capacity of the building in the new simplified hourly method.

The results in this study cannot be generalized, since they are related to a heavyweight case study building. Moreover, the present work was affected by the lack of transparency of the commercial tool implementing the EN ISO 52016-1 hourly calculation model. Due to the limited inputs and outputs of the tool (temperatures and thermal needs), it was not possible to investigate the deviation between the two models in depth.

Future research is planned to focus on a larger number of case studies and on the investigation of the deviation caused by the solar heat gains and building heat capacity modelling.

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