The Effect of the External Driving Forces Modelling on the Calculated Building Energy Need Through the Use of Dynamic Simulation

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Abstract

An extensive validation of the EN ISO 52016-1 hourly method is still missing. In this paper, the main modelling assumptions related to the envelope outdoor surface heat balance are analysed. The variation in the accuracy of a detailed dynamic model is assessed when the EN ISO 52016-1 assumptions are applied to the model. To guarantee a general validity of the outcomes, two case studies in three Italian cities are considered. The results showed that the assumptions related to the definition of the convective and radiative heat transfer lead to non-negligible variation in the energy needs.

Key Innovations

- Validation of a simplified dynamic method of the building energy performance.
- Single modelling assumptions evaluated one at a time through a sensitivity analysis.

Practical Implications

The validation of simplified calculation methods through detailed dynamic simulation requires not straightforward implementation of model assumptions. The outcomes of this research would affect standards and tools to be used by practitioners (building engineers and architects).

Introduction

During the last decades, the issue of improving the energy performance in buildings (European Commission, 2010) led to the rapid development of different calculation methods for the building energy performance assessment. Several approaches, varying according to the specific purpose or level of accuracy and detail required, can thus be found. However, the current trend of using increasingly detailed methods to obtain accurate results presents an issue due to the low accessibility to detailed input data. To overcome this issue, different simplified dynamic methods were developed. Among them, the recently introduced EN ISO 52016-1 hourly method (European Committee for Standardization, 2018b) is based on assumptions and simplifications selected so as to allow a sufficient accuracy in the outcomes with a low amount of input data required (Van Dijk, 2019). However, the modelling assumption introduced by this simplified method may lead to inaccurate predictions in the energy consumption of buildings in both design phases and energy audits. The validation of the simplified method is thus of foremost importance, and the effects related to the introduction of its simplified assumptions need therefore to be investigated.

Three approaches are commonly used for the building energy models validation: the analytical verification, the comparative testing, and the empirical validation (Judkoff et al., 2008). The first technique consists in the comparison of the results of the tested model with the known analytical solution for an isolated heat transfer mechanism. However, its use is limited to the cases for which an analytical solution can be derived. In the empirical validation, the tested calculation method results are instead compared to monitored data from a real building. Finally, the comparative testing approach consists in the comparison of the results of the tested model to itself or to other codes. Although it relies on the accuracy of the model to which the tested one is compared, the last approach shows significant advantages. Above all, it enables to perform many comparisons and it allows to avoid the uncertainty due to the input data (Judkoff et al., 2008). Due to the strengths and weaknesses of all the three techniques, these are generally coupled into comprehensive methodologies for the building energy models validation. Alongside the widely acknowledged SERI methodology (Judkoff et al., 1998), these testing techniques are also included in the PASSYS methodology (Jensen, 1995). The PASSYS approach highlights two fundamental aspects related to the model validation. Firstly, it suggests that the model validation should be applied not only to the whole calculation model, but also to its single components. The main advantage of such validation method is the possibility to clearly detect inaccuracies in the algorithms or in the assumptions (Jensen, 1995). Secondly, it includes a critical literature review in which the theory behind the different heat transfer processes is evaluated and possible alternatives are investigated.

As far as the EN ISO 52016-1 model validation is concerned, only a few research studies can be found in literature. Most of these studies apply the comparative whole model validation technique. Zakula et al. (Zakula et al., 2019) tested the accuracy of the new simplified method for several buildings, including different levels of thermal insulation and building uses, and different climate zones. Their results showed that the use of fixed window solar properties (i.e. solar angle independent), as introduced by the EN ISO 52016-1 hourly method, leads to significant discrepancies in the outcomes between the simplified method and the detailed hourly method

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implemented in TRNSYS for most of the considered buildings. Similar results were achieved also by Kamaraj (2018), who applied the BESTEST approach (Judkoff et al., 2008) to evaluate the accuracy of the new standard in comparison with the TRNSYS model. Ballarini et al. (2019) analysed the discrepancy between the results of the EN ISO 52016-1 hourly method and the detailed dynamic calculation of EnergyPlus. Moreover, the authors proposed a validation methodology to identify the causes of deviations between the two models (Ballarini et al., 2020). The proposed methodology consists in splitting the contributions of the air heat balance equation by dynamic driving force. This approach allowed the authors to detect the use of constant surface heat transfer coefficients as the main cause for the differences in the outcomes. In the studies presented, the effect of some modelling options of the EN ISO 52016-1 hourly model on the accuracy of the method was clearly highlighted. The effect of single assumptions on the simulation results have been so far investigated by Mazzarella et al. (2020). The authors applied an analytical single process approach for the validation of the EN ISO 52016-1 conduction heat transfer model and an improved version of this, introduced in the Italian National Annex of the standard.

Besides the above investigations, an extensive evaluation of the single modelling assumptions is still missing and should be addressed with the aim to detect possible inaccuracies and to consider alternative calculation options. Thus, the model accuracy could be increased while ensuring its compliance with the model requirements of transparency, robustness, simplicity, and reproducibility. Within this framework, the present study investigates the influence of the assumptions related to the envelope outdoor surface heat balance, specified in the EN ISO 52016-1 technical standard, on the building thermal energy needs. To fulfil the research goals, a single-process validation approach fitting into the comparative testing technique is proposed. Firstly, the assumptions of the simplified method are documented and compared with the full detailed dynamic calculation model of EnergyPlus, and the effects of these simplifications are evaluated one at a time through a parametric analysis. The analysis is carried out by testing each calculation assumption on a detailed dynamic EnergyPlus model. Such approach allows the so called "external errors" (input data) to be controlled and discarded (Judkoff et al., 2008), and the "internal errors" (modelling options and assumptions) to be clearly investigated. Since the assumptions may influence the accuracy of a simulation depending on the building analysed (Judkoff et al., 2008), different building categories and weather conditions are considered to guarantee a general validity of the outcomes. In more detail, a residential and an office building are analysed in different Italian climatic zones.

Methods

Modelling options

In literature, different calculation models and assumptions on the physical phenomena related to the interaction between the outdoor environment and the outdoor building envelope are provided. The above assumptions can be related either to the mathematical models used to describe the phenomenon, or to the temporal variation of the parameters, or to the boundary conditions definition. Different assumptions applied to the outside surface heat balance were introduced in the EN ISO 52016-1 hourly method. Beside the general assumptions commonly adopted for building loads calculations (European Committee for Standardization, 2018c), an in depth documentation activity highlighted the differences between the EnergyPlus detailed dynamic method and the standardised method in the modelling of the convective heat transfer, the longwave and the shortwave radiation heat transfer.

In particular, the main differences between the detailed and the simplified methods identified for each heat balance component are briefly described below.

- Convective heat transfer ($HC_{v,st}$, $HC_{c,av}$, HC_c, $HC_{c,st}$). The classical formulation for heat transfer from surface convection,

$$q_c = h_{c,ext}\cdot(\theta_{surf} - \theta_{air}) \quad (1)$$

  is applied in both models. However, EnergyPlus considers a timestep temporal variation for the external convective heat transfer coefficient ($h_{c,ext}$), if not specifically required by the user, while a constant value over the simulation period is assumed in EN ISO 52016-1. Differences can be also found in the numerical models for the $h_{c,ext}$ determination. In fact, the simplified hourly method applies the EN ISO 6946 formulation (European Committee for Standardization, 2018a),

$$h_{c,ext} = 4 + 4\cdot v \quad (2)$$

  where v is the outdoor wind speed (m/s). On the other hand, EnergyPlus offers a wide selection of different methods, including both wind- and/or temperature difference-driven correlations (EnergyPlus). In this research activity, the TARP (Thermal Analysis Research Program) algorithm (Walton, 1983) was adopted as a reference.
- Longwave radiation heat transfer (HR_{st}, HR_{st}_SKY, SKY). In EnergyPlus, the external longwave radiation heat transfer between the surface, the sky and the ground is calculated by applying the Stefan-Boltzmann law. On the other hand, its linearised formulation is assumed for the exchanged heat flux calculation in EN ISO 52016-1,

$$q_{lr} = h_{r,ext}\cdot(\theta_{air} - \theta_{surf}) - F_{sky}\cdot h_{r,ext}\cdot\Delta\theta_{sky} \quad (3)$$

  where $h_{r,ext}$ is the external radiative heat transfer coefficient, θ_{air} and θ_{surf} are the air and the surface temperatures, respectively, F_{sky} is the view factor between the surface and the sky, and $\Delta\theta_{sky}$ is the difference between the apparent sky and the air temperatures. According to this formulation, the outdoor environment is assumed to be at the air temperature. To take into account the difference between the sky and the air temperatures, the second

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term in Equation (3) represents the extra thermal radiation to the sky, i.e. the correction for the longwave radiation exchanged from the surface to the sky. As for the convective heat transfer coefficient, $h_{r,ext}$ is assumed constant over the calculation period, and it is calculated by means of the EN ISO 6946 formulation,

$$h_{r,ext} = 4 \cdot \varepsilon \cdot \sigma \cdot T_m^3 \quad (4)$$

where ε is the surface emissivity, σ is the Stephan-Boltzmann constant and T_m is the average temperature of the surface and of its surroundings. As far as the extra thermal radiation to the sky is concerned, a direct sky temperature model is used in the standardised method for the apparent sky temperature calculation. In particular, a constant difference between the apparent sky and the air temperatures is assumed. On the other hand, the Clark-Allen atmospheric emissivity correlation (Clark and Allen, 1978) is applied in EnergyPlus for the sky temperature calculation.

- Solar (shortwave) radiation absorbed by the outdoor surface for shaded building envelope components (FSH). The reduction of the direct solar radiation component reaching the surface is considered by means of the sunlit fraction (f_s) in both the standardised and the detailed methods. The shadowing of diffuse solar radiation from the sky is instead considered only in EnergyPlus, by means of a correction factor (Anisotropic Sky Multiplier) that takes into account the angle factor between the surface and the sky, and the radiance distribution of the sky.
- Solar gains through windows (GV, GV_FW_{eu}, GV_FW_{ita}). The EN ISO 52016-1 hourly calculation method introduces two basic assumptions on the heat flow rates due to solar radiation entering the zone through transparent components. Primarly, the total transmitted solar radiation into the zone is assumed to be all short wavelength radiation. Secondarly, the solar properties of windows are considered solar angle independent, and a weighted time average value of the total solar energy transmittance (*g* or *SHGC*) is assumed over the simulation period. This is calculated by means of the F_w correction factor,

$$g_{gl} = F_w \cdot g_{gl,n} \quad (5)$$

where $g_{gl,n}$ is the total solar energy transmittance at normal incidence. The F_w correction factor is assumed constant over the calculation period in EN ISO 52016-1, while in the Italian Annex is assumed time dependent and it is calculated according to the empirical model introduced by Karlsson and Roos (2000).

In EnergyPlus, instead, the solar properties of windows are considered solar angle dependent and are determined by means of the Fresnel's equation.

Methodology

The effect of the above modelling options on the model accuracy is investigated in the present work by applying a code-to-code comparison methodology. A case-study approach was used to facilitate the achievement of the research goals. The procedure applied is summarised in Figure 1.

Firstly, an energy model is created in EnergyPlus for the considered case study (*baseline model*). The considered assumption is then implemented in the detailed model (*test model*). In this way, an input equivalence between the baseline and the test model is achieved, and the only difference between them is related to the tested modelling option. The effect of the modelling assumption is evaluated by means of the sensible energy needs for heating and cooling. The simulation results are compared and the sensitivity of the accuracy model to the variation of the input data related to the modelling option is assessed. In particular, it is evaluated by means of the influence coefficient (*IC*),

$$IC = (\Delta OP / OP_b) / (\Delta IP / IP_b) \quad (6)$$

where *OP* is the output data value, *IP* is the input data value and the subscript *b* refers to the *baseline model*. As concerns the output data, the total annual energy needs are applied in the calculation of the *IC* coefficient; for the input data, instead, the average annual value of the varied parameter is considered.

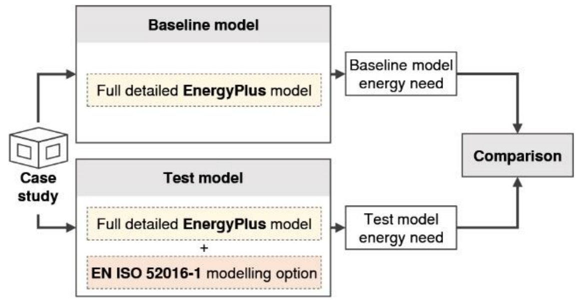

Figure 1. Methodology flowchart.

The procedure presented is applied separately for each tested modelling option. All simulations were performed through the Python applicative pyEp (pyEp), which implements the Ptolemy EnergyPlus's external interface.

Application

Case studies description

To fulfil the research goals and to guarantee a general validity of the outcomes, two different case studies were considered: an office module (Figure 2a) and a residential apartment unit (Figure 2b).

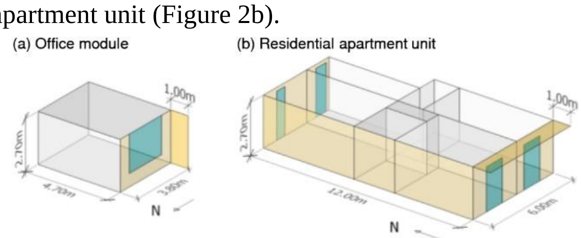

Figure 2. Case studies 3D visualisation.

The office module (referenced as Off. in Table 1) is representative of the Italian existing office building stock built in the '90s (Italian Ministry of Economic Development, 2018). This is an enclosed office of 17,9 m^2 (3,8 m x 4,7 m), with an internal height of 2,7 m. It was

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assumed to be characterised by one exposed wall (West-oriented) with a window of 4,8 m^2. The thermal envelope surface area to volume ratio (S/V) is equal to 0,21 m^{-1}. Horizontal and vertical internal partitions were instead modelled as adiabatic components. To evaluate the effect of the shadowing of both the opaque and the transparent components, a side fin of 1 m depth was placed on the left side of the exposed wall. The external wall is a prefabricated scarcely insulated concrete wall (U_{wall}=0,76 $W{\cdot}m^{-2}K^{-1}$), while the window is characterised by a double glazing unit (DGU) with aluminium frame (U_{win}=2,8 $W{\cdot}m^{-2}K^{-1}$, g=0,752).

The residential apartment unit (referenced as Res. in Table 1) is instead representative of the Italian existing residential building stock built in the period 1946-1976 (Italian Ministry of Economic Development, 2018). The apartment has a conditioned floor area of 66,3 m^2 and an internal height of 2,7 m. It is characterised by three exposed walls (South-, West- and North-oriented), and by a S/V ratio equal to 0,34 m^{-1}. In particular, the South-oriented wall presents two windows of 2,8 m^2, while the North-oriented wall has two windows of 1,5 and 2 m^2, respectively. Horizontal and vertical partitions were modelled as adiabatic components and the internal walls were modelled for the sake of internal mass. An overhang of 1 m depth was considered on the South-oriented wall. The external walls are made of uninsulated brick masonry with internal air cavity (U_{wall}=1,1 $W\,m^{-2}K^{-1}$), while the windows are characterised by a single glazing unit with wooden frame (U_{win}=4,9 $W{\cdot}m^{-2}K^{-1}$, g=0,852). For both case studies, the opaque envelope components where derived from the UNI/TR 11552 technical standard (Ente Italiano di Normazione, 2014) that provides typical Italian building components.

Standardised user behaviour regarding occupancy, heat gains, natural ventilation and HVAC system operation were considered for both case studies. The scheduled hourly values were derived from the EN 16798-1 technical standard (European Committee for Standardization, 2019). The Ideal Load Air system of EnergyPlus was considered to evaluate the energy needs for heating and cooling of the case studies. A dead-band setpoint thermostat was considered for the energy need evaluation, equal to 20 °C and 26 °C for heating and cooling, respectively. Both case studies were supposed to be located in Milan (Northern Italy), Rome (Central Italy), and Palermo (Southern Italy). The evaluations were carried out using the International Weather for Energy Calculations (IWEC) data file for the three cities.

Modelling strategies

The documentation analysis highlighted the differences between the detailed and the simplified calculation methods in the modelling of the phenomena involved in the outdoor surface heat balance. Based on this documentation, eleven different modelling options were selected to be tested. In this paragraph, a detailed description of the specific parameters used in describing the tested modelling assumptions is provided. For some of these, the implementation in EnergyPlus was not straightforward. The strategies used for the correct modelling of these assumptions are therefore outlined.

With regards to the convection heat transfer assumptions, four evaluation steps were considered. In the first step (ID: $HC_{v,st}$), the convective heat transfer coefficient formulation specified in EN ISO 52016-1 (Equation (2)) is evaluated; its temporal variation is maintained variable on a timestep basis. The implementation of a constant convective heat transfer coefficient was instead evaluated in the following steps. An average convective heat transfer coefficient, derived from the *baseline model* for each external surface, is considered in the second step (ID: $HC_{c,av}$). In the third step (ID: HC_c), the $h_{c,ext}$ was calculated by means of the formulation in Equation (2), where the annual average wind speed value was assumed for the calculations; specifically, wind speeds of 0,9, 3,7 and 3,8 m/s were used, respectively for Milan, Rome, and Palermo. The impact of the convective heat transfer standard value was assessed instead in the fourth step (ID: $HC_{c,st}$). In this case, a wind speed reference value equal to 4 m/s was used in Equation (2), as specified by EN ISO 6946.

In EnergyPlus, the external net longwave radiation heat flux is calculated by applying the Stefan-Boltzmann law. Thus, the definition of the radiative heat transfer coefficients as input values was not possible. To assess the influence of the EN ISO 52016-1 formulation (Equation (3)), a simple modelling strategy was applied. Firstly, the outdoor surface emittances were set equal to 0 to annul the external longwave heat transfer automatically calculated by EnergyPlus. Then, an additional heat balance term, calculated as specified in Equation (3), was added to the external surface of the envelope components. Two evaluation steps were considered in this case. The standard radiative heat transfer coefficient ($h_{r,ext}$) was used in the first step (ID: HR_{st}) and was calculated by assuming a surface emissivity equal to 0,9 and a reference mean temperature of 0 °C (European Committee for Standardization, 2018a). With regards to the extra thermal radiation to the sky, the EnergyPlus's calculated view factor between the surface and the sky (F_{sky}) was assumed. Moreover, the sky temperature was calculated by means of the Clark and Allen formulation (Clark and Allen, 1978). In the second step (ID: HR_{st}_SKY), the radiative heat transfer coefficient ($h_{r,ext}$) and the view factor (F_{sky}) were defined as in HR_{st}, while a constant temperature difference between the outdoor air and the sky temperature ($\Delta\theta_{sky}$) equal to 11°C was used in the calculation of the extra thermal radiation to the sky. It is necessary to report that the last two modelling assumptions were implemented only on the opaque building envelope components, due to software limitations. Finally, the influence of the sole direct sky temperature model for the apparent sky temperature calculation was assessed in the last model (ID: SKY). Specifically, the sky temperature was assumed 11°C below the air temperature.

Three evaluation steps were considered to test the assumption related to the solar radiation entering the zone through windows. Firstly, the effect of considering the

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total solar radiation entering the zone as shortwave radiation was assessed (ID: GV). In this case, the solar transmittance coefficient of windows was set equal to the *g*-value (at normal incidence), while 0 was assumed for the absorption factor. In this case, the glazing solar properties were defined on a timestep basis accordingly to Fresnel's equation. In the second step (ID: GV_FW_{EU}), instead, the solar properties of the windows were considered solar angle independent by assuming a constant value for the F_w correction factor equal to 0,9, as specified by the EN ISO 52016-1 technical standard. In addition, the assumption related to this field introduced by the Italian National Annex was tested (ID: GV_FW_{ITA}). This is a hybrid between the detailed and the European simplified method. In fact, the solar properties are considered solar angle dependent and are defined through a variable F_w correction factor, calculated accordingly to the Karlsson and Roos formulation (Karlsson and Roos, 2000). For both GV_FW_{EU} and GV_FW_{ITA}, the glazing solar properties at normal incidence were defined as in GV, and the assumptions were implemented by means of the EnergyPlus Energy Management System (EMS).

The parameters described above and implemented in the dynamic model to test its sensitivity to the modelling assumptions are summarised in Table 1.

Table 1. Modelling options specifications.

ID	Parameter	Unit	Value / Notes
$HC_{v,st}$	$h_{c,ext}$	$W \cdot m^{-2} K^{-1}$	Variable (Equation (2))
$HC_{c,av}$	$h_{c,ext}$	$W \cdot m^{-2} K^{-1}$	Average (*baseline model*)
HC_c	$h_{c,ext}$	$W \cdot m^{-2} K^{-1}$	7,6 (Milan)/ 18,8 (Rome)/ 19,2 (Palermo)
HC_{st}	$h_{c,ext}$	$W \cdot m^{-2} K^{-1}$	20
HR_{st}	$h_{r,ext}$	$W \cdot m^{-2} K^{-1}$	4,14
	θ_{sky}	°C	Clark and Allen, 1978
HR_{st}_SKY	$h_{r,ext}$	$W \cdot m^{-2} K^{-1}$	4,14
	$\Delta\theta_{sky}$	°C	11
SKY	θ_{sky}	°C	$\theta_{air,t} - 11$
FSH	$F_{sh,ob,dir}$	-	Sunlit fraction
GV	τ_{sol}	-	0,752 (Off.)/ 0,852 (Res.)
	α_{sol}	-	0
	ρ_{sol}	-	0,248 (Off.)/ 0,148(Res.)
GV_FW_{EU}	τ_{sol}	-	0,752 (Off.)/ 0,852 (Res.)
	α_{sol}	-	0
	ρ_{sol}	-	0,248 (Off.)/ 0,148(Res.)
	F_w	-	0,9
GV_FW_{ITA}	τ_{sol}	-	0,752 (Off.)/ 0,852 (Res.)
	α_{sol}	-	0
	ρ_{sol}	-	0,248 (Off.)/ 0,148 (Res.)
	F_w	-	Karlsson and Roos, 2000

Results

In this section, the impact of the tested modelling options on the thermal behaviour of the buildings are presented. Firstly, the variation of the energy needs for heating and cooling is evaluated through the comparison with the *baseline model* results (EnergyPlus full detailed method). These variations are presented in Figure 4 and Figure 5, for the office module and the residential unit, respectively. In both figures, the percentage values represent the relative variations of the energy needs for the different tested assumption and for the different Italian cities. The sensitivity of the overall energy needs to the tested modelling assumptions is assessed as well.

Energy need evaluation

Convective heat transfer. As far as the modelling assumptions related to the convection heat transfer are concerned, significant discrepancies between the *baseline* and the *test models* are highlighted. Generally, an increase of the annual energy needs for heating, and a decrease in the one for cooling occur for both the case studies in all the three cities. The use of a constant value for the heat transfer coefficient, calculated considering either an average (HC_c) or a reference wind speed ($HC_{c,st}$), leads to the highest variations of the energy need for heating among all the tested modelling assumptions. For the office module, a 9% and a 17% energy need for heating increase occurs in Milan, respectively for the average wind-speed $h_{c,ext}$ (HC_c) and for the reference $h_{c,ext}$ ($HC_{c,st}$). Even higher discrepancies can be highlighted in Rome and Palermo, where the average wind speed for both the climates is close to the reference wind-speed value, and thus the results for HC_c (27% in Rome, 101% in Palermo) and $HC_{c,st}$ (28% in Rome, 105% in Palermo) are almost the same. Contrary to expectations, a decrease in the model accuracy occurs when a time dependant $h_{c,ext}$ is considered as well ($HC_{v,st}$). In fact, the formulation in Equation (2), applied on a timestep basis, leads to not negligible increases in the heating need (7%, 24% and 93% for the office module respectively in Milan, Rome and Palermo) and decreases in the cooling need (–20%, –29% and –21% respectively in Milan, Rome and Palermo). On the other hand, a very good agreement between the *baseline* and the *test model* can be found by implementing the average constant convective heat transfer coefficient ($HC_{c,av}$). The variation between the two models is in the order of ±1–4% for both the case studies in all the climates. The better fitting of the average constant value ($HC_{c,av}$) compared to the variable one ($HC_{v,st}$) can be explained by analysing the convective coefficient profiles shown in Figure 3.

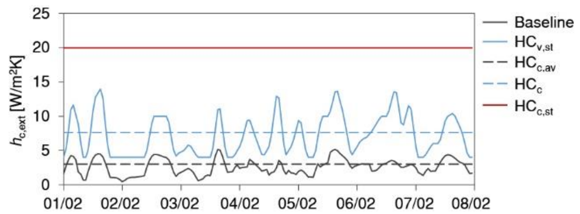

Figure 3. Variation of the $h_{c,ext}$ for the office module.

In Figure 3, the different $h_{c,ext}$ profiles for the office module in Milan are presented for a typical winter week. The $h_{c,ext}$ values calculated by means of the formulation in Equation (2) are consistently higher than the ones calculated by means of the TARP algorithm (*baseline model*). Thus, a higher convection heat transfer rate occurs for the $HC_{c,st}$ assumption, leading to the reported discrepancies between the outcomes. The same results can be referred also to the residential building, whereas the modelling assumptions related to the convection heat transfer have a greater impact on the energy needs compared to the office module. The higher *S*/*V* factor

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($0{,}34\ m^{-1}$) of the residential unit makes this building to be more exposed to the heat transfer by transmission and thus more influenced by these assumptions than the office building ($0{,}21\ m^{-1}$ S/V ratio). In fact, the energy need for heating of the residential apartment increases by a 26% in Milan, and by a 38% and a 114% in Rome and Palermo, respectively, when the standard heat transfer coefficient is considered ($HC_{c,st}$).

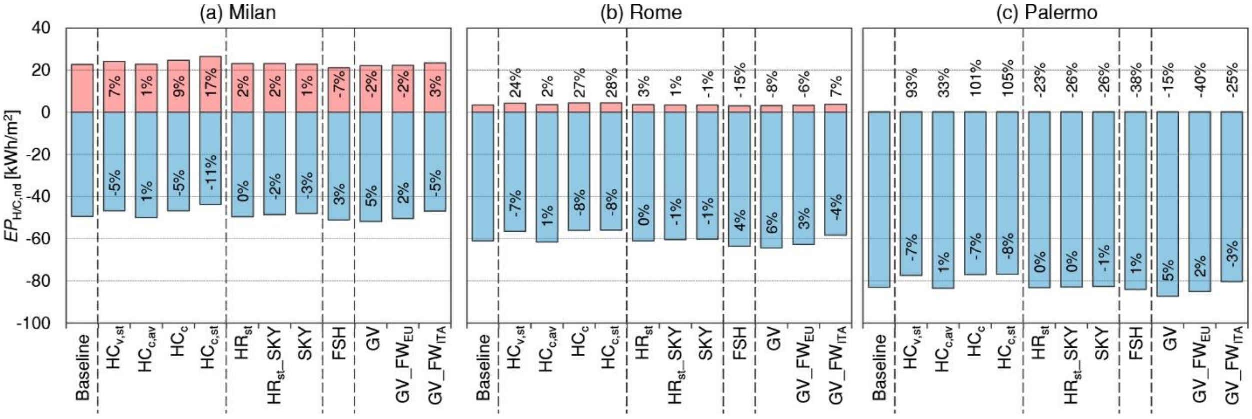

Figure 4. Variations of energy needs for heating and cooling for the office module.

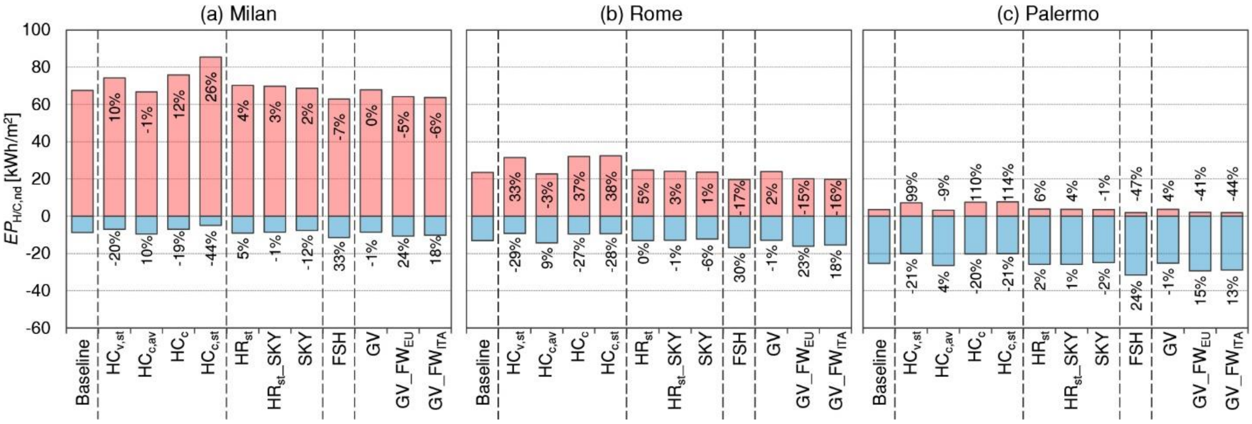

Figure 5. Variations of energy needs for heating and cooling for the residential unit.

<u>Longwave radiation heat transfer</u>. Similar results are obtained by analysing the effects of the modelling assumptions related to the longwave heat transfer phenomenon. In fact, a general increase in the energy need for heating and a decrease in the one for cooling can be observed. The linearization of the longwave heat transfer phenomenon (HR_{st} and HR_{st}_SKY) results to influence the energy need of the buildings more than the simplified definition of the sky temperature (SKY). For example, the energy need for heating increases by a 4% for the residential unit in Milan when the standard constant $h_{r,ext}$ and the EnergyPlus sky temperature are considered (HR_{st}). The introduction of the EN ISO 52016-1 assumption related to the sky temperature definition (HR_{st}_SKY) shows comparable results with the HR_{st} modelling option. This is due to the fact that the actual average difference between the apparent sky and the air temperatures is similar to the reference value of 11°C (i.e. equal to 11,5 °C for Milan and Rome, and 11,2 °C for Palermo) used in the simulations. Likewise, good agreements between the *baseline* and the *test models* can be found when the sky temperature is assumed to be 11°C below the external air temperature (SKY). In fact, the variation in the energy need for heating is around ±2% for all the case studies.

<u>Solar (shortwave) radiation absorbed by the outdoor surface for shaded building envelope components</u>. The assumption related to the shading of diffuse solar radiation (FSH) leads to a decrease in the needs for heating and to an increase in the needs for cooling, as expected. Its influence is particularly considerable on the cooling need of the residential case study. The incident diffuse radiation on the obstructed surface (South-oriented facade) was compared to the incident radiation without the obstruction, i.e. if the surface is considered not shaded to the diffuse component of solar radiation. In summer, the incident diffuse solar radiation is almost halved due to the presence of the overhang (e.g. from 160 to 84 W/m² in Milan). Not considering the shading of the diffuse solar radiation leads to considerable discrepancies in the cooling need between the *baseline* and the *test models*. In fact, this increases by a 30% in Milan and Rome, and by a 24% in Palermo.

<u>Solar gains through windows.</u> As introduced in the previous sections, the EN ISO 52016-1 hourly method introduces two different assumptions related to the solar radiation entering the zone through the transparent components. Firstly, the GV assumption, i.e. considering the solar heat flux as shortwave radiation, leads to a

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slightly decrease in the energy need for heating due to a higher amount of solar radiation directly entering the zone, and thus, higher solar heat gains. This modelling assumption has a greater effect on the energy need for cooling than on the energy need for heating of the office module (in Milan, +5% and –2%, respectively), due to its low internal heat capacity. When the glazing parameters are considered to be solar angle and time independent (GV_FW_{EU}), the energy need for heating slightly decreases compared to the *baseline model*, while the need for cooling increases. Although the implementation of a correction factor F_w of 0,9 entails the lowering of the solar transmittance of the glazing compared to that at normal incidence, an overestimation of the transmitted solar radiation occurs in presence of high values of incidence solar angle. This is the case of extreme situations such as winter's morning/evenings or summer's middays. The energy need for cooling thus increases due to higher solar heat gains. Due to the presence of a larger window area, the extent of the effect of the GV_FW_{EU} assumption is greater for the residential apartment (e.g. 23% and 15% for Rome and Palermo, respectively). On the other hand, a variable F_w correction factor, calculated as specified by the Italian national Annex (Karlsson and Roos, 2000), leads to discrepancies between the *test* and the *baseline models*, especially for the office module. This formulation entails the use of a F_w correction factor equal to 0,8 in absence of incident beam solar radiation on the window. In this case, an underrating of the solar heat gains leads to an increase of the energy need for heating (e.g. in Rome, 7% and –4% for the energy needs for heating and cooling respectively).

Sensitivity of the model accuracy

The sensitivity of the model accuracy to the modelling assumptions was assessed. In particular, the influence coefficient *IC* was calculated to quantify the sensitivity of the total energy need of the analysed buildings to the variation of the single input values. A general ranking of the tested assumptions is reported in Table 2 and Table 3 for the office and the residential building, respectively. In both tables, the first place was assigned to the assumption that most influences the model results, i.e. the assumption with the highest *IC* value.

Despite the modelling options on the convection heat transfer lead to the highest discrepancies in the outcomes, the dynamic detailed model resulted not to be highly sensitive to these assumptions. Such differences in the outcomes are in fact referred to high variations in the inputs, resulting in low *IC* values. On the other hand, the accuracy of the model proved to be more sensible to the assumptions related to the radiative heat transfer for both the case studies. In particular, the linearization of the radiative heat transfer phenomenon (considering the standard radiative heat transfer coefficient) is the modelling assumption that causes the higher variation in the outcomes, compared to the *baseline model*, referred to the input variation. Moreover, due to its envelope insulation, the office module is highly influenced also by the assumptions that affect the amount of solar radiation entering the zone (FSH and GVs modelling assumptions).

Table 2. Office module: modelling options ranking (IC).

	Office module		
	Milan	**Rome**	**Palermo**
1°	HR_{st} (0,74)	HR_{st}_SKY (0,49)	HR_{st}_SKY (0,45)
2°	SKY (0,35)	GV_FW_{ITA} (0,41)	SKY (0,32)
3°	GV_FW_{ITA} (0,28)	SKY (0,319)	GV_FW_{ITA} (0,31)
4°	HR_{st}_SKY (0,24)	FSH (0,26)	HR_{st} (0,29)
5°	GV (0,13)	GV (0,25)	GV (0,25)
6°	$HC_{c,av}$ (0,11)	HR_{st} (0,24)	GV_FW_{EU} (0,14)
7°	GV_FW_{EU} (0,05)	GV_FW_{EU} (0,14)	FSH (0,12)
8°	$HC_{v,st}$ (0,03)	$HC_{c,av}$ (0,12)	$HC_{c,st}$ (0,11)
9°	$HC_{c,st}$ (0,02)	$HC_{c,st}$ (0,09)	HC_{c} (0,11)
10°	FSH (0,02)	HC_{c} (0,09)	$HC_{v,st}$ (0,10)
11°	HC_{c} (0,02)	$HC_{v,st}$ (0,09)	$HC_{c,av}$ (0,08)

Table 3. Residential unit: modelling options ranking (IC)

	Residential unit		
	Milan	**Rome**	**Palermo**
1°	HR_{st} (0,79)	HR_{st} (0,70)	SKY (0,80)
2°	HR_{st}_SKY (0,66)	SKY (0,49)	HR_{st} (0,70)
3°	$HC_{c,av}$ (0,24)	HR_{st}_SKY (0,41)	FSH (0,52)
4°	$HC_{v,st}$ (0,19)	$HC_{c,st}$ (0,19)	HR_{st}_SKY (0,47)
5°	$HC_{c,st}$ (0,14)	HC_{c} (0,19)	$HC_{c,av}$ (0,30)
6°	HC_{c} (0,14)	FSH (0,17)	GV_FW_{EU} (0,29)
7°	GV_FW_{ITA}(0,11)	$HC_{c,av}$ (0,17)	GV_FW_{ITA}(0,22)
8°	GV_FW_{EU} (0,07)	$HC_{v,st}$ (0,17)	$HC_{v,st}$ (0,10)
9°	GV (0,06)	GV_FW_{ITA}(0,14)	HC_{c} (0,06)
10°	FSH (0,01)	GV (0,07)	$HC_{c,st}$ (0,06)
11°	SKY (0,01)	GV_FW_{EU} (0,05)	GV (0,05)

Discussion and conclusion

In the present work, the variation in the accuracy of a detailed dynamic simulation method was quantified as to assess the effect of the simplifying modelling assumptions introduced by the EN ISO 52016-1 hourly method. A single process validation approach, based on a detailed documentation analysis, was proposed, and applied to identify at which extent the modelling assumptions can affect the accuracy of the model. Specifically, eleven modelling options related to the envelope outdoor surface heat balance were tested.

The results draw the attention to the effect of the modelling assumption connected to the temperature difference between the surfaces and the outdoor environment, i.e. convection and radiative heat transfer. In fact, these assumptions resulted to be the most influencing in terms of both percentage variation in the energy needs, and the model accuracy.

Besides the identification of the modelling assumptions that may lead to non-negligible inaccuracies in the outcomes, the research underlined important aspects as regards the EN ISO 52016-1 hourly model validation. Firstly, the analysis highlighted that the effectiveness of different modelling options seems to be strictly related to the accuracy in the definition of the considered parameters. For example, the use of a simplified model for the convective heat transfer coefficient calculation resulted to negatively affect the accuracy of the energy need assessment, even if applied on a timestep basis. This may indicate that the discrepancies are caused by a decrease in the accuracy of the numerical method used for

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parameter definition rather than by a variation in its temporal discretisation. Therefore, it would be preferable to select detailed approaches.

Moreover, the results of the research proved the advantages of performing the validation separately for the different assumptions. The proposed approach led in fact to clearly detect specific inaccuracies in the modelling assumptions that a whole-model approach would not have probably allowed to identify. Therefore, the use of single component validation approaches should be enhanced to guarantee a complete and extensive EN ISO 52016-1 model validation.

Considering these aspects, the research outcomes are intended to address the model validation as to contribute to the enhancement of the standardisation activity. Further works will include in-depth analyses of the modelling options here tested and the exploration of alternative calculation methods for the definition of the parameters involved. These further researches will be addressed to increase the accuracy simplified dynamic methods (such as EN ISO 52016-1 hourly method), while guaranteeing the simplicity of the building energy performance assessment.

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