Quasi-steady state and dynamic simulation approaches for the calculation of building energy needs: Part 2 thermal gains

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Abstract

In order to assess the coherence between the dynamic simulation and the EN ISO 13790:2008 quasi-steady state method, this paper, differently from previous works in literature, analysed the discrepancy sources directly for thermal losses and gains instead of considering only the final result in term of energy needs. In the first part, the deviations between the thermal losses were evaluated. In this second part, the authors investigate the deviations between the estimation of thermal gains, both solar and internal ones, by means of an extensive use of dynamic simulation. More than 800 configurations obtained by the factorial combination of different values for building shape, envelope insulation and composition, window type, size and orientation and climatic conditions, are considered to identify the most important discrepancy sources and to improve the correspondence between simulation and quasi-steady state methods.

1. Introduction

According to the Energy Performance of Building (EPB) Directive 2010/31/EU and the former 2002/91/EC (European Parliament, 2010; European Parliament, 2002), in order to implement the energy labelling of buildings, the energy performance can be evaluated either with simplified approaches or with enhanced simulation tools. As reminded in the first part of this work, the coherence of the methods is of crucial importance in order to obtain a perception of the reliability of energy certification by the market and to ensure the EPB Directive effectiveness (Tronchin and Fabbri, 2008). Moreover, the European Standard EN ISO 13790:2008 (CEN, 2008) suggests to use the dynamic simulation in improving and tuning the proposed quasi-steady state method, by refining the estimation of the utilization factors, i.e. the dynamic parameters that reduce the thermal gains for heating need calculation and the thermal losses for cooling when evaluating the balance between thermal losses and thermal gains. The utilization factor is considered as a function of the ratio between the thermal losses and the thermal gains. Those are calculated through conventional expressions reported in the technical Standard. Extending the method of studying the dynamic factor by van Dijk and Arkesteijn (1987), the Standard proposes the recourse to dynamic simulation also in determining the thermal losses and gains. As indicated by van Dijk and Arkesteijn (1987) and remarked by Corrado and Fabrizio (2007), the utilization factor considers the mismatch between heat losses and gains leading to heating or cooling energy needs. What is of crucial importance, then, is that the heat losses and gains are determined accurately.

According to the quasi-steady state method, the heat gains consist in all thermal fluxes to the internal air node not driven by the temperature gradient between indoor and outdoor environment. Those can be distinguished in solar gains, internal gains and infrared extra flow towards the sky vault.

In many applications, the solar heat flow entering through the transparent envelope is the most relevant thermal gain component. The control of the entering solar radiation is becoming more and more important in designing passive systems (Orosa and Oliveira, 2012). For instance, Gasparella *et al.* (2011) simulated a well-insulated building with different kinds of glazing systems, with or without fixed shading overhangs and fins for different window sizes, orientations and European localities, showing the influence of the choice of the

glazing on the heating and cooling energy needs and peak loads. The correct estimation of the entering solar radiation is necessary since the early stages of the design process, in particular when using the simplified quasi-steady methods. Moreover, as underlined by Oliveti *et al.* (2011), the black body cavity hypothesis adopted by the EN ISO 13790:2008 method, according to which the whole solar radiation entering into the thermal zone is absorbed, is not representative of the real physical phenomena. In many cases a certain amount of the radiation is reflected by the walls and dispersed through the windows themselves. Thus, Oliveti *et al.* proposed a correction to the solar transmittance of the glazings in order to take into account the radiation lost because of the reflections. In addition to the entering radiation, the solar gains by transmission through the opaque envelope have also been studied by many researchers in different contexts. Some of them (Oliveira Pañao *et al.*, 2012; Oliveti *et al.*, 2012a) focused on the sunspaces and analysed the EN ISO 13790:2008 calculation method. Other authors paid particular attention to the roofs, underling the importance of the solar absorption coefficient (Suehrcke *et al.*, 2008), especially for the cooling energy needs. Finally, Oliveti *et al.* (2012b) assessed the methods proposed by the EN ISO 13790:2008 for the calculation of the infrared extra flow towards the sky dome, comparing the Standard with the empirical collected data and finding inaccuracies in the Standard estimations.

In the present work, a large number of configurations have been simulated with TRNSYS in order to calculate the different components of the heat gains and to compare them with the EN ISO 13790:2008 monthly procedure. By means of different statistical analyses, some correction factors have been determined to improve the accuracy of the technical Standard, estimating the actual amount of heat gains.

2. Methods

2.1 EN ISO 13790:2008 model

The technical Standard EN ISO 13790:2008 considers as heat gains Q_{gn} the term of the heat balance that is independent of the difference of temperature between the indoor and the outdoor environments. A positive sign is assumed for heat added to the air node, while negative for subtracted. The thermal gains are defined as:

$$Q_{gn} = Q_{\text{int}} + Q_{sol} \quad (1)$$

The internal heat gains are:

$$Q_{int} = t \cdot \sum_k \Phi_{int,mn,k} + t \cdot \sum_l \left(1 - b_{tr,l}\right) \Phi_{int,mn,u,l} \quad (2)$$

where the effect of the heat sources from adjacent unconditioned thermal zones is considered with a contribution weighed by the reduction factor $b_{tr,l}$ defined in the Standard ISO 13789:2007 (CEN, 2007). Different heat sources (occupants, appliances, lighting, hot and mains water, HVAC system, processes and goods) can be identified:

$$\Phi_{int} = \begin{pmatrix} \Phi_{int,Oc} + \Phi_{int,A} + \Phi_{int,L} + \\ + \Phi_{int,WA} + \Phi_{int,HVAC} + \Phi_{int,Proc} \end{pmatrix} \quad (3)$$

Case by case, it is possible to estimate the heat gain due to each single source, even if national typical values are generally proposed by national annexes or technical Standards. Whatever the entity of the internal gains, the EN ISO 13790:2008 states that they should be considered as half radiative and half convective gains.

Similar to the internal gains, the solar gains are estimated considering also the solar gains of the adjacent unconditioned thermal zones, properly weighed by the reduction factor $b_{tr,l}$:

$$Q_{sol} = t \cdot \sum_k \Phi_{sol,mn,k} + t \cdot \sum_l \left(1 - b_{tr,l}\right) \Phi_{sol,mn,u,l} \quad (4)$$

In particular, the heat flow by solar gains consists in the solar gains transmitted through a general element k of the building envelope, in which the infrared extra flow towards the sky-dome is subtracted:

$$\Phi_{sol,k} = F_{sh,ob,k} A_{sol,k} I_{sol,k} - F_{r,k} \Phi_{r,k} \quad (5)$$

where $F_{sh,ob,k}$ is the shading reduction factor for the external obstacles on $A_{sol,k}$, the effective solar collecting area of the element k, with a view factor of the sky $F_{r,k}$. $I_{sol,k}$ is the solar irradiance on the element k and $\Phi_{r,k}$ its infrared extra flow.

The effective solar collecting area is defined differently depending on the type of element.

For the glazings, it is calculated as:

$$A_{sol} = F_{sh,gl} g_{gl} \left(1 - F_f\right) A_{win,p} \quad (6)$$

The overall projected window area $A_{win,p}$ is reduced in order to take into account the frame factor F_f, the

total solar transmittance of the glazing g_{gl} and the shading reduction factor for movable shadings $F_{sh,gl,}$ neglected in this work. The term g_{gl} is calculated in accordance with Eq. (7):

$$g_{gl} = F_w g_{gl,n} \quad (7)$$

where $g_{gl,n}$ is the solar energy transmittance for radiation perpendicular to the glazing and F_w is the correction factor for non-scattering glazings which takes into account for the different incidence angles. The scattered glazings are not considered in this work and are treated separately also by the Standard. An approximated value of F_w is 0.9 but, if available, the values indicated by the technical Standard of the EU Member States should be used. The values reported by the draft of the revUNI/TS 11300-1:2012 have been considered.

For the opaque surfaces:

$$A_{sol} = \alpha_{S,env.k} R_{se} U_{env,k} A_{env,k} \quad (8)$$

where $A_{env,k}$ and $U_{env,k}$ are, respectively, the projected area and the thermal transmittance of the opaque component k, R_{se} its external surface resistance and $\alpha_{S,env,k}$ its absorption coefficient.

The infrared extra flow can be calculated by means of Eq. (9):

$$\Phi_r = R_{se} \cdot U_{env,k} \cdot A_{env,k} \cdot h_{re} \cdot \left(\theta_e - \theta_{sky}\right) \quad (9)$$

The average difference between the air temperature θ_e and the sky fictive temperature θ_{sky} can be approximated as 11 K at the latitudes of interest. Assuming an external surface temperature equal to the air temperature, the surface radiative heat exchange coefficient h_{re} can be calculated as:

$$h_{re} = 4 \cdot \sigma \cdot \varepsilon \cdot \left(273.15 + \frac{\theta_e + \theta_{sky}}{2}\right)^3 \quad (10)$$

2.2 TRNSYS heat gains

As observed in the first part of this work, TRNSYS implements and solves an air heat balance model as function of the convective thermal exchanges:

$$\phi_{c,i} + \phi_{ve} + \phi_{gc} + \phi_{sys} = C_{air} \frac{d\theta_{air}}{dt} \quad (11)$$

The convective part ϕ_{gc} of the internal gains is the only one directly involved in the balance of Eq. (11). The other gains indirectly affect the air heat balance through the radiation exchanges with the internal surface of the envelope. Per unit of surface:

$$\dot{q}_{c,i} + \dot{q}_{sol,i} + \dot{q}_{gswr,i} + \dot{q}_{IR,i} + \dot{q}_{glwr,i} + \dot{q}_{tr,i} = 0 \quad (12)$$

The radiative part of the internal gains (both shortwave $\dot{q}_{gswr,i}$, for instance from internal lighting, and longwave $\dot{q}_{glwr,i}$) and $\dot{q}_{sol,i}$, the solar irradiance entering through the glazings are considered here. In particular, in TRNSYS, the diffuse entering solar radiation is distributed homogenously on the various surfaces of the envelope and the beam entering component is controlled by a distribution parameter called *geosurf*. Following more detailed models implemented in other simulation tools (as EnergyPlus) and the suggestions of the BESTEST procedure (Judkoff and Neymark, 1995), the *geosurf* is imposed equal to 1 for the floor and 0 for the other surfaces, so that the entering beam solar radiation first falls entirely on this surface. The solar radiation is then partially absorbed by each surface in accordance with its absorption coefficient and partially reflected as diffuse solar radiation. Due to the reflections, a certain amount of the total entering solar radiation is lost through the transparent surfaces. It is also clear that the whole heat gains involved in the internal surface heat balance do not affect the air heat balance because a fraction of the absorbed terms is lost by transmission. All these effects have been recognized by the EN ISO 13790:2008 as sources of disagreement between the quasi-steady state approach and detailed simulations.

The temperatures of the external surfaces are defined by the following balance equation:

$$\dot{q}_{c,o} + \dot{q}_{sol,o} + \dot{q}_{IR,o} + \dot{q}_{tr,o} = 0 \quad (13)$$

The extra flow infrared radiation towards the sky vault is considered in the total external long wave radiation $\dot{q}_{IR,o}$. Also in this case, the estimation of the effect on the indoor air heat balance of the solar heat gains for the opaque components and the infrared extra flow are affected by the heat transfer between the internal and the external surfaces of the envelope.

2.3 Thermal gains calculation procedure with the dynamic simulation approach

In order to evaluate the thermal gains by means of dynamic simulation, the EN ISO 13790:2008 prescribes first to calculate the thermal losses, as in

the first part of this work (Pernigotto and Gasparella, 2013). This time the internal gains, the solar gains and the infrared extra flow to the sky vault are set as in a standard simulation but the heating and cooling setpoints have to assume the same value (as for the calculation of the thermal losses). The thermal gains can be calculated from the previously determined thermal losses and from the heating and cooling energy needs of this second set of simulations:

$$Q_{gn} = Q_{ht} - \left(Q_{H,nd} - Q_{C,nd}\right) \quad (14)$$

Since the heat gains are independent from the chosen simulation setpoint, using either air or operative temperatures is irrelevant, as well as considering a value of 20 °C or 26 °C. In this analysis an air temperature setpoint of 20 °C has been assumed and the results have been used in Eq. (14), together with the correspondent set of thermal losses.

As in the first part, in order to compare simulated and quasi-steady state results, boundary conditions and calculation parameters for the simulation have been selected coherently with the ones assumed in the quasi-steady state approach. As regards the external conditions, the hourly weather data have been calculated by means of the subroutine Type 54 starting from the monthly average values reported by the Italian technical Standard UNI 10349:1994 (UNI, 1994) and used in the simplified method. The horizontal global solar radiation is split into the beam and the diffuse components in accordance with the Erbs' algorithm implemented in the Type 54. The diffuse components of the solar radiation on the vertical façades have been calculated in accordance with the algorithm by Perez *et al.* (1990). The mean daily solar radiation on a monthly basis has been calculated for each orientation and used in the quasi-steady state method instead of the ones reported in the UNI 10349:1994. Starting from the horizontal infrared flux reported in the EPW weather files, the fictive sky temperature has been calculated for each timestep and used in TRNSYS simulations. As for the solar radiation, monthly averages have been calculated for the quasi-steady state method, in place of the gradient of 11 K suggested by the EN ISO 13790:2008. Constant internal heat gains equal to 4 W m^{-2} have been set in TRNSYS, half convective and half radiative as the Standard prescribes.

The same surface convective coefficients have been considered both in TRNSYS and in the quasi-steady state method: 20 W m^{-2} K^{-1} for the external side, and 5.0, 0.7 or 2.5 W m^{-2} K^{-1} respectively for upward, downward and horizontal flow on the internal side, as in the EN ISO 6946:2007 (CEN, 2007). As underlined in the first part of the analysis, in TRNSYS, both internal (ε=1) and external emissivity values (ε=0.9) are non-modifiable and so the internal long wave radiation heat transfer coefficient used in the quasi-steady state approach has been recalculated by means of Eq. (15), assuming a mean radiant temperature equal to the setpoint value.

$$h_{ri} = 4 \cdot \sigma \cdot \varepsilon \cdot T_{mr}^3 \quad (15)$$

2.4 Reference building model and set of configurations

The simulation plan presented in (Pernigotto and Gasparella, 2013) has been modified in order to study the heat gain problem. The plan considers a single base building module and a selected group of parameters varied within a predefined set of values, in order to develop a variety of configurations. The module is single-storey with 100 m^2 of floor area and a horizontal roof.

The opaque envelope is composed by a two-layer structure, whose thermo-physical characteristics are reported in Table 1. An insulation layer, with a thickness depending on the simulation plan, is positioned on the external side. Three possible materials have been considered for the internal layer (timber, clay-block or concrete) with a thickness chosen to have a thermal resistance around 0.8 m^2 K W^{-1}, as 0.2 m of clay-block. The absorption coefficients of the sun-exposed walls are 0.3 for the vertical walls (both sides) and for the ceiling (internal side), 0.6 for the roof (external side) and for the internal floor. When a surface is exposed to the external environment but not to the sun, its coefficient is 0. It is the case of the non-adiabatic floors directly in contact with the external air, modelled as if they are on a well-ventilated cavity. Coherently with the first part, the presence of thermal bridges has been neglected.

	Timber	Clay Block	Concrete	Insulation
λ	0.13	0.25	0.37	0.04
c	1880	840	840	1470
ρ	399	893	1190	40
s	0.1	0.2	0.3	0/0.05/0.10
R	0.77	0.80	0.81	0/1.25/2.5

Table 1 – Properties of the opaque components

The window frame is a timber frame with a low performance (U_f = 3.2 W m^{-2} K^{-1}) when coupled with the single glass or high performance (U_f = 1.2 W m^{-2} K^{-1}) in the other cases. The frame area covers about 20 % of the whole window area and its absorption coefficient is 0.6.

The following geometrical and thermo-physical characteristics have been determined in accordance with the factorial plan:

8. the amount of envelope surface exposed to the external conditions;
9. the level of insulation added to the internal layer;
10. the base material of the opaque envelope;
11. the percentage ratio of glazings A_{gl} to floor area A_{fl};
12. the orientation of the windows, all positioned in the same façade;
13. the kind of glazings;
14. the climatic conditions.

For each of the above factors, a certain number of levels were considered as reported in Table 2. Since not pertinent with the topic of the second part, the ventilation rate has been neglected as variable and the simulations have been performed considering 0 ACH. The orientation of the windows has been introduced in particular to assess more profiles of entering radiation.

The first factor allows to consider different ratios between the dispersing surface and so can influence the amount of solar gains received by the opaque components and the infrared extra flow (from the external side) and the dispersion of the entering solar radiation absorbed (on the internal side). Similarly, the variation of the thickness of the insulation layer from 0 to 10 cm (factor 2) affects the heat exchanges from the internal and external

1	a	one wall, floor and ceiling adiabatic; S/V=0.30 m^{-1}
	b	one wall and floor adiabatic; S/V=0.63 m^{-1}
	c	one wall adiabatic; S/V=0.97 m^{-1}
2	a	0 cm – U_{env} = 1.03 W m^{-2} K^{-1}
	b	5 cm – U_{env} = 0.45 W m^{-2} K^{-1}
	c	10 cm – U_{env} = 0.29 W m^{-2} K^{-1}
3	a	Timber
	b	Clay-block
	c	Concrete
4	a	11.7%
	b	23.4%
5	a	(S) single glass U_{gl} = 5.68 W m^{-2} K^{-1}, $SHGC$ = 0.855
	b	(DH) double glazing high solar transmittance U_{gl} = 1.140 W m^{-2} K^{-1}, $SHGC$ = 0.608
	c	(DL) double glazing low solar transmittance U_{gl} = 1.099 W m^{-2} K^{-1}, $SHGC$ = 0.352
	d	(TH) triple glazing high solar transmittance U_{gl} = 0.613 W m^{-2} K^{-1}, $SHGC$ = 0.575
	e	(TL) triple glazing low solar transmittance U_{gl} = 0.602 W m^{-2} K^{-1}, $SHGC$ = 0.343
6	a	East
	b	South
	c	West
7	a	Messina – HDD_{20}: 707 K d
	b	Milan – HDD_{20}: 2 404 K d

Table 2 – Factors and levels in the simulation plan

surfaces. The kind of glazings (factor 6), is probably the most important in this analysis because it strongly influences the entering solar radiation, which is generally the major heat gain source, together with factors 4 and 5. Factor 5 is also important in affecting the profile of the entering solar radiation during the day. Two climates have been considered to calculate the thermal losses for different profiles of external temperatures. Since the comparison is on a thermal flow and on a monthly basis, as stated in the thermal losses part, the heat capacity of the opaque envelope (factor 3) is not supposed to be relevant and it has been considered as variable because of the small deviations in the thermal resistance of the 3 alternatives and with the

perspective of further development on the calculation of the utilization factor.

Considering 3 shape ratios, 3 possible insulation thicknesses, 3 base materials, 2 different ratios between the window surface and the floor, 5 types of glazings and 3 orientations, 810 different configurations have been evaluated for each month of each climate. 19440 monthly values have been elaborated.

3. Results and discussion

The thermal gains have been analysed considering separately their 4 main components (entering solar gains through the glazings, solar gains transmitted through the opaque elements, internal gains and infrared extra flow towards the sky vault) and some correction factors based on the envelope properties have been developed. In Figures 1 and 2 the thermal gains evaluated in accordance with the EN ISO 13790:2008 method and the simulated ones have been compared, as well as the corrected results and the simulated ones. The coefficients of the regressions performed to correlate the correction factors with the envelope characteristics are reported in Table 3.

3.1 Entering solar heat gains

The entering solar radiation gains are clearly overestimated by the EN ISO 13790:2008. As we observed before, this is consistent with the lack of consideration for the redispersion of these gains by transmission or by radiation through the windows. The deviations are strongly dependent on the amount of dispersing surface (i.e., the S/V ratio) and, in particular, on the insulation level, which is also the variable considered in Figure 1 to distinguish the results in two groups: insulated one in light red and uninsulated one in dark red. The spread of the points of these two groups around the trend line is mainly due to S/V ratio. As it can be seen, the trend line of the uninsulated cases demonstrates a general overestimation of +51.2% given by the EN ISO 13790:2008 method. In case of insulation, it is reduced to +28.5%. For the analysed cases, a correction factor $f_{sol,gl}$ has been determined and a regression has been performed in order to correlate $f_{sol,gl}$ with the characteristics of the envelope.

$$f_{sol,gl} = k_0 + U_{env} \cdot (k_1 + k_2 \cdot x_{env}) + \\ + x_{win} \cdot (k_3 + k_4 \cdot U_{win}) + k_5 \cdot x_{ad} \quad (16)$$

The regression, with an adjusted index of determination R^2_{adj} of 0.957, underlines also the importance of the interactions between the windowed fraction (calculated with respect of the whole envelope, including the adiabatic surfaces) with the window thermal transmittance and the opaque dispersing fraction with the mean opaque thermal transmittance (with a standardized coefficient of -0.527 and -0.448, respectively). By using Eq. (16) the quasi-steady state results have been corrected, obtaining a percentage deviation within the 5% respect of the simulations.

3.2 Solar heat gains by transmission

For the solar gains transmitted through the opaque envelope, the EN ISO 13790:2008 underestimates the results respect of the simulations. The trend is the same both for insulated and uninsulated cases and it is around -25%. The spreads of the results around the trend lines are similar in both cases (a little larger for the insulated ones).

$$f_{sol,env} = \\ k_0 + k_1 \cdot A_{env} + \\ + x_{env} \cdot (k_2 \cdot x_{ad} + k_3 \cdot U_{env} + k_4 \cdot \theta_e) + \\ + k_5 \cdot U_{env} + k_6 \cdot U_{win} \quad (17)$$

The regression has an adjusted R^2_{adj} of 0.948 and the most influencing parameters are the opaque dispersing surface (with a standardized coefficient of 1.165) and the interaction between the opaque and the adiabatic fractions (0.609). By using Eq. (17) the quasi-steady state results have been corrected, and brought close to the 5% range of deviation respect of the simulations.

3.3 Internal gains

The convective internal gains are the same in both calculation methods and the deviations are due to the radiative part. The variability in the EN ISO 13790:2008 results is simply due to the different lengths of the months and a trend line cannot be defined. In simulation results, also the partial

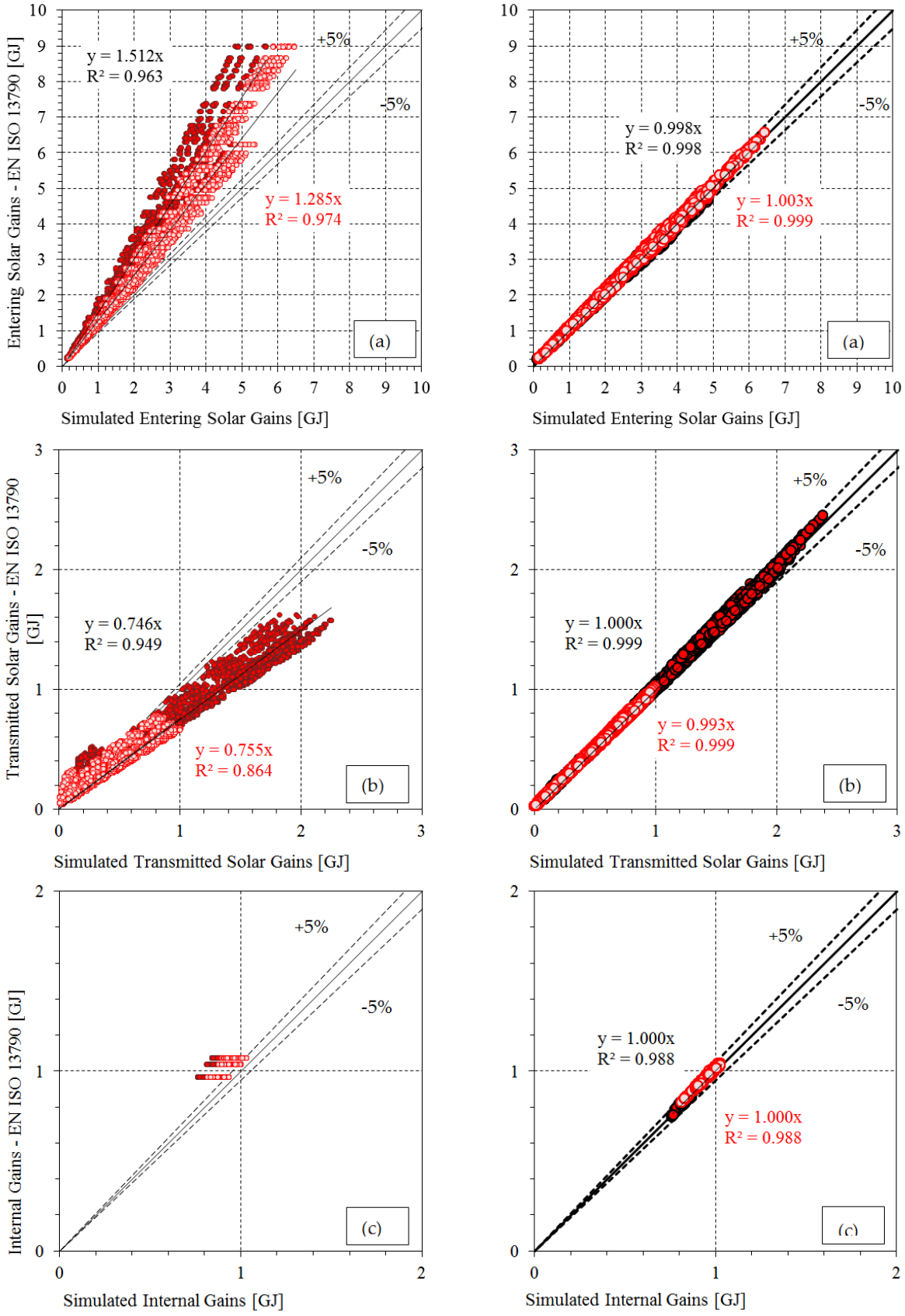

Fig. 1 – EN ISO 13790:2008 entering solar gains (a), transmitted solar gains (b) and internal gains (c), calculated according to the Standard (on the left) and using the correction coefficients (right) compared to the simulated gains. Insulated cases in lighter colours

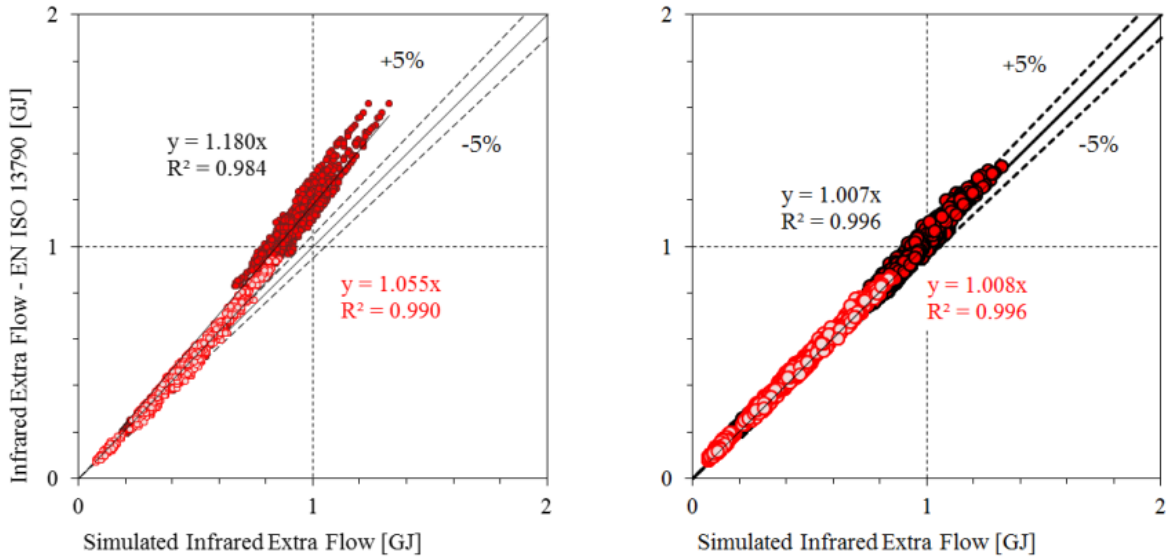

Fig. 2 – EN ISO 13790:2008 infrared extra flow towards the sky vault, calculated according to the Standard (on the left) and using the correction coefficients (right) compared to the simulated gains. Insulated cases in lighter colours

Entering solar gains						
k_0	**k_1**	**k_2**	**k_3**	**k_4**	**k_5**	
0.9346	-0.1014	0.1531	-0.2889	-0.3248	2.487E-2	
Transmitted solar gains						
k_0	**k_1**	**k_2**	**k_3**	**k_4**	**k_5**	**k_6**
-0.3265	4.964E-3	3.780	-0.4017	6.765E-3	0.3228	-5.766E-2
Internal gains						
k_0	**k_1**	**k_2**	**k_3**			
0.9885	-4.610E-2	-9.773E-2	-0.1709			
Infrared extra flow towards the sky vault						
k_0	**k_1**	**k_2**	**k_3**	**k_4**	**k_5**	**k_6**	**k_7**	**k_8**
1.044	-0.3144	-0.1433	2.217E-3	7.914E-3	-0.1562	0.2187	-3.738E-3	-5.795E-2

Table 3 – Regression coefficients

dispersion of the radiative part is considered. The overestimation provided by the Standard is between 10-20% for uninsulated cases and 5-10% for the insulated ones.

Also the S/V ratios, as expected, are relevant.

The regression adjusted R^2_{adj} is 0.99 and the interactions between the fraction of opaque surface and its mean thermal transmittance and the one between the fraction of window surface and its thermal transmittance have the same standardized coefficients (around -0.5).

$$f_{int} = k_0 + U_{env} \cdot (k_1 + k_2 \cdot x_{env}) + \\ + k_3 \cdot U_{win} \cdot x_{win} \quad (18)$$

3.4 Infrared extra flow towards the sky vault

In the calculation of the infrared extra flow towards the sky dome, a different behaviour from the insulated to the uninsulated cases can be noticed: while for the insulated cases a good agreement is registered, for the uninsulated ones the EN ISO 13790:2008 overestimates (+18%). The difference is probably due to the estimation of the surface temperature for the calculation of h_{re}. The

adjusted determination index is 0.878 and the most influencing parameters are the interaction between the thermal transmittance of the opaque envelope and its fraction (standardized coefficient equal to -0.418) and the fraction of adiabatic surface (0.665).

$$f_{IR,sky} = k_0 + x_{env} \cdot \left(k_1 \cdot x_{ad} + k_2 \cdot U_{env} + k_3 \cdot \theta_e\right) + \\ + U_{win} \cdot \left(k_4 + k_5 \cdot x_{win}\right) + k_6 \cdot x_{ad} + \\ + k_7 \cdot \theta_e + k_8 \cdot U_{env} \quad (19)$$

4. Conclusions

In the present work two thermal gains estimation methods have been analysed: the EN ISO 13790:2008 quasi-steady state approach and dynamic simulations. The most important sources of discrepancies, due to the dispersion of the thermal gains involved in the surface balance of the envelope, such as the amount of dispersing surface and the envelope insulation, have been analysed. A correction, which takes into account this phenomenon, has been proposed for each heat gain component, in order to improve the coherence between dynamic simulation and quasi-steady state approach.

5. Nomenclature

Symbols

A	area (m²)
b/*F*	reduction factor (-)
C	heat capacity (J K^{-1})
c	specific heat capacity (J kg^{-1} K^{-1})
F	view factor (-)
g	g-factor (-)
f	correction factor (-)
h	heat transfer surf. coeff. (W m^{-2} K^{-1})
HDD	heating degree-days (K d)
I	solar irradiance (W m^{-2})
Q	energy (GJ)
$\dot{q}$	thermal flux (W m^{-2})
R	thermal resistance (W m^{-2} K^{-1})
s	thickness (m)
S	dispersing surface (m²)
SHGC	solar heat gain coefficient (-)
t	time (s)
U	thermal transmittance (W m^{-2} K^{-1})
V	conditioned volume (m³)
x	surface fraction: $x_{env}+x_{win}+x_{ad}=1$ (-)
α	absorption coefficient (-)
ε	surface emissivity (-)
Φ/ ϕ	thermal flow (W)
λ	thermal conductivity (W m^{-1} K^{-1})
ρ	density (kg m^{-3})
σ	Stefan-Boltzmann constant ($5.67 \cdot 10^{-8}$ W m^{-2} K^{-4})
θ/T	temperature (°C) (K if absolute)

Subscripts/Superscripts

A	appliances
a/air	internal air
ad	adiabatic
c	convective
C	cooling
e/o	external/external side
env	opaque envelope
f	frame
fl	floor
gn	heat gain
gc	convective gains
gl	glazing
H	heating
ht	heat transfer
i	internal/internal side
int	internal heat gain
IR	infrared radiation
glwr	longwave radiative gains
gswr	shortwave radiative gains
L	lighting
Proc	processes
ob	obstacles

Oc	occupants
mr	mean radiant
n	normal incidence
nd	energy need
r	radiative
sh	shading
sky	sky vault
sol/S	solar
sys/HVAC	system
tr	transmission
u	unconditioned
ve	ventilation
WA	water mains
win/w	window

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