

Solar and internal gains in low-energy and passive houses

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ABSTRACT: *The increasing energy efficiency of the thermal envelop induces evolutions in the whole energetic equilibrium of buildings. This paper illustrated some of these evolutions regarding internal and solar gains through dynamic simulations. The increased relative impact of internal gains compared to solar gains is shown, such as a reduction in the utilization of solar gains during the heating period. The accuracy of ISO 13790:2008 calculation method facing these evolutions is discussed.*

INTRODUCTION

Today's focus in housing design is on the reduction of heat losses (e.g. Passive House principles [1]). Solar gains are of course always considered but maybe with less emphasis than in the 70' or 80' solar architecture. For their part internal gains, although part of the thermal balance are scarcely seen as a useful and practical design parameter by architects. But heat gains do still play a major role in energy performance since the heat losses reduction allows them covering an increasing part of the heat demand.

Today's calculation methods such as ISO 13790:2008 consider a global utilization factor for solar and internal gains [2]. This factor is calculated based on the time constant and the heat gain-heat loss ratio of the building for the period. This method does not allow the designer to identify the specific behaviour of both solar and internal gains although they could induce specific design strategies.

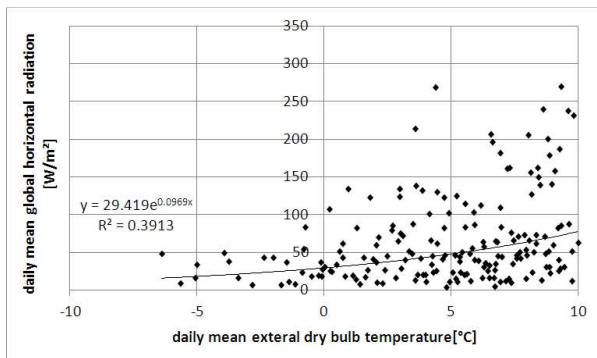


Figure 1: daily mean global horizontal radiation correlated with the daily mean external dry bulb temperature for Uccle, Belgium (northern Europe oceanic climate), based on Météonorm [3].

Further, increased energy efficiency centres the residual heat demand on very cold period that are also characterized by low radiation in central oceanic European climate (see figure 1). In the same time internal gains may be assumed constant throughout the year. Once it may be suspected that the reduction of the heat demand generated by the increased energy efficiency of building causes internal and solar gains to evolve in different way. In this paper, we look for a better understanding of how both internal and solar gains evolve when considering low energy housing.

STATE OF THE ART

The ISO 13790:2008 methods to calculate the dimensionless gain utilization factor $\eta_{G,H}$ is described by equation I and II.

$$\text{If } \gamma_H \neq 1 \longrightarrow \eta_{G,H} = \frac{1 - \gamma_H^{a_H}}{1 - \gamma_H^{(a_H+1)}} \quad \text{I}$$

$$\text{If } \gamma_H = 1 \longrightarrow \eta_{G,H} = \frac{a_H}{a_H + 1}$$

$$\text{with for each month } \gamma_H = \frac{Q_{G,H}}{Q_{L,H}}$$

$$\text{and for residential buildings } a_H = 1 + \frac{\tau_H}{15}$$

$$\text{with } \tau_H = \frac{\sum \chi_j A_j / 3.6}{H_{L,H}} \quad \text{II}$$

In equation I, γ_H is the gain/loss ratio, $Q_{G,H}$ the total heat gains for the heating mode in MJ and $Q_{L,H}$ the total heat losses for the heating mode in MJ. In equation II τ_H is the time constant of the building in hours, χ_j the internal heat capacity per area of the building element j in kJ/(m²K), A_j the area of the element j and $H_{L,H}$ the heat

loss coefficient of the building for the heating mode in W/K. τ_H is a constant for a given building while γ_H and $\eta_{G,H}$ are to be calculated monthly or weekly.

We see in those equations that the utilization factor is dependant from the heat losses of the building and its thermal mass. The effusivity and diffusivity of the thermal mass are not considered. The time and spatial distribution of solar and internal gains are also neglected.

METHODOLOGY

This paper investigates the variation of the utilization of solar and internal gains according to the heat demand of the building. This is done through Trnsys 17 dynamic simulation of an isolated house ranging in performance from poorly insulated to the Passive House Standard under the north European oceanic climate.

For various heat losses levels, parallel simulations are conducted with internal and solar gains, with solar gains only, internal gains only, or without both gains. By comparing the heat demand obtained in those parallel simulations, we deduce the actual utilization factors from equations III to V. Those utilization factors are then compared with ISO 13790's $\eta_{G,H}$ factor on a monthly basis. This factor is calculated based on $Q_{G,H}$ and $Q_{L,H}$ values extracted from the simulations and a a_H value based on the analytically calculated time constant of the building in all cases ($54 \text{ h} < \tau_H < 174 \text{ h}$).

$$UF_{\text{solar}} = \frac{HD_{\text{nosun}} - HD_{\text{sun}}}{SG_{HP}} \quad \text{III}$$

$$UF_{\text{int}} = \frac{HD_{\text{no int}} - HD_{\text{int}}}{IG_{HP}} \quad \text{IV}$$

$$UF_{\text{total}} = \frac{HD_{\text{nogain}} - HD_{\text{gain}}}{SG_{HP} + IG_{HP}} \quad \text{V}$$

In equation III to V, UF_{solar} , UF_{int} and UF_{total} are the utilization factors for solar gains, internal gains and solar+internal gains respectively, HD is the heating demand with indices defining simulation conditions regarding solar and internal gains, and SG_{HP} and IG_{HP} are the solar and internal gains during the heating period.

CASE STUDY

The studied house is a theoretical detached house previously considered by S.Trachte et al. or L.George et al. [4, 5] (see figure 2). This typology represents a significant share of the Belgian real estate heritage (32% of built-up areas [6]) and since years, single houses represent the most built typology for new construction in Belgium. This fact justifies the typology chosen for the research, even though this type of dwelling is substantially opposed to the priorities of sustainable architecture and urban development.

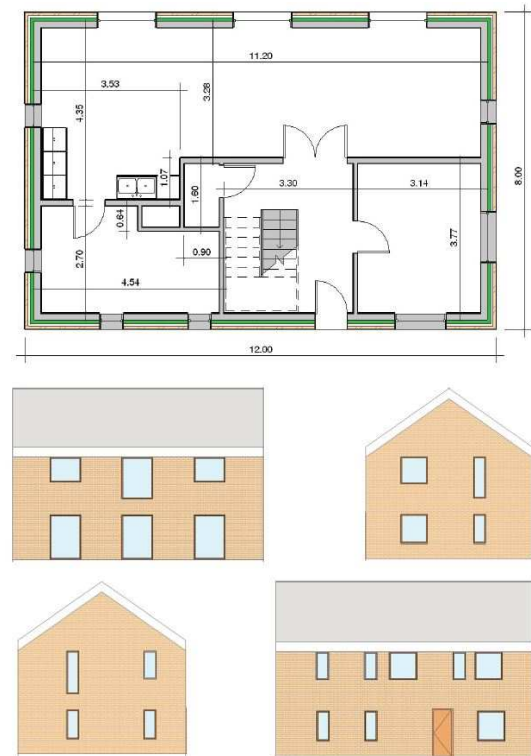


Figure 2: ground floor plan, south, east, west and north facades for the case study house.

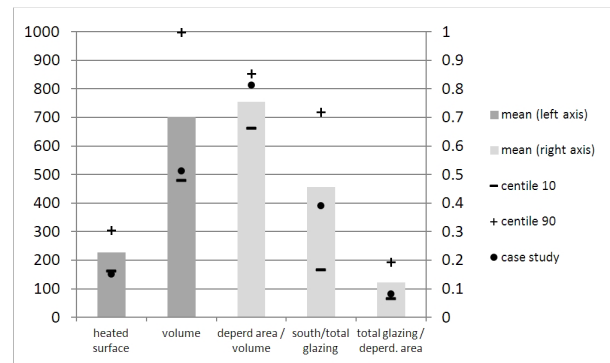


Figure 3: Comparison of the case study with the CALE database.

The single house used has a heated surface of 152 m² with windows ratios of 26 % of South Façade, 15 % of North Façade, 12 % of West Façade and 8 % of East Façade. That is a 34.63m²/417.7m²=0.083 ratio of openings relative to the whole building envelop. The compactness ratio is 1.07m⁻¹.

Those values are consistent with statistics obtained from the CALE database (figure 3), although this house is a relatively small one with limited glazing area. CALE database includes 1029 residential units designed between 2004 and 2011. 535 units are actually built when writing this paper, the other being still at design or building stages. This database describes projects submitted to the operation "Construire Avec L'Energie

(Build with energy)” supported by Wallonia regional authorities. The CALE operation was launched in February 2004. It aimed to grant low energy housing design. So the database build through this operation actually reflects today’s low energy design practice in Wallonia.

The internal gains are set according to a profile shown in figure 4. The spatial mean peak load is 7.42W/m^2 and the global average load in time and space is 2.63W/m^2 . The gains are higher at night than during the day, with peak values early morning and in the evening.

Table 1 indicates the statistical properties of the internal and solar gain profiles. Both are similar in spatial distribution in the various thermal zones of the buildings but the larger temporal variation of solar gains appears through the residual standard deviation (RSD_{time}) value.

The wall, windows, air tightness and heat recovery on the ventilation network properties vary in order to obtain different heat demand. This results in a variation of the heat loss coefficient between 287 and 89W/K , or between 0.69 and $0.41\text{W/m}^2\text{K}$ relative to the thermal envelop area. The g value of windows and the window area are set constant (max 1% variation in the g value occurs in some cases when selecting various U_g values).

In all cases, the heating set point is 20°C between 6am and 9am and between 16pm and 22pm on weekdays, and between 8am and 22pm on weekends. A mechanical ventilation network with heat recovery is considered in all cases.

RESULTS

The figure 5 shows the evolution of various parameters according to the heat demand. Those parameters are:

- 1/ the solar gains inside the building for the whole year or during the heating period only
- 2/ the internal gains inside the building for the whole year or during the heating period only

3/ the heat demand in various cases: without solar gains, without internal gains or without both

4/ the length of the heating period. This period is observed on the simulation results as the number of days with a heating demand higher than $0.02\text{kWh/m}^2\text{day}$. This limit is set in order to exclude days when an actual house would probably not be heated although the simulation indicates residual heating demand. The heating demand profiles in figure 6 for the most and least energy efficient

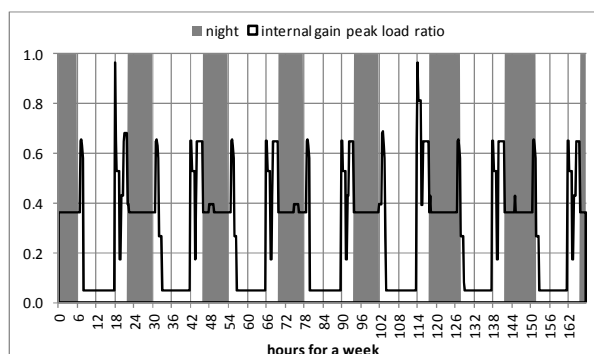


Figure 4: spatial average of the internal gain profile expressed as a ratio of the 7.42W/m^2 peak load.

Table 1: Solar and internal gain statistical analysis for the 1st week of January.

	Internal gains	Solar gains
<i>Spatial distribution in the 10 zones of the dynamic model</i>		
Mean value [$\text{Wh/m}^2\text{week}$]	363	2324
Standard deviation in the thermal zones [$\text{Wh/m}^2\text{week}$]	239	1680
$\text{RSD}_{\text{space}}$ [%]	66	72
<i>Temporal distribution in the all model</i>		
Mean value [$\text{Wh/m}^2\text{week}$]	2163	15968
Standard deviation for hourly values [$\text{Wh/m}^2\text{week}$]	1590	26253
RSD_{time} [%]	74	166

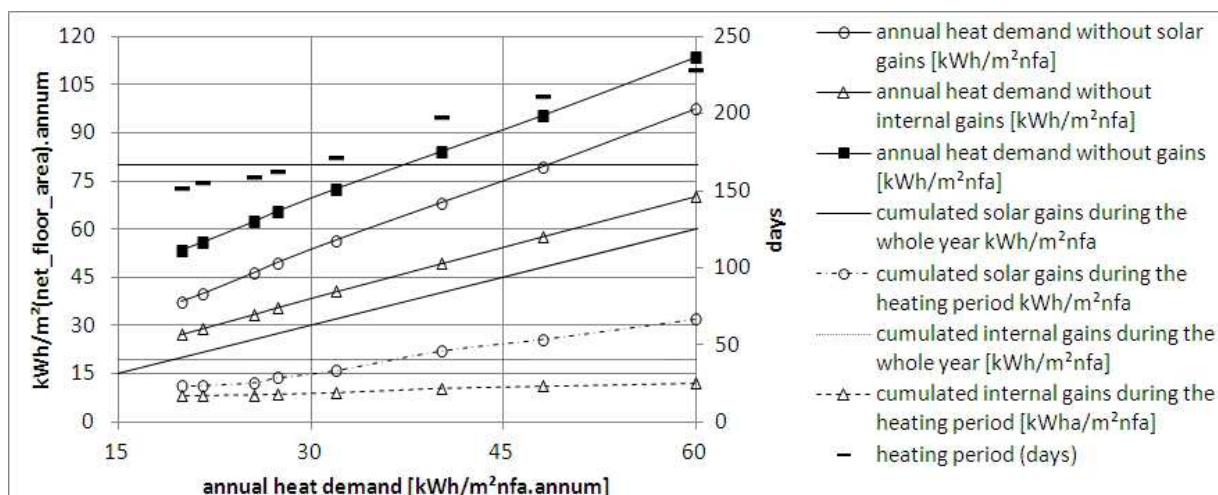


Figure 5: Impact of solar and internal gains on the heat demand for various heat demand level (nfa is used for “net floor area”)

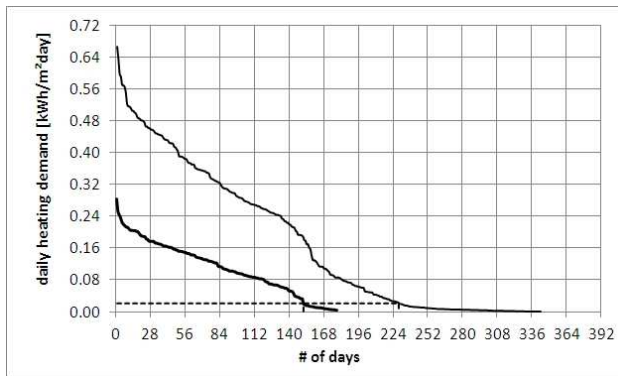


Figure 6: Heating demand profile for the most and least energy efficient cases.

cases show that this limit is low enough to have a limited impact on the results and correspond to an inflexion point in the profiles.

The figure 5 shows that the solar gains during the heating period decreases faster than internal gains when the annual heat demand is reduced. Solar gains are 265% of internal gains for a 60kWh/m²a heat demand but only 138% for a 20kWh/m²a heat demand.

Figure 7 compares ISO 13790's $\eta_{G,H}$ factor values with the simulation based utilization factor for the best and least energy efficient cases. We can see that the calculated $\eta_{G,H}$ value is close from the UF value obtained through simulation for the 60kWh/m²a heat demand case. But while $\eta_{G,H}$ is nearly constant regarding the heat demand, especially for the winter months, this is not the case for UF_{solar} factor and consequently for the UF_{total} factor that decrease in winter for low heating demand cases.

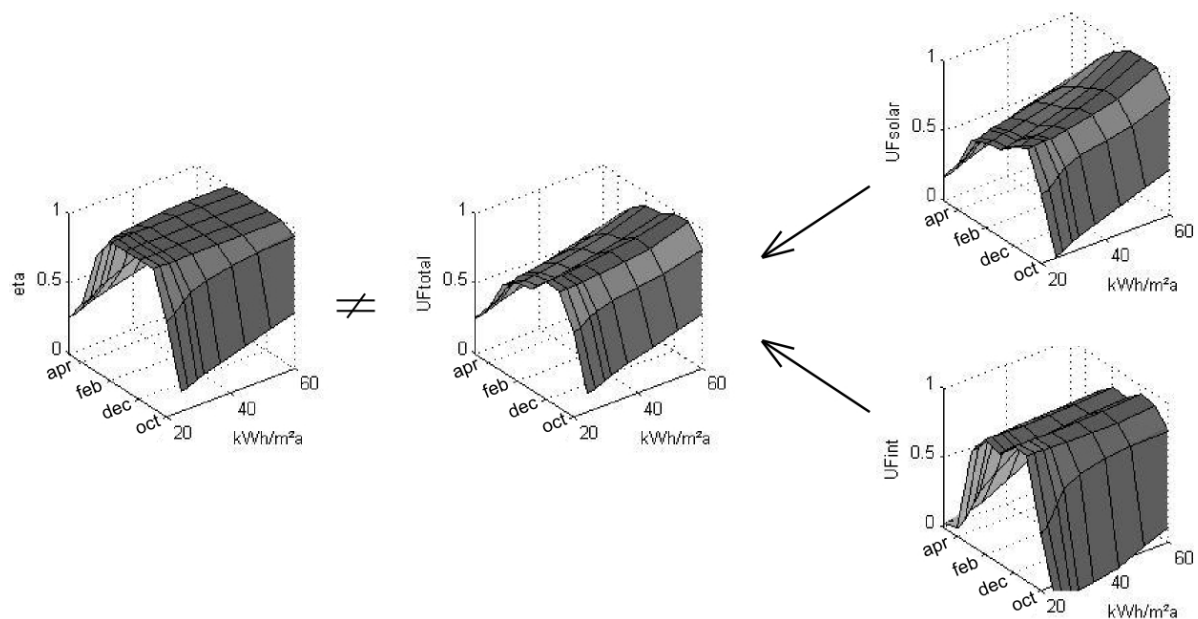


Figure 7: Monthly values of $\eta_{G,H}$ and UF factors for various annual heat demand cases

Figure 8 looks for the origin of that difference by indicating the evolution of the relative error between $\eta_{G,H}$ and UF_{solar} as a function of the two parameters determining $\eta_{G,H}$, i.e. the time constant τ_H and the gain/loss ratio γ_H . A correlation appears between the error and the time constant τ_H : the highest the time constant, the highest the relative error. An high time constant indicates either a high thermal inertia or a low $H_{L,H}$ heat loss coefficient in W/K. Since the thermal inertia is constant in our study, figure 8 indicates that the highest the energy efficiency of the building envelop, the less accurate is the $\eta_{G,H}$ value. The right part of figure 8 indicates a complex relation between the relative error and γ_H . Although this parameter doesn't explain why a very low energy building is less accurately approached by the ISO 13790's method, we can see a pattern in the figure if we link values for a given month. For a given month, a higher gain/loss ratio γ_H (i.e. low the heat losses) result in a higher error. That was already indicated by figure 7.

DISCUSSION

This paper shows that when the heat demand of the building is reduced thanks to insulation and air tightness, the relative impact of solar and internal gains is modified (figure 5). Although the impact of solar gains on the heat demand remains larger than the one of the internal gains, internal gains acquire more importance.

The results also show that if the internal gain actual utilization factor remains good in very low energy

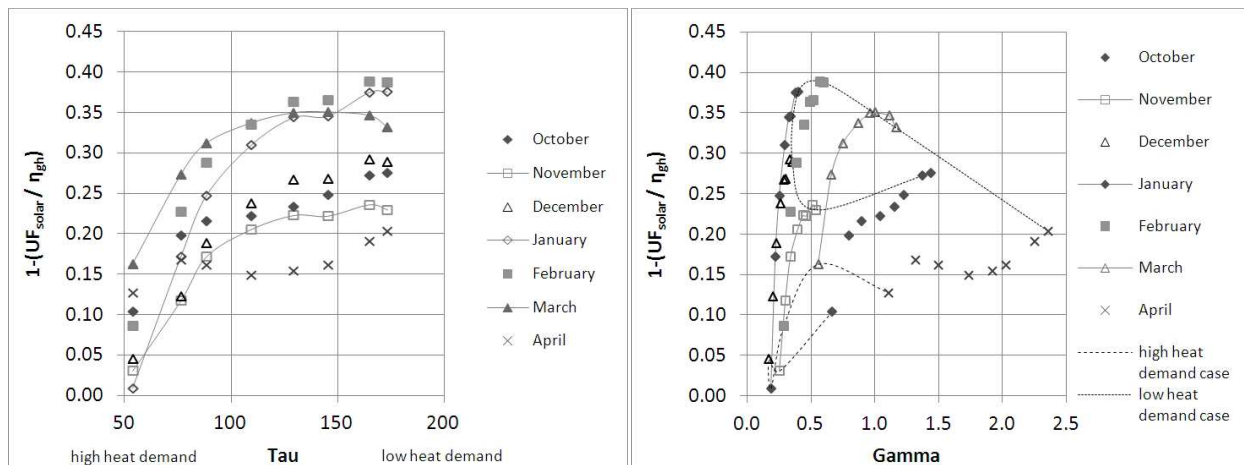


Figure 8: relative difference between the utilization factors for solar gains and $\eta_{G,H}$ expressed as $1 - UF_{solar} / \eta_{G,H}$ as a function of the time constant τ_H and the gain/loss ratio γ_H

buildings, this is not the case for the solar gains utilization factor (figure 7). The highest temporal variation of solar gains (table 1) may be an explanation for that particular behaviour: for very low energy houses, some part of the solar gains would cause the internal temperature in some rooms to exceed the heating set point even in cold periods, raising the heat losses and wasting energy. Yet this hypothesis is not demonstrated in this paper and should require further examination.

The results also show the reduced accuracy of the ISO 13790:2008 $\eta_{G,H}$ gain valorisation factor for very low energy buildings (figure 7). They indicate that this reduced accuracy is correlated with the time constant τ_H (figure 8). It might then be suggested that the calculation of either the numerical parameter $a_H = f(\tau_H)$ or the time constant τ_H should be adapted for very low energy buildings. As said before, this paper doesn't allow explaining why a bigger part of solar gains are wasted in such houses. If the explanation is the one suggested in the preceding paragraph, a possible adaptation could be to dampen the a_H growth when $H_{L,H}$ is reducing.

CONCLUSION

Based on dynamic multizonal simulations, this paper discussed the distribution of internal and solar gains in a house according to its energy efficiency regarding heat demand. The specific behaviour of very low energy houses facing solar gains is noticed. The accuracy of ISO 13790's $\eta_{G,H}$ factor facing that behaviour is discussed.

On a larger scale, this paper investigates the idea that very low energy buildings have a specific behaviour that might differ from traditional or low energy buildings. If this is true, calculations codes and design strategies should be adapted to them. Especially the increasing impact of internal gains should be analyzed and specific design strategies defined to make the most of it.

In future works, this paper's conclusions should be analyzed when modifying some assumptions such as the

heat recovery on the ventilation network that allows for a spatial distribution of solar and internal gains. This recovery is suspected to maximize the actual utilization factor and its impact in very low energy building should be analyzed. Also, the impact of the simulated daily heating period, that is limited to some hours every day, could be analyzed. The impact of the inaccuracy of $\eta_{G,H}$ on the heat demand should also be calculated.

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