The Effect of Shading Calculation on Passive Solar Gains

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Abstract

Parametric studies and sensitivity analyses applied on calculation of energy need for space heating indicate that passive solar gains in well insulated buildings appear to be a very important but on the other hand quite unreliable source. Generally used calculation procedure (ISO 13790) assigns every translucent construction in monthly based calculation each month for the whole year the same value of shading reduction factor and total solar energy transmittance. The question is how appropriate is this simplification in case of low-energy, passive or net zero energy houses.

The paper deals with the comparison of the ISO and more precise calculation of passive solar gains in situations with extended shading caused by usual building construction elements. Focus is stressed on shading reduction factor, total solar energy transmittance and utilization factor that differ for various shading situations every month in the course of the year. Finally the effect of shading calculation on energy need for space heating in a building is presented.

1. Calculation method

1.1. ISO 13790

Standards used for the calculation of the energy need for heating like [2] approach the calculation of solar gains on monthly basis according to the formula (1-1)

$$Q_S = \sum_j I_{sj} \cdot \sum_n A_{nj} \cdot \left(F_h \cdot F_o \cdot F_f\right) \cdot F_F \cdot F_C \cdot \left(0{,}9 \cdot g_n\right) \cdot \eta \qquad (1\text{-}1)$$

where I_{sj} is the total amount of global solar radiation on surface n with the orientation j

A_{nj} is the surface of evaluated translucent element (window) n with the orientation j

F_h, F_o, F_f are partial shading correction factors for horizon, overhang and side fins

F_F is a frame factor

F_C is reduction factor for permanent curtains

g_0 is the total solar energy transmittance

η is the efficiency of gains

The shading reduction factors for horizon and constructions (F_h, Fo, F_f) are obtained by interpolation from table values based on a certain geographical latitude and the angle between the link of the obstacle's shading edge and the centre of the glass and the plain of the window [2]. By multiplying all the F members in the equation (2-1) a total shading reduction factor can be generated. Its value stays the same for all the months in the year. The total solar energy transmittance is also taken for every month as the same value (90% of g_o) irrespective of window orientation and the varying sun paths during the year.

1.2. Hour-step simulation

The main goal of the calculation is a detailed evaluation of shading of a certain collector (window) by usual building construction (window lining and lintel, overhang, near desk obstacles, side fins,…) The focus is stress on magnitudes that change during the course of the year:

- g - total solar energy transmittance
- F - total shading reduction factor
- η - efficiency of gains

The calculation is based on numerical-analytical approach. Numerical part lies in division of the collector area in small elemental areas represented by a node in their centre. Analytically are modelled the shading obstructions. Every node is then assessed individually.

The basic input data for the simulation are hourly values of incident global solar irradiation data on horizontal surface. Meteonorm 6.0 [4] was used as a data source. An average year for locality Prague for a year span 1981-2000 was selected. The data is processed further on using Perez model [1]. The total incident radiation on the window surface consists of beam, circumsolar, diffuse and a sum of reflected components of solar radiation which are all treated individually. A total shading reduction factor is determined by a back synthesis of calculated contributions of the individual solar components for desired slope and orientation of the window and the modelled shading situation. The value is weighted according to the intensity of incident solar radiation.

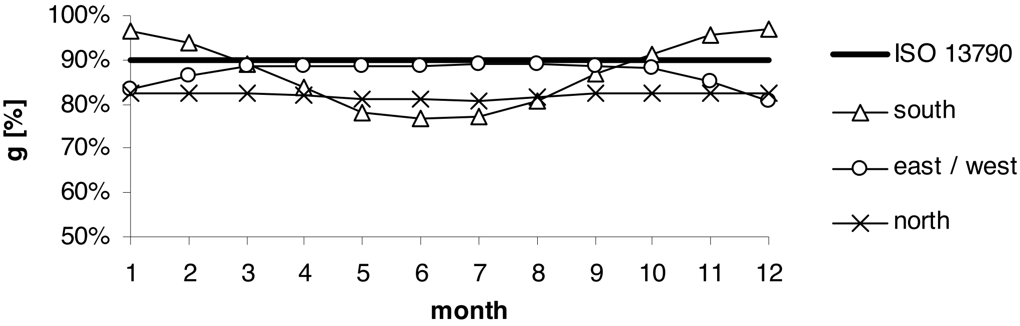
2. Comparison of key values

2.1. Total solar energy transmittance

To be able to find out and interpret the effect of solar energy on the internal environment, it is necessary to concern deeplier with its transmittance through the glazing. The g-value is dependant on the angle of incidence of solar radiation, which is simplified in the ISO standard for monthly method. The shape of the angle dependency curve is determined primarily by the number of window panes and used coatings. In the hour-step simulation the g-value is calculated according to [3] in every step for all solar components and their respective incident angles. In the further presented calculation a triple glazing with g_0=0,5 and low-emissivity coatings is used.

Parametric studies of various shading situations indicated that the monthly values of total solar energy transmittance are markedly dependant on orientation of evaluated window. Shading situation does not seem to be the major factor in this case. Characteristic courses are displayed in Fifure 1.

The g-values are ranged form 77% to 96 % of the normal transmittance. The ISO standard undervalues southern orientation in the winter months, east and west orientation are slightly overestimated in this period. Summer period is from the terms the energy need for heating almost irrelevant to evaluate in case of low energy and passive buildings.



Fif. 1. Percentage decrease of g-value in dependency on the window orientation during the year.

2.2 Shading reduction factor

Simple situations were deliberately chosen for the comparison of total shading reduction factor calculated according to [2] and hour-step simulation. Characteristic variations are therefore well noticeable. Only a few cases with major divergences are presented further on.

The calculation is done on a window 1000 mm wide and 1000 mm high. The frame width is taken as zero (frameless) to avoid disclarification of selected shading situation results. The overhang extension and side fin extension is determined by angle α according to [2].

Table 1. The length **d** of overhang or side fins for considered window (1000 mm x 1000 mm) dependant on **α**

α [°]	10	20	30	40	50	60
d [mm]	88	182	289	420	596	866

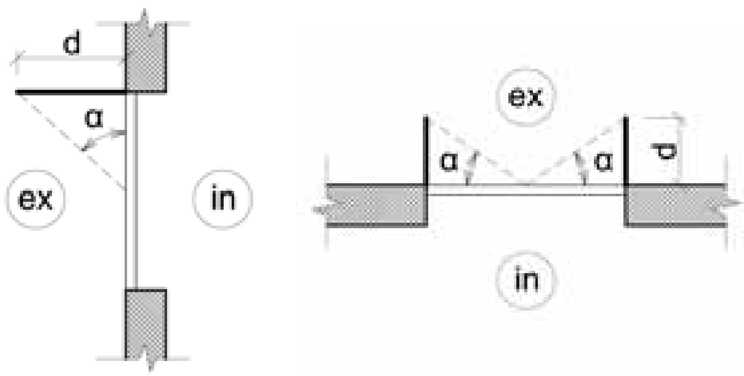
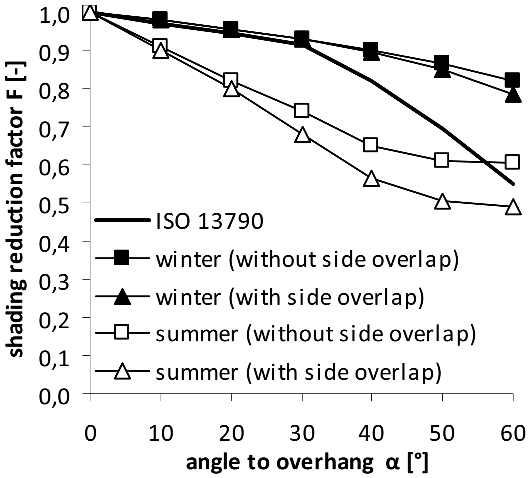


Fig. 2, 3. Schema of shading obstacles definition: overhang and side fins

Overhang – southern orientation

The ISO standard sets for window oriented southward a lower shading reduction factor (less solar gains). The trend is highlighted with growing extension length **d** and shortening of the side overlap of the overhang. Curves with a triangle sign in Figures 4 and 5 show the courses of **F** for the case when the width of the overhang is equal to the window width. A square sign represents the case with infinite side overlap of the overhang.



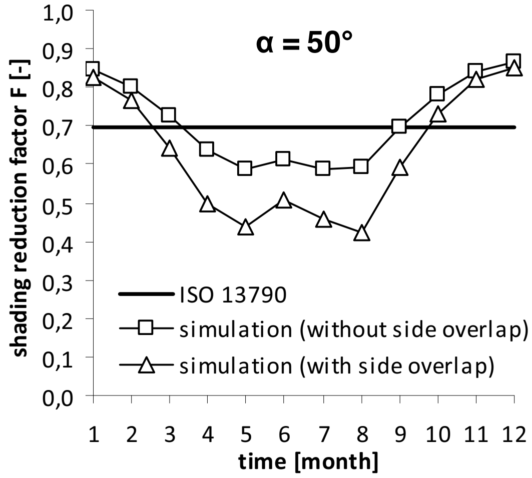
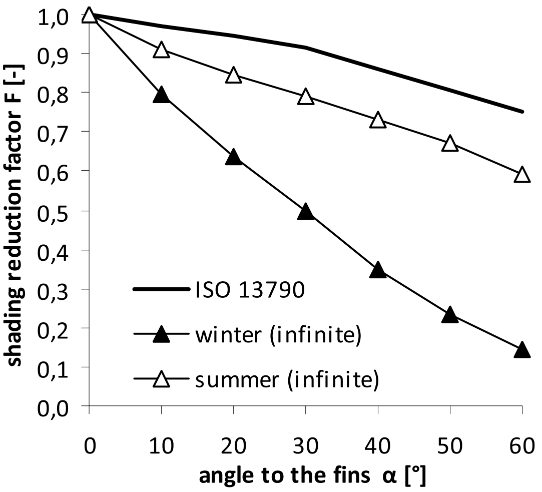


Fig. 4. Comparison of shading reduction factor according to ISO vs. simulation results for a window with a overhang facing southward, α is measured according to [2]
Fig. 5. Monthly values of shading reduction for overhang under the angle α =50°

Side fins – western orientation

The ISO standard markedly under estimates the shading effect of the side fins. The divergence is increasing with the growing length of the fins and is bigger in the winter period, when the fin on from the southern side considerably shades the strong noon sun which set as early as at south-west. The northern fin does not shade the beam radiation but still detracts some of the diffuse solar component.



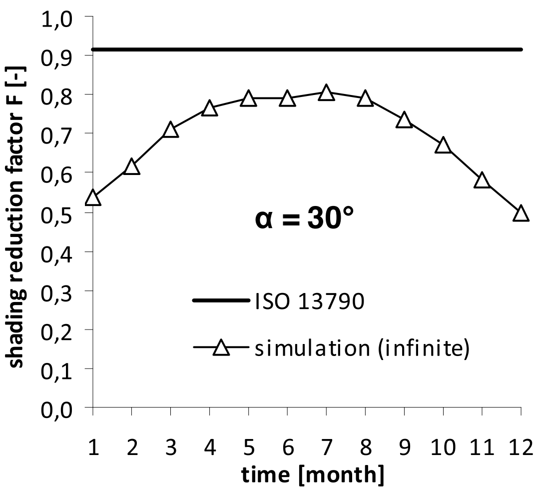


Fig. 6. Comparison of shading reduction factor according to ISO vs. simulation results for a window with a side fins facing westward, α is measured according to [2]
Fig. 7. Monthly values of shading reduction for side fins under the angle α =30°

2.3. Utilization factor of passive solar gains

ISO standard defines utilization factor of thermal gains on the basis of proportion between thermal gains and heat loss. Effective heat capacity of the building plays an important role in the formula as well. All is derived from monthly sums, not taking into account the origin of the gains or time when they are available. These questions led to a closer exploration of this issue. To include the mentioned factors and then compare with the common procedure, a dynamic simulation is run on a simple one-node thermal model that represents the building.

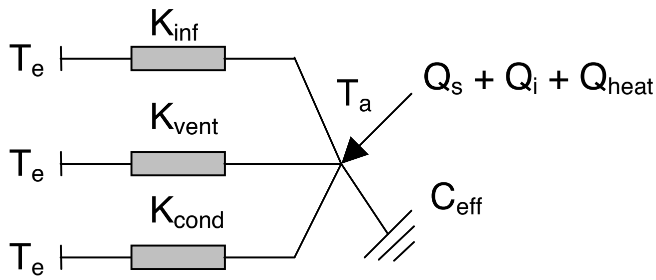


Fig. 8. A scheme of the used one-node thermal model

The simulation is run in an hour step. Prague was chosen as the locality for external temperatures and solar radiation. The hourly input of solar thermal radiation entering the interior is computed by the software described above. Minimal internal temperature is permanently kept to 21°C.

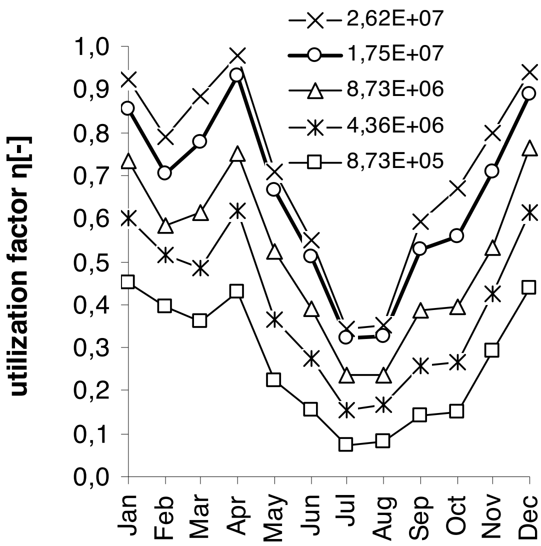
The further calculations are shown on case of a mid-size family house, details in Table 2.

Table 2. Characteristics of a mid-size family house

Floor area	150 m^2
H_T – heat transfer coefficient by conduction	70 W/K
H_V – heat transfer coefficient by ventilation	8,3 W/K
A_g – glazed area	19 m^2 (only southward, with overhang)
U_{em} – average thermal transmittance	0,17 $W/m^2.K$
e_A – specific energy need for heating	18 $kWh/m^2.K$

The sum value of internal gains is calculated according to [5] (i.e. 2,5 W/m^2) and two distribution patterns of this value in the course of the day are compared. The first one (Q_i1) is representing the usual scheme when the residents are not present during the working hours (from 9 a.m. to 4 p.m. just 100 W, then 500 W) and in the second (Q_i2) is the internal gain displaced equally in time (380 W). This issue did not prove to be very important. There is only a small difference in the course of efficiency lines. Q_i1 pattern enables a better usage of solar gains during the day when the internal gains are suppressed. The divergence between the two variants is rising with decreasing effective heat capacity of the building.

Heat capacity and a chosen maximal temperature to which the internal temperature can rise so that the solar gains can still be counted seem to be the two very important parameters. Figure 9 shows the range in which the factor moves depending on the effective heat capacity with maximal creditable temperature for solar gains set to 22 °C. Thick line marks the estimated capacity the modelled house.



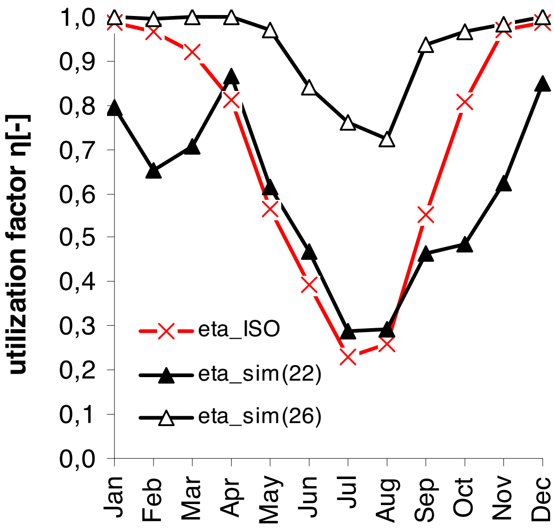


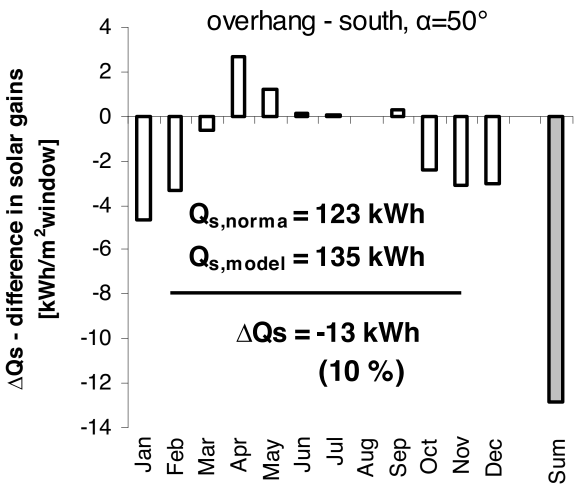
Fig. 9. Utilization factor with regard to the effective heat capacity, Ta, max = 22°C

Fig. 10. Utilization factors according to ISO standard and according to simulation result for Ta, max = 22°C and Ta, max = 26°C for heat capacity $C_{eff} = 1{,}38.10^7$ J/K (corresponds to time constant τ=48 hours).

It seems that the creditable solar gains in the summer period are limited by the internal temperature around 21–22 °C. It usually does not depend on the accuracy of solar gain calculation in this period for heating reasons since much of the available gains remain unused. In the winter period higher temperatures (than 22-23 °C) caused by the solar radiation are welcome and according to comparison with ISO (Figure 10) also counted. Not all winter solar gains would be useful according to simulation with internal temperature limit for counting the solar gains set 22 °C.

3. Energy consequences

Analyses indicated that in cases where major obstructions are present the shading reduction factor differs quite significantly. In contrary the total solar energy transmittance accounts smaller oscillation in the course of the year. The incident solar radiation, window area and gain utilization factor however according to the equation (1-1) also participate in the final value of passive solar gain each month. Relatively large differences in shading reduction factor e.g. in December might then be lessened in absolute numbers by lower amount of incident solar energy and vice versa a small difference after the multiplying by higher amount of incident solar energy (e.g. southern orientation in April) gains the importance. Monthly values of solar gains differences and their yearly sum for presented cases of south facing overhang (α =50°) and west facing side fins (α =30°) are displayed in figures 11 and 12. Positive ΔQs means that ISO standard overestimates the gains, negative ΔQs mean the contrary.



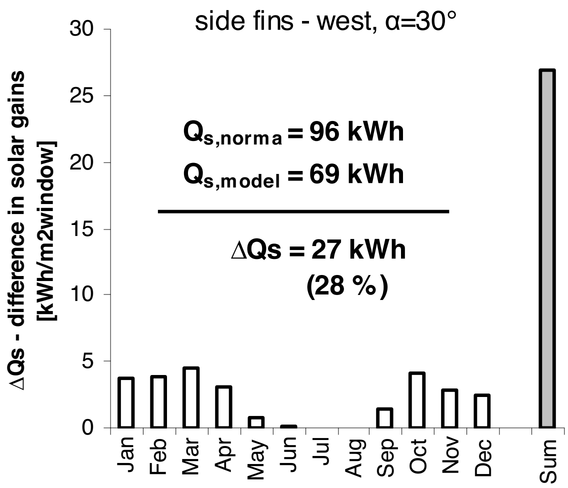


Fig. 11 resp. 12 Difference in solar gains calculated according to [2] and according to hour-step detailed simulation for two selected cases. The efficiency of thermal gains is consider according to ISO [2].

The remaining question is how much the calculated difference in solar gains ΔQs influences the energy need for heating Qh. Based on classical equation (3-1), it is possible to write the ratio of ΔQs to Qh using a coefficient **k** in (3-2).

$$Q_h = Q_L - (Q_{g,v,in} + Q_{g,v,sol}) \tag{3-1}$$

$$\Delta Q_s = k \cdot Q_h \qquad k = \frac{b \cdot c}{a + 1 - a \cdot b - b} \tag{3-2}$$

where $a = \frac{Q_{g,v,in}}{Q_{g,v,sol}}$, $b = \frac{Q_{g,v}}{Q_L}$, $c = \frac{\Delta Q_s}{Q_{g,v,sol}}$

ΔQs	is the difference in solar heat gains caused by a calculation method
Qh	is the need for space heating of the building
Qg,v,in	is the useful internal thermal gain
Qg,v,sol	is the useful solar thermal (according to ISO standard)
Qg,v	is the useful thermal gain (internal + solar)
Q_L	is the thermal heat loss of the building (in evaluated period, in kWh)

Studies proved that the influence of inaccuracy in calculation of passive solar gains on the building's need for space heating (coefficient k) increases with:

- descending ratio of internal gains to solar gains

• ascending ratio of gains to thermal losses

• ascending difference in calculation of solar gains to the value of solar gains

It has been verified that the inaccuracy in solar heat gain calculation plays the more important role the lower need for heating of the building is, the more important the role of the solar gains are in the heat balance and the more shading obstacles are present.

4. Conclusions

The inaccuracy in calculation of passive solar gains can change the need for space heating for ordinary dwelling houses with e_A=15-20 kWh/m^2.a in extreme cases around 10 to 12%. It is important to note that ΔQs is growing the more the more distinct shading occurs, which also causes a decrease of the ratio of passive solar gains to heat loss. Further on, the difference ΔQs can be both either positive or negative, depending on the shading situation and orientation of the window. Therefore it can be compensated itself due to various obstructions around one window or among windows in the building.

Generally it can be concluded that for the most low-energy and passive buildings, the influence of more accurate calculation of the shading reduction factor and total solar energy transmittance coefficient on the building energy need for heating is around +/- 2-3%. This influence is decreasing with raising the specific energy need for space heating. More significant impact can be expected among buildings with large window areas or repeated shading scheme with the same orientation. The difference also increases with higher amount of incident solar radiation.

More accurate calculation method will find a better fulfilment among more glazed buildings (office buildings, hospitals, schools …). The potential is seen especially in internal environment evaluation and possible effective overheating prevention.

References

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