EFFECT OF WALL THICKNESS ON THE SOLAR GAIN

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Abstract - Utilized passive solar gain covers considerable part of heat losses, especially in well insulated buildings. At the same time the thermal insulation of the wall in such a building, e.g. approaching the "Passivhaus" standard is about 20 cm thick. Unless a light weight building is spoken of further 20-30 cm loadbearing layer and the surface finishing should be added resulting in a total thickness of 45-60 cm.
The thick wall narrows the cross section through which the direct solar beam may enter the room thus decreases the solar gain. The movement of the solar beam during the day and season can be followed on the base of the sun path diagram. One could say that on the other hand a massive loadbearing layer - especially if it is on the inner side - increases the heat storage capacity, thus increases the utilized part of the solar gain.
Series of thermal simulation proves that the effect of heat storage capacity is less important in comparison with the cross section through which the solar beam enters the room. In other terms a light weight building with thin walls performs better than a massive one with thick wall providing the U-value is the same in both cases. In this paper the results of simulation will be presented. Certainly the wall should fulfill many requirements including load, weather-proofness, thermal insulation, building technology. Solar beam is only one of the many aspects. Nevertheless simple geometric tricks may lead to a good compromise, e.g. bevel edge reveal which is not perpendicular to the façade. No doubt in this case the thermal bridge losses around the window perimeter will be higher however this will be compensated by the solar gain.

Keywords: wall thickness, passive solar gain, reveal geometry

1. INTRODUCTION

Utilized passive solar gain covers considerable part of heat losses, especially in well insulated buildings. At the same time the thermal insulation of the wall in such a building, e.g. approaching the "Passivhaus"or nearly Zero Energy Building standard is about 20 cm thick. Unless light weight construction is spoken of together with the loadbearing layer and the surface finishing the total thickness is 45-60 cm.

The thick wall narrows the cross section through which the direct beam and circumsolar diffuse solar radiation may enter the room thus decreases the solar gain. The role of the radiation reflected by the outer reveal surface modifies the balance. On the other hand one could say that a massive loadbearing layer increases the heat storage capacity thus increases the utilized part of the solar gain. No doubt it is true, however the heat storage capacity of the building as a whole depends first of all on the floor slabs, influenced by the partition walls – the external walls represent only a part of the mass.

2. METHODOLOGY

In order to investigate these phenomena and illustrate the effects a realistic sample building has been selected. It is a single family house consisting of rooms with different sizes. Most of the windows are facing to the South in order to make use of passive solar gain however there are some windows of other orientations. The layout of the house is shown in Fig.1.

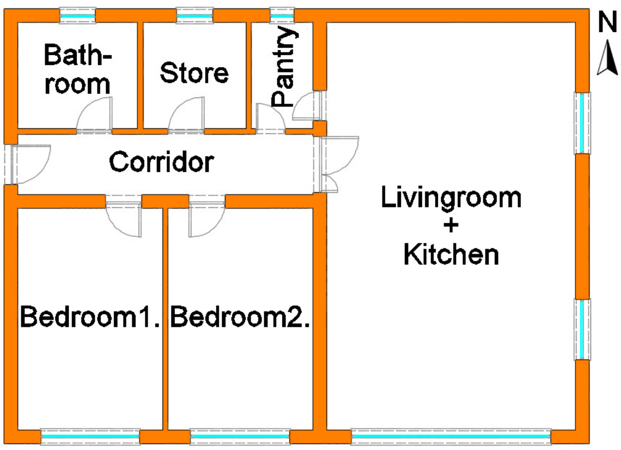


Fig. 1. Layout of the sample building

Table 1. The building's rooms

Room	Room area [m^2]
Bathroom	7,54
Store	6,50
Pantry	3,90
Corridor	10,65
Livingroom + Kitchen	59,40
Bedroom1.	18,90
Bedroom2.	18,90
Total area	**125,79**

Table 2. Thermal data of building elements

Construction	Type	U value [W/m²K]
Wall	Masonry	0,24
Partition	Light weight	1,32/2,07
Floor	Linoleum	0,208
Attic	Light weight	0,14
Window	Insulated glazing	1,06 *
Entrance door	Insulated wooden	0,60

* $U_{glazing}$

In harmony with the insulation a glazing of g-value 0,579 has been selected. Certainly the effect of the reveal depends on the g-value, since it would be higher by 30% in case of a traditional "normal" glazing. Two versions have been investigated: "small glazed" means a window ratio is 0,101, while "large glazed" means 0,208. Here the ratio of the total window area to the total façade area is spoken of.

Two versions of wall thickness have been investigated: 25 cm and 50 cm (later a theoretical option with zero has been examined too, in order to show clearly the effect of the reveal).

Material properties of external wall have been selected so that the U-value and the thermal mass remained the same in both versions.

In the followings the final energy balance of this sample building is analyzed using EnergyPlus v.8.4.0 Energy Simulation Software. In different versions the effect of wall thickness, glazed ratio have been varied and the results have been compared.

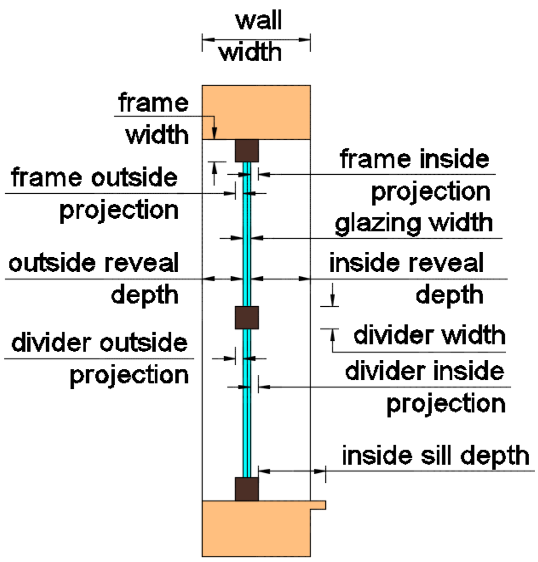


Fig. 2. Interpretation of geometric data [3]

Table 3. Window sizes

	Wall width [m]	
	0,25	**0,56**
Frame width [m]	0,06	0,06
Frame inside projection [m]	0,01	0,01
Frame outside projection [m]	0,04	0,04
Divider width [m]	0,06	0,06
Divider inside projection [m]	0,01	0,01
Divider outside projection [m]	0,01	0,01
Inside reveal depth [m]	0,12	0,22
Outside reveal depth [m]	0,095	0,305
Inside sill depth [m]	0,15	0,25
Glazing width [m]	0,035	0,035

3. DIRECT BEAM

In the followings direct beam is considered to enter the room which crosses the plane of the inner surface of the wall.

No doubt some direct radiation hits the inner surface of the reveal where a part of it (typically 90%) will be absorbed. Nevertheless this absorbed heat will be lost due to the shortcut along the reveal which is a serious thermal bridge.

The cross section in the plane of the inner wall surface can be calculated with simple geometric equations.

Fig.3. shows the effect of the wall thickness: the thicker the wall is the less the irradiated area is in the plane of the inner surface of the wall. As a first approximation the direct solar beam crossing this irradiated area can be considered as direct radiation entering the room. Certainly some radiation can be reflected into the room from the window sill and the insolated reveal, however it is less by order in comparison with the intensity of direct beam.

Obviously at a given wall thickness the bigger the opening is the higher this ratio will be. It is to be mentioned that dividers have a similar effect on the irradiated area even if their projection (measured from the glass sheet) is small in comparison with the reveal.

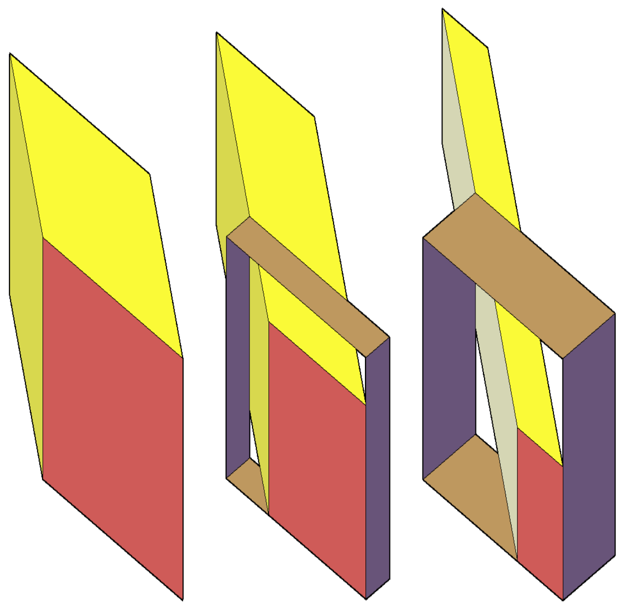


Fig. 3 Insolated area A_{ir} in the plane ot the internal wall surface show the "cross section" through which the direct beam enters the room. Its ratio to the area of the opening A_0 (measured on the outer surface) shows the diminuation effect due to the reveal.

The ratios shown in Fig. 3. belong to the following data:

Azimuth angle – 60°, altitude 45°, opening height 1,5 m, opening width 1,5 m, the wall thickness from the left to the right 0, 25 and 50 cm, the irradiated area in the same order 2,25 m², 1,26 m², 0,40 m².

The irradiated area can be calculated for different altitudes and azimuth angles according to Fig. 4.

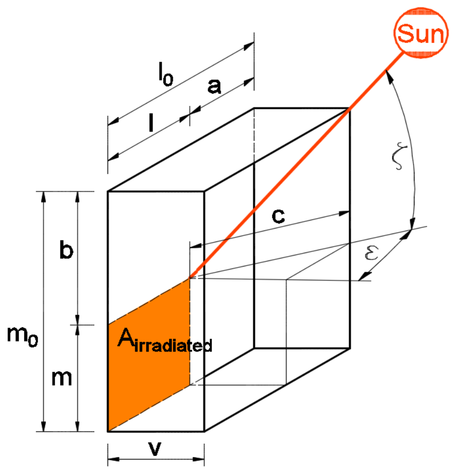


Fig. 4. Interpretation of altitude and azimuth angles for the insolated area for given window sizes

In Figure 4

A_{ir} – irradiated surface [m^2]

ζ - altitude angle of the sun [°]

ε - the difference between the azimuth angle of the sun and the azimuth angle of the surface [°]

v - wall thickness [m]

m_0 - opening height [m]

l_0 - opening width [m]

m – high of the irradiated surface [m]

l – width of the irradiated surface [m]

With these data the irradiated area in the plane of the inner wall surface can be calculated with simple trigonometric equation:

$$A_{ir} = (m_0 - v\sqrt{1+tg^2\varepsilon} \cdot tg\zeta)\cdot(l_0 - v\cdot tg\varepsilon) \quad (1)$$

With equation (2.) the irradiated area and its ratio to the opening can be calculated.

$$f_b = \frac{A_{ir}}{A_0} = \frac{A_{ir}}{l_0 \cdot m_0} \quad (2)$$

where the symbols are the same as in Eq, 1. furthermore A_0 – opening surface [m^2]

Discrete values of the $f_b = A_{ir}/A_0$ ratio (the irradiated proportion) can be presented with a set of curves which depends exclusively on the geometry of the window.

For a given geographical location these angles can be presented e.g. in cylindric sun-path diagrams.

Providing its scale is the same as the above set of curves the two diagrams can be overlapped in such a way that the zero azimuth of the set of curves coincides with the azimuth angle of the window on the horizontal scale of the sun-path diagram.

Overlapping the two diagrams the A_{ir}/A_0 ratio can easily be seen in the different months and hours.

The above diagrams are shown in Fig. 5. and 6. for South facing windows. The sun-path diagrams relates to the Northern latitude 47°31'38". Here only the sun-path of winter months are shown since we investigate the contribution of passive solar gain to the heating.

The set of curves presenting the A_{ir}/A_0 ratio belongs to an opening 150 x 150 cm and wall thickness 56 and 25 cm respectively.

Obviously other sets can be determined for other geometric data.

Since the set of curves presenting the A_{ir}/A_0 ratio depend exclusively on the window geometry it can be overlapped with any other cylindric sun-path diagram for any other latitude.

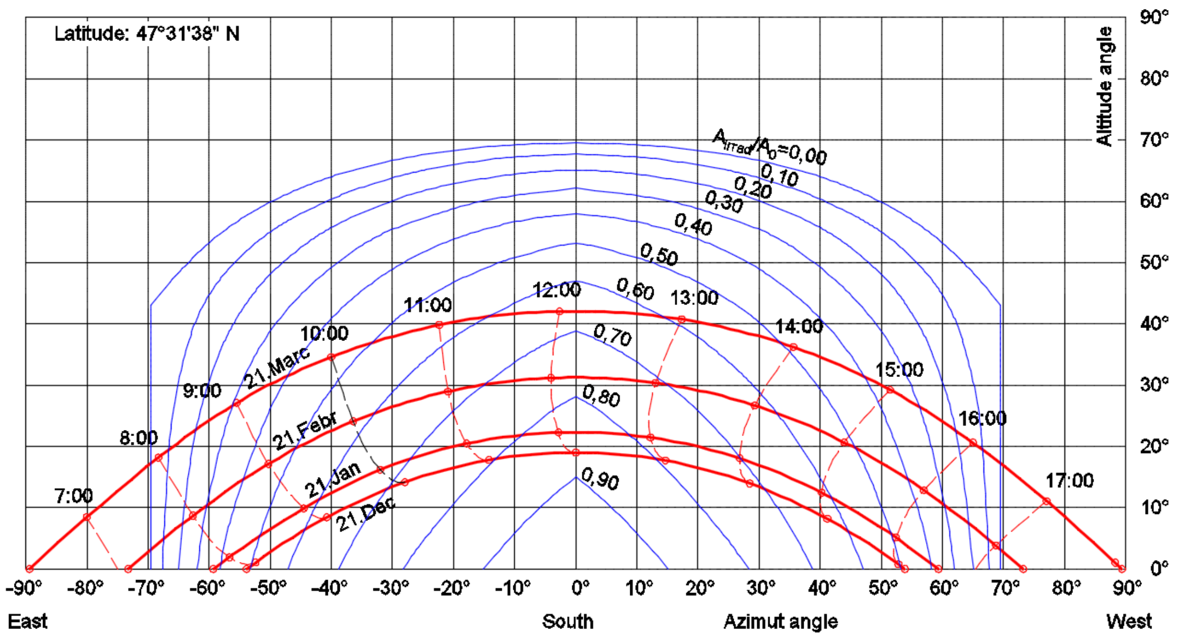


Fig 5. The A_{ir}/A_0 ratio in case of wall thickness 56 cm on the sun-path diagram – orientation South, opening 1,5 x 1,5 m

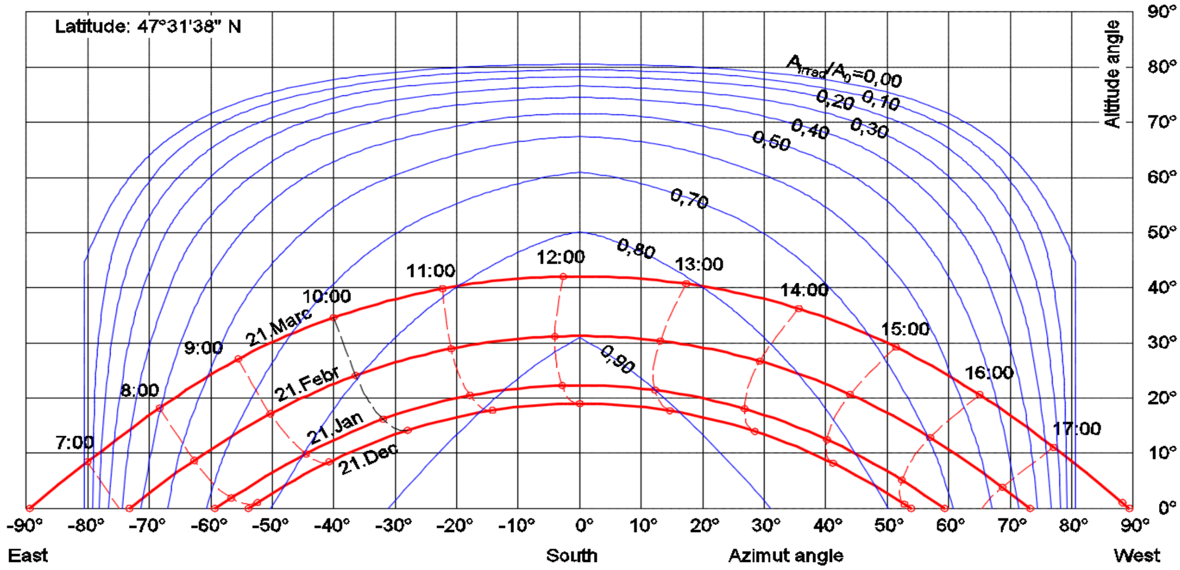


Fig 6. The A_{ir}/A_0 ratio in case of wall thickness 25 cm on the sun-path diagram – orientation South opening 1,5 x 1,5 m

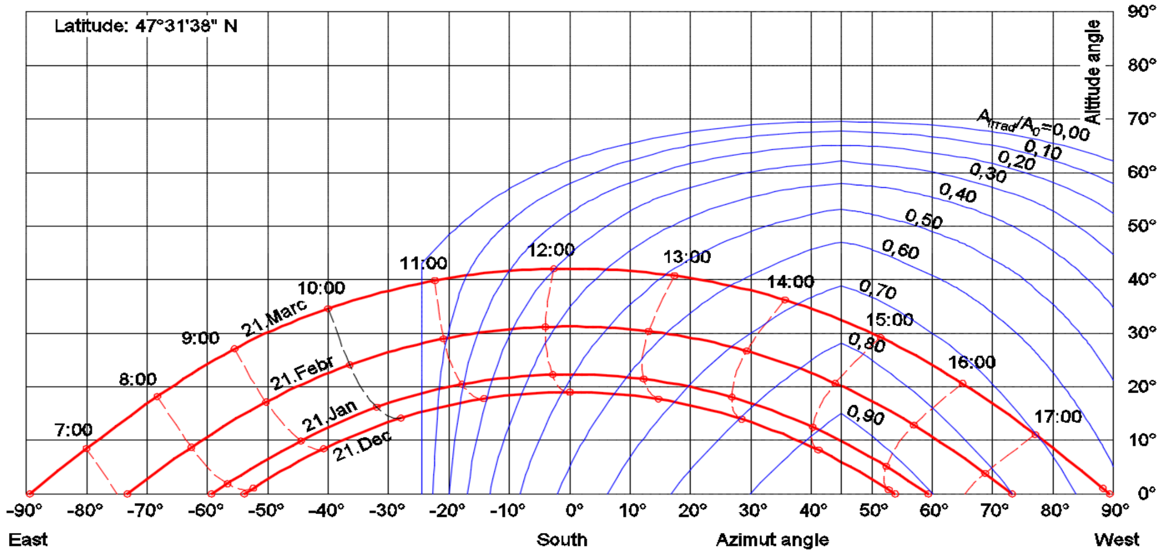


Fig. 7. A_{ir}/A_0 ratio in case of wall thickness 56 cm on the sun-path diagram - orientation South-West, opening 1,5 x 1,5 m

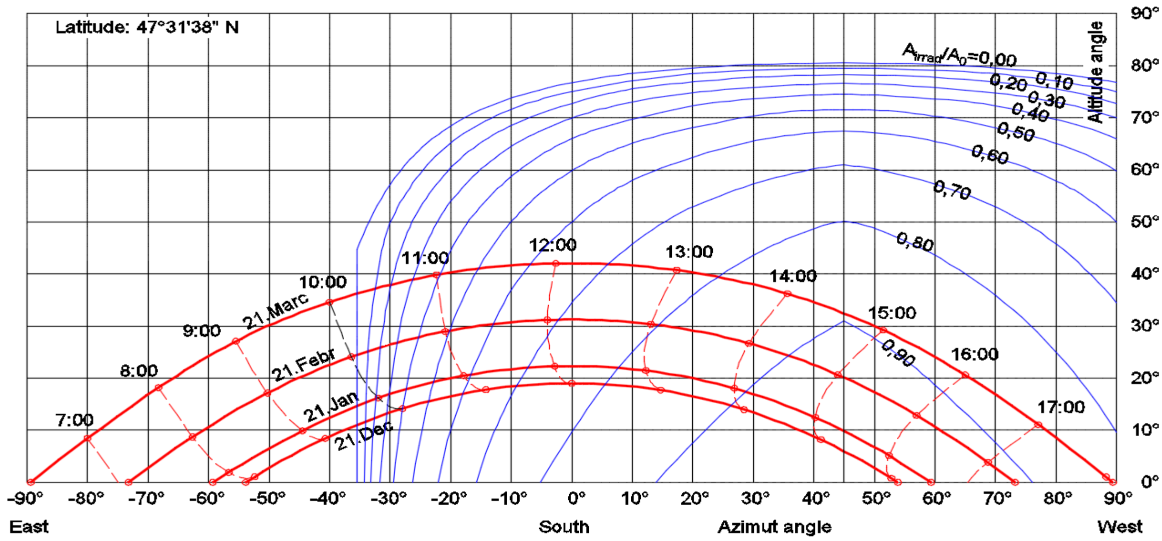


Fig. 8. A_{ir}/A_0 ratio in case of wall thickness 25 cm on the sun-path diagram - orientation South-West, opening 1,5 x 1,5 m

4. DIFFUSE RADIATION

Theoretically the diffuse radiation consists of the following components:

- circumsolar radiation from the direction of the Sun,
- horizon band radiation
- isotropic radiation from the rest of the sky[1] [3]

A simplified approach is applied supposing that the diffuse radiation is isotropic. Would be the glazing in a wall with zero thickness its each point would be hit from diffuse radiation from each point of the sky in π sr solid angle interval (Fig. 9.). In reality the reveal discloses a part of the sky decreasing the gain from the diffuse radiation. Obviously the deeper the reveal is the bigger part of the sky will be disclosed.

The solid angle intervals are bordered with the lines between the edge of the glazing and the reveal to the edge of the outer plane of the wall and the reveal (Fig. 9.)

Viewing from the centre of the glazing the solid angle is bordered by the upper horizontal edge of the reveal. The disclosed part of the sky is bigger if the reveal is deeper.

Having the above border the solid angel intervals from where the diffuse radiation can hit the glazing can be plotted.

These spherical triangles are shown in Fig. 10. For an opening of 1,5 m x 1.5 m these solid angle intervals are π sr, 0,93π sr, 0,85π sr for reveal depths of 0, 0,25 and 0,50 m reveal depths respectively.

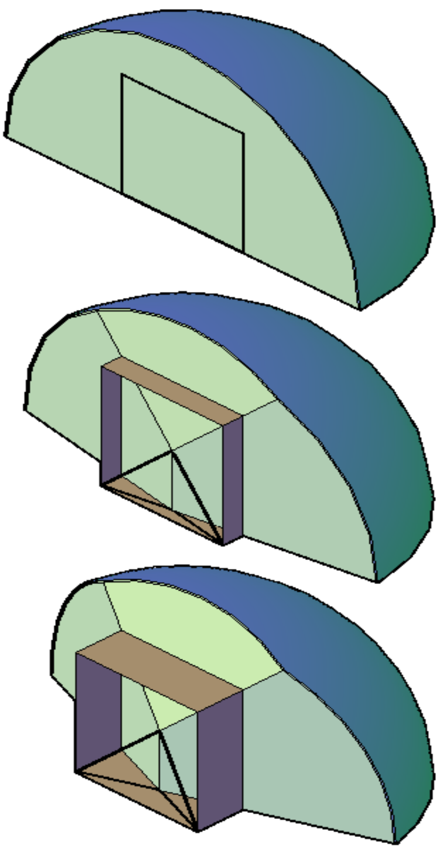


Fig 9. Solid angle intervals in which the diffuse radiation hits the glazing for different reveal depths.

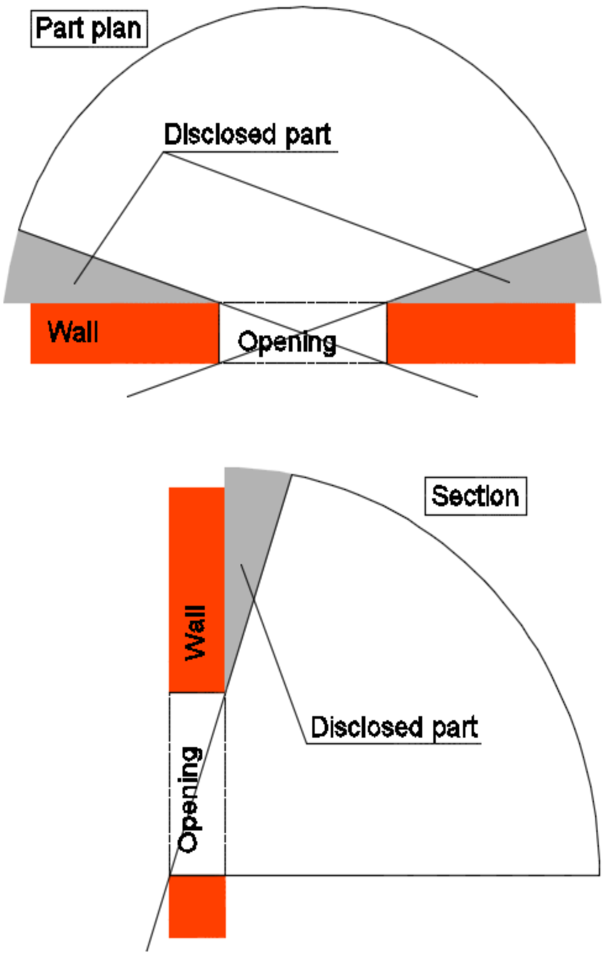


Fig 10. Borders disclosing a part of the sky

5. REFLECTED RADIATION

The reveal partly shadows the glazing, partly reflects the radiation towards the glazing. The reflected radiation is diffuse. Half of the reflection hits the glazing whilst the other half is oriented to the environment (Fig. 11.)

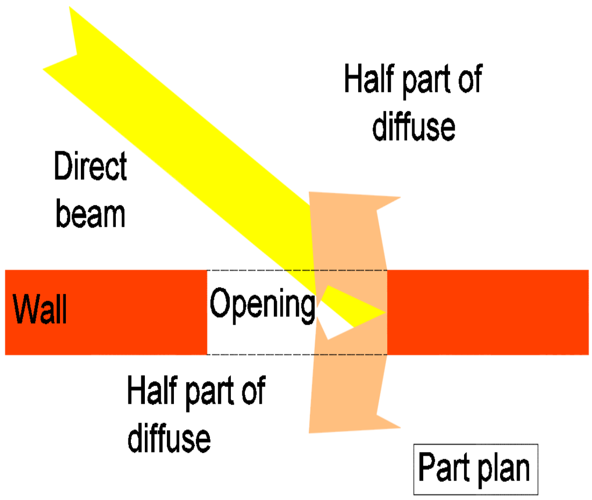


Fig. 11. Half of the radiation hitting the reveal is reflected to the glazing in case of beam solar radiation.

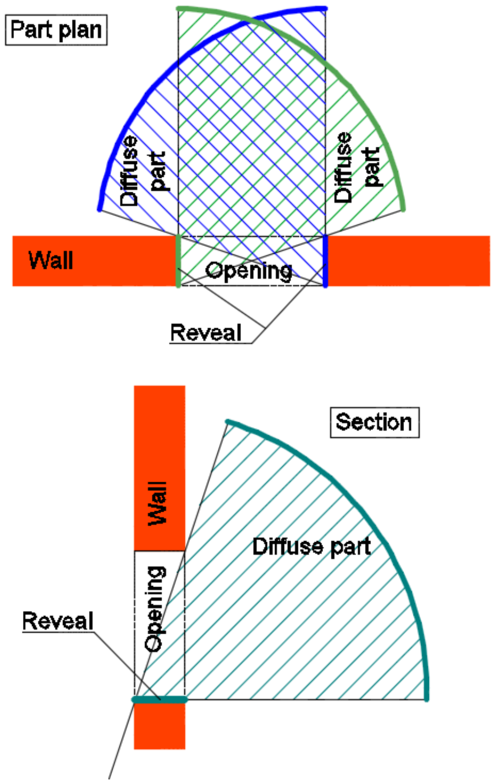


Fig. 12. Diffuse irradiation reveals domains

Similar is the effect of the dividers, if any. This component is taken into account, too. Window sill of high reflectance increases the solar gain and mitigates the shading effect.

6. RESULTS AND DISCUSSION

Series of thermal simulation prove that the effect of the cross section through which the solar beam enters the room is considerable, moreover the reveal depth influence the diffuse radiation too. Diagrams in Figs. 13. and 14. show examples of the results – on the vertical axis the total heating energy consumption of the building can be seen.

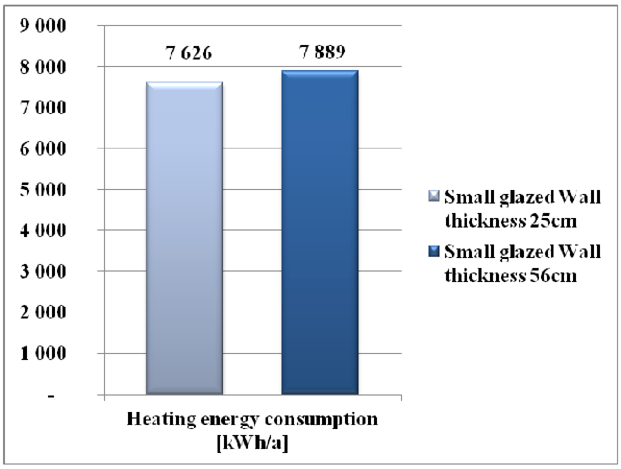


Fig. 13. Heating energy consumption of the building in function of the wall thickness– small glazed ratio

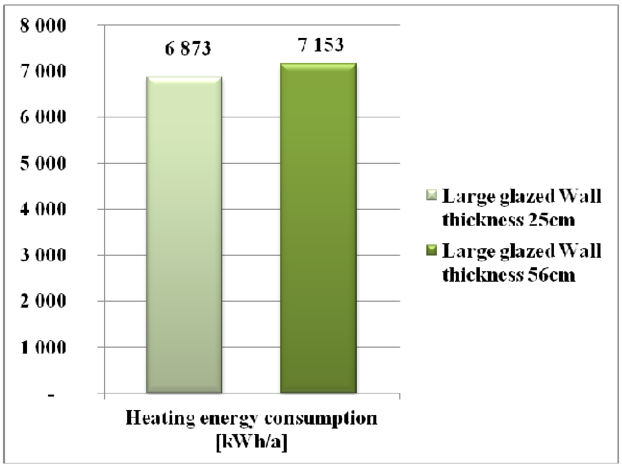


Fig. 14. Heating energy consumption of the building in function of the wall thickness reveal depths–high glazed ratio

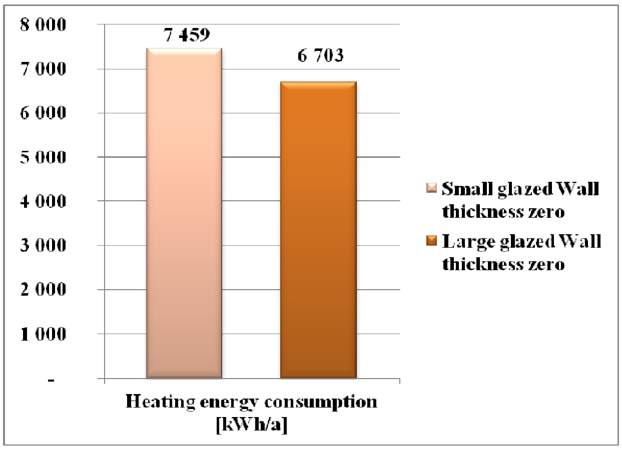


Fig. 15. The theoretical extreme heating energy consumption with zero wall thickness

The best illustration of the reveal effect is the theoretical case of zero wall thickness where this effect is eliminated. Keeping all other parameters with the same value, including the U-value of the external walls the simulation results in the lowest energy consumption data, shown in Fig. 15.

In order to express the reveal effect in Fig. 16. the increasment of energy consumption of the sample building is shown in %.

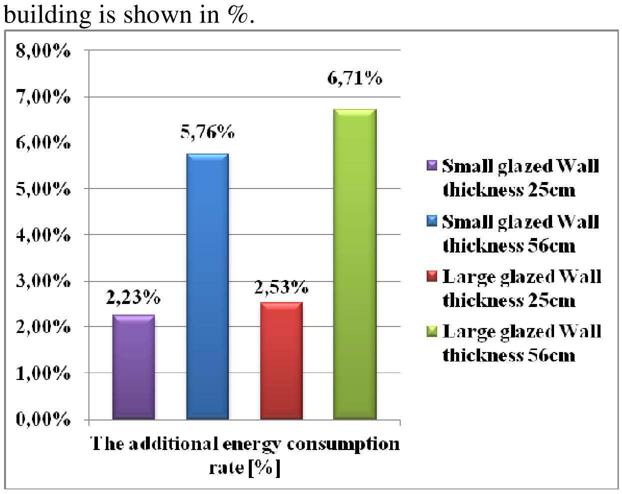


Fig. 16. The additional energy consumption caused by the reveal

Certainly the wall should fulfill many requirements, including load, weather-proofness, thermal insulation, building technology. Solar gain is only one of the many aspects. Another relevant aspect of the reveal is the insolation in summer when the same phenomenon has an other expressive name: load instead of gain. Obviously the aim is to decrease the load in order to prevent the summer overheating of the rooms.

7. CONCLUSION AND RECOMMENDATIONS

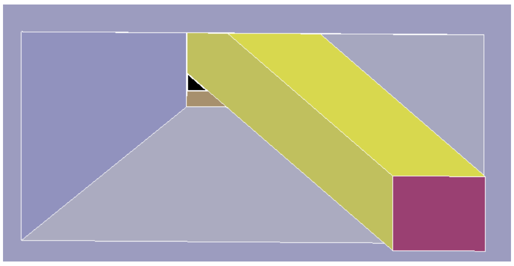
Details of a building may have significant effect on the energy balance of buildings. This is the case of the wall thickness and the depth of the reveal.

Simulations proved that changing the wall thickness from 25 to 56 cm changed the total heating energy consumption (transmission plus ventilation losses from 6873 to 7153 kWh/a) in the case of the sample building.

The sample building is an ordinary one. Certainly having other building geometry we can obtain different results. Nevertheless the tendency is clear as well as the order of the effect.

Certainly the thickness of the wall is not governed by the aspects of insolation, shadow and reveal. The thickness of a wall in a light weight building with loadbearing truss can be as low as 20-25 cm – enough for an acceptable thermal insulation of a contemporary building. If the external wall consists loadbearing layer the thickness of the last is about 15 cm in case of reinforced concrete and about 30-40 cm in case of brick or masonry blocks. Their thermal resistance is low therefore the thickness of the insulation layer can be decreased only with a few centimetres. So the total wall thickness becomes as big as 55-60 cm, resulting in a very deep reveal. This is the case of the energy conscious refurbishment of existing building when added thermal insulation is put externally. The consequences are seen in the results of the simulation.

Nevertheless simple geometric tricks may lead to a good compromise, e.g. a bevel edge reveal (Fig. 17.) which is not perpendicular to the façade. No doubt the thermal bridge losses around the window perimeter may become higher however this will be compensated by the solar gain.



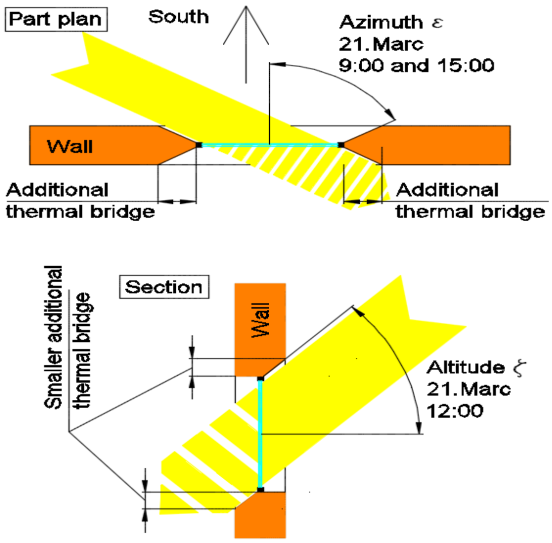


Fig. 17. Bevel edge reveal

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