Interrelation between glazed Surfaces, Building Structure and Thermal Comfort

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ABSTRACT: In Hungary there are approximately four millions of households, placed in buildings with various thermal characteristics of the envelope. In the last years different national programs were started in order to improve the mean thermal resistance of the existing building stock. The main goal is to reduce the energy consumption in the building sector. Because the thermal comfort needs are continuously increasing, more and more dwellings/houses are equipped with air-conditioning systems. This paper analyses the effects of glazed area and different building structures, used especially at detached houses, on the internal temperature in the Hungarian climate. Using the Hungarian Standard for cooling load calculation, a program was developed and the obtained results were compared with measured data. Assuming that the required temperature is obtained without air conditioning system, the maximal glazed area is determined for different orientations for the most used building structures at detached houses. Also, the effect of additional thermal insulation was analysed.

Keywords: glazed area, indoor temperature, heat gains

1. INTRODUCTION

The building sector is the biggest energy consumer in east European countries with its 30…35% from the total energy consumption [4]. Based on the European Directive 2002/91/EC new buildings and the envelope of renovated buildings must comply with the new requirements related to thermal properties. In Hungary more than 50% of households are in detached houses. The structure of the external envelope of these houses varies. Some characteristics are presented in Table 1.

Table 1: Characteristics of houses

Mean *U* value of the envelope	>1.3 W/m^{2}K	78.8%
	0.8…1.3 W/m^{2}K	14.8%
	<0.8 W/m^{2}K	6.4%
Ventilation	spontaneous	100 %
Expected lifetime	<10 years	15.8%
	10…30 years	11.6%
	>30 years	72.6%

As it could be observed the heat losses are very high in more than 95% of these houses. Thermal rehabilitation is sorely needed, taking into account also the expected lifetime.

In the last years different national and local programs were started in order to reduce the energy consumption in the building sector, but these are conceived mainly for block of flats, where a high number of persons can benefit by these interventions, [3]. These blocks of flats are usually connected to district heating systems and the DH companies support their customers to reduce the energy consumption, disengaged in this way part of the system output (which could be used for other purposes) [1].

Improving the thermal resistance of the building envelope not only the heat losses in the winter, but also the heat gains in the summer are reduced. So, the better indoor thermal comfort is obtained as a side-effect of the additional thermal insulation of the building envelope [2].

In houses the situation is critical both from energy and thermal comfort point of view. In the last years more and more houses were equipped with central heating systems using mainly natural gas as fuel. In this way at least the heating system may have acceptable efficiency.

The new houses are built especially from brick with vertical cavities, but the increased use of light-framed structures may be also observed. At light-frame construction the external building elements consist by 14…16 cm mineral wool between two wood panels. The heat transfer coefficient of these elements is lower than 0.45 W/m^{2}K. At light structures values around 0.22 W/m^{2}K are obtained. In this way at these buildings the energy consumption for heating is significantly less than at old houses.

Because thermal comfort needs are continuously increasing, more and more houses are equipped with air conditioning systems. This is specific not only for old but even for new houses. In this way the energy consumption increases taking into account that at these systems electrical energy is consumed which is produced by power plants having low efficiency, so it is the most expensive type of energy.

In the following three different structures are analyzed considering the same orientation of the facades and the same geometrical parameters of the rooms. The scope is to compare the internal temperature variation in rooms situated in different building types. The same comparison is made when the old structures get an external additional insulation. Assuming different maximal values of the internal temperature the maximal value of the glazed area was determined for the analysed structures.

2. ANALYZED STRUCTURES

The analysis was made for three different buildings, having the same geometrical parameters and the same orientation of the facades. The chosen structures are: external walls from adobe bricks (Sun-dried brick), bricks with vertical cavities and light frame construction.

Buildings from SD brick are the oldest buildings in Hungary even though nowadays there are several new buildings built with this technology. The thickness of external walls exceeds 50 cm and the rendering is around 3 cm because of the roughness of the walling. Most of these buildings are older than 50 years.

The second type of building has the external walls built from bricks with vertical cavities type B30. This structure was used especially until 1990. The thickness of external walls is 30 cm with a 2 cm rendering on the internal and external surface.

The third type of building has a light frame structure with 16 cm mineral wool and the additional internal and external wood panels.

The structure of ceilings and floors is specific for each building type and technology.

The analysed 4.0×5.0×2.8 m room has two external walls and a window. Thermal properties of these rooms are presented in Table 2. The heat losses *Q*, were determined considering the same window type (with U_{win}=1.6 W/m^{2}K) and air change rate (ACH=0.5 h^{-1}).

Table 2: Thermal properties of the analysed structures and rooms

Type	U_{wall} [W/m^{2}K]	*Q* [W]
SD brick	0.984	2479
B30	1,466	3478
Light	0,220	1168

Having the above presented structures and parameters the heat storage capacity of the room and the room time constant could be calculated. The thermal capacity of a room *C* is given by:

$$C = \sum_j \sum_i \rho_{ij} c_{ij} d_{ij} A_j \qquad (1)$$

where: ρ_{ij} – material density of layer *i* in the building element *j*; c_{ij} – specific heat of layer *i* in the building element *j* d_{ij} – thickness of layer *i* in the building element *j*; A_j – area of building element *j*.

In the thermal mass of a structure only the active layers are included. These are contained in a 10 cm thick storage zone. If the structure contains insulation layers the active zone is taken into consideration up to this layer. If the structure is narrower than 20 cm than the active zone is considered to be up to the middle of the structure. The thermal mass is calculated from the internal surface of the structure. As it could be seen the thermal mass and the storage capacity remain the same after additional insulation if the insulation layer is fixed on the external surface of the walls.

The room time constant *T* is given by the ratio between heat storage capacity and heat loss coefficient of the building *K*:

$$T = \frac{C}{K} \qquad (2)$$

The heat loss coefficient of a building is considered to be equal to the heat losses when the temperature difference is 1 K.

In Table 3 the heat storage capacity and the room time constant are presented for the studied structures.

Table 3: Heat storage and room time constant

Type	*C* [MJ/K]	*T,* [h]
SD brick	13.96	54.76
B30	11.23	31.4
Light	3.68	33.37

3. INTERNAL TEMPERATURE

Internal temperature in detached houses varies during a day depending on the external temperature, orientation of the facades, glazed area and thermo-physical properties of the opaque building elements. These characteristics determine the variation of heat gains in the rooms.

The total gains are given by the sum of internal and external gains:

$$Q_g = Q_i + Q_e = Q_i + Q_o + Q_w = Q_i + Q_o + q_w A_w \qquad (3)$$

where: Q_i – is the internal gains, [W]; Q_e – external gains, [W]; Q_o – gains through opaque building elements, [W]; Q_w – gains through glazed building elements, [W]; q_w – specific gains through windows, [W/m^2]; A_w – area of windows, [m^2].

These gains could be considered as a heat source which is placed in the room. The output of this “heat source” is variable during a day and is variable from day to day. If we would like to keep constant the internal temperature an air conditioning system is needed. Usually, the requirement is that the internal temperature should not exceed a maximal permitted value. The higher this value is, the lower the energy consumption of air conditioning system will be.

If there is no air conditioning system in the room/building the internal temperature varies during a day in function of heat gains variation. If the difference between internal and external temperature is noted T_i:

$$T_i = t_i - t_e \quad (4)$$

then the energy balance equation of the room could be written:

$$CdT_i + T_i K d\tau = Q_g d\tau \quad (5)$$

where: C – the heat storage capacity of the internal air and building elements, [J/K]; K – heat loss coefficient of the room, [W/K]; τ -time.
Solving this equation the internal temperature will be:

$$t_i = \bar{t}_e + \frac{\left(t_{i0} - \bar{t}_e\right) + \frac{Q_g}{K}\left(\exp(\tau / T) - 1\right)}{\exp(\tau / T)} \quad (6)$$

where: $\bar{t}_e$ - is the daily average external temperature; t_{io} – is the internal temperature when τ =0, T – room time constant, [h].

Considering as original internal temperature the value which is accepted as "optimal" value in summer (24 ^oC) using the Hungarian national standard for cooling load calculation the heat gains could be determined [5]. The variation of these gains for West orientation of the facades and 1 m^2 glazed area is presented in Figure 1.

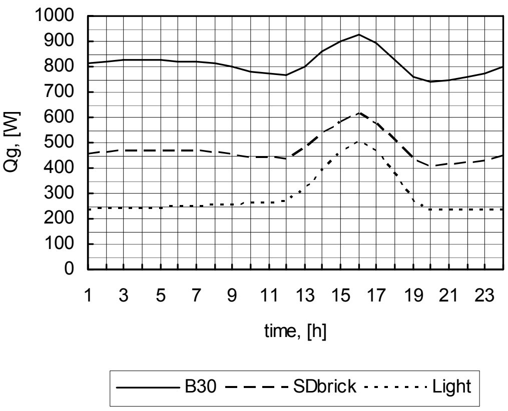

Figure 1: Heat gains for a room with W orientation of the glazed area

As it could be seen the highest values of heat gains appears at B30. These are almost twice as much as the light structure. The effect of direct gains through the glazing could be observed. This effect is higher at the light structure which could not break the internal temperature variation because of the low heat storage capacity.

Having these values of heat gains using the mathematical method presented above the internal temperature variation could be determined. As it is shown in Figure 2 the highest values of the internal temperature are obtained in the room with light structure. In such a room the internal temperature can reach values higher than 30 ^oC in the hottest days. Naturally this value depends on the original value registered in the room. Also in this case no ventilation during the night and no shadows were taken into account. But the calculus was done with the same conditions for the other structures. The best results are given by SD brick where the internal temperature exceeds the maximum permitted value (26 ^oC) with ca. 1 ^oC from14^{00} to 18^{00}. For the other two structures the situation is dramatic. The maximal admitted value is exceeded almost half a day. The amplitude of the internal temperature variation is 4.5 ^oC for B30 and 9 ^oC for the light structure.

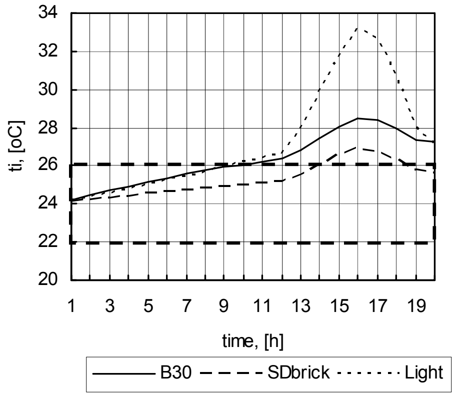

Figure 2: Internal temperature in a room with W orientation of the glazed area (A_w=2 m^2)

4. ADDITIONAL INSULATION OF B30 AND SD BRICK

Taking into account the high heat losses of this old structures let us see how the internal temperature varies if the structure is provided with an external insulation layer of expanded polystyrene.

The external walls of B30 structure get an additional thermal insulation of 10 cm, the heat transfer coefficients of ceiling and floor are reduced to the new required values (0.3 W/m^2K and 0.5 W/m^2K respectively).

The external walls of the SD brick structure were provided with an external insulation of 8 cm thickness, the ceiling and floor were insulated according to the new requirements.

The new values are presented in Table 4 (the light frame structure was not insulated additionally).

Table 4: Thermal properties of the analysed structures and rooms

Type	U_{wall} [W/m^{2}K]	Q [W]
SD brick	0.413	1363
B30	0,410	1363
Light	0,220	1168

Having these new thermal properties let us see how the room thermo-physical properties changed (Table 5). As it could be seen while the room time constant of the light structure remain 33,6 hours, at B30 this value became 79,92 hours and at the SD brick structure the new value is 99,6 hours. For B30 the new time constant value increases with ca. 150% comparing with the value before thermal insulation. Naturally if the structure is insulated on the internal surface the room will lose its thermal storage capacity and the situation may become worse than it was before the intervention.

Table 5: Heat storage and room time constant for insulated structures

Type	*C* [MJ/K]	*T,* [h]
SD brick	13.96	99.65
B30	11.23	80.08
Light	3.68	33.37

For a room with 1 m^2 West oriented glazed area the variation of heat gains are presented in Figure 3.

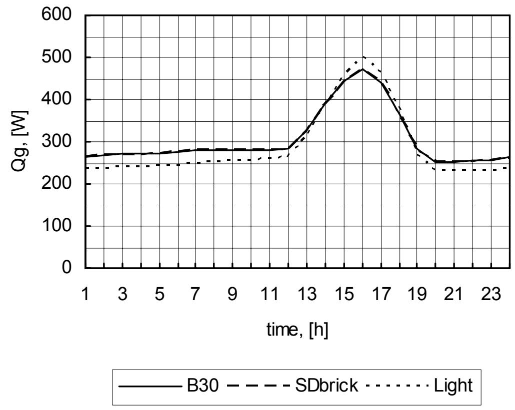

Figure 4: Heat gains for a room with W orientation of the glazed area

As it could be seen the heat gains for refurbished structures decreased approximately at the values registered at light structures. In this way the internal temperature amplitude decreases at the insulated structures. As it is shown in Figure 5 at B30 the internal temperature variation is similar with SD brick before thermal insulation. At the SD brick structure the maximal permitted value is exceeded only for 2.5 hours in the afternoon, from 15^{00} to 17^{30}.

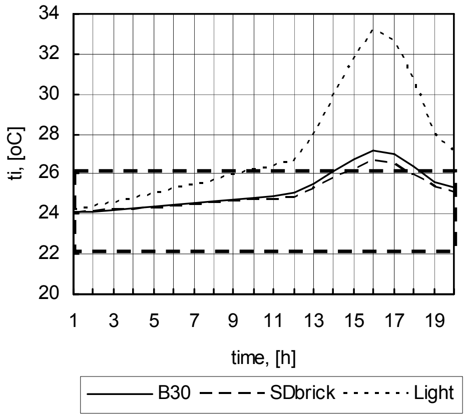

Figure 5: Internal temperature in a room with W orientation of the glazed area (A_w=2 m^2)

5. GLAZED AREA

In Equation 6 heat gains depends on the glazed area. If in this relation the maximal value of the internal temperature is fixed results the maximal area of the glazed surface for different orientations. This area could be determined using the following equation:

$$A_w = \frac{K\left[(t_i - t_e)\exp(\tau / T) - (t_{i0} - t_{e0})\right]}{(\exp(\tau / T) - 1)q_w} - \frac{Q_o + Q_i}{q_w} \quad (7)$$

where t_i is the maximal accepted value of the internal temperature.

In Figure 6 and 7 the glazed area variation is presented for different orientations before and after thermal insulation of the structures assuming the maximal internal temperature equal to 26 ^oC. As it could be seen also negative values were obtained. These indicate the situation when the set value of the internal temperature could not be obtained even with 0 m^2 glazed area.

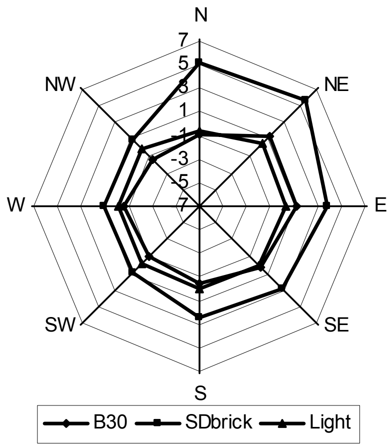

Figure 6: Glazed area before refurbishing

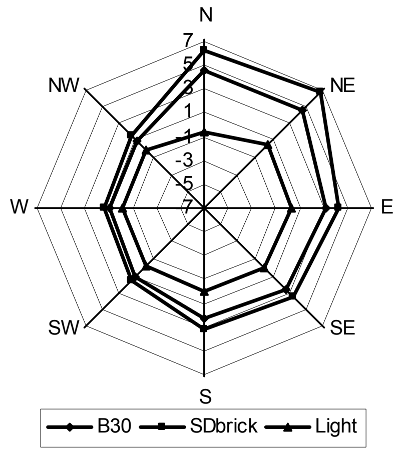

Figure 7: Glazed area before refurbishing

Analysing the diagrams it could be observed that the best values are given by SD brick which was used long time ago. For our case the highest values of the glazed area are obtained for N, NE, E, SE orientation. The worst case is W and NW. Obviously these surfaces were obtained analysing the internal temperature oscillation in the hottest days of the summer period. If an optimization calculus is needed, the analysis of heat gains during the heating season has to be done. Also the effects of natural lighting on the energy consumption should be taken into account.

6. MEASUREMENTS

In 2005, in Debrecen, measurements were carried out in buildings with different structure of the external walls. Obviously the measured data have to be treated carefully taking into account all factors which may have influenced the results.

In Figure 8 the variation of the internal temperature could be seen for rooms with the same characteristics as presented above (before rehabilitation). It could be observed first that the original internal temperature differs because this value always depends be the previous days and as a consequence in different buildings will have different values. The highest value of the internal temperature was registered in the room built from B30. This room has the glazed area oriented to East. The oscillation of the internal temperature could be observed, but the amplitude is small because the gains through opaque surfaces are very high.

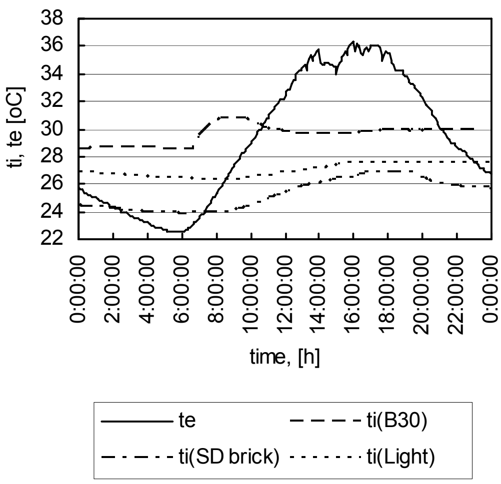

Figure 8: Measured data in different buildings

As it could be observed for the light structure (which has its window oriented to West) the oscillation of the internal temperature is ca 2 °C (difference between the highest and lowest values). This might be curious, but in this case due to shadows there were no direct solar gains and the floor was tiled, so that the room time constant was increased significantly. In this case the obtained internal temperature is higher than 26 °C, but the highest value does not exceed 28 °C. Probably that with ventilation during the night better values could be obtained.

The best results were obtained at the room having its walls from SD brick, even though in this case there were no shadows. As it could be seen in this case the internal temperature varies between 24 and 27 °C. So, the permitted value (26 °C) was exceeded by a maximum of 1 °C from 14^{00} to 20^{00}. This is approximately the same result as that obtained at the simulations.

If the daily average internal temperature values are calculated it may be observed a difference of some 2 K may be observed between SD brick and light structure and 2 K again between light structure and B30.

7. CONCLUSIONS

As the simulated and measured values have shown from the analysed structures SD brick gave the best results related to internal temperature oscillation in the summer period. After thermal rehabilitation of the old structures (SD brick and B30) thermal comfort was significantly improved reducing considerably the amplitude of the internal temperature oscillation and the period when the internal temperature exceeds the maximum admitted value (26 °C).

Measurements have shown that at light structures the situation is not so worse. Having smaller glazed area and properly designed shading the internal temperature amplitude may be reduced. Further reduction of the amplitude may be obtained if the floor is a heavy structure (tiled concrete).

In all cases the ventilation during the night will have a positive influence on the daytime indoor climate.

The growing comfort needs of the owners have to be satisfied with minimal energy consumption. Having an appropriate architectural design the energy consumption of heating or air conditioning system could be reduced significantly. In the Hungarian climate, over the summer period, a well designed detached house does not need an air conditioning system to keep the internal temperature below the upper comfort limits.

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