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RESEARCH ARTICLE

Effect of Architectural Glazing Parameters, Shading, Thermal Mass and Night Ventilation on Public Building Energy Consumption under Hungarian Climate

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Abstract

An important field of improving energy efficiency of public and office buildings with glazed facades is a conscious design of the building skin. The study first sets categories of available (conventional and sophisticated) glazing product types used in exterior walls on the basis of thermal transmission, solar heat gain and light transmission properties. A large number of computer simulations has been run using different glazing types, fenestration rates, fixed and moveable (controlled) external shadings, night ventilation rates and internal heat storage capacity in order to determine their effect on energy demands. The study compares heating, cooling and lighting energy demands of the internal spaces, independently from choice of mechanical systems and energy sources in order to analyse the clear effect of building skin and related parameters on energy needs. The simulation were run for Hungarian location (Szombathely), however the results and findings can be adopted for regions of similar continental climate. The target of the study is to set guidelines for the early stages of architectural design of energy efficient glazed façade constructions and buildings.

Keywords

Architectural glazing · glass façade · energy conservation · energy efficiency · building energy simulation · energy design

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1 Introduction

The race is on – with time, with energy. It is well known that buildings are responsible for a major part, 20 - 40 - 50% in developed countries [1], of the total energy consumption. Dramatically improving energy efficiency is becoming a must, in new construction primarily and in retrofit as well. Extended research has been carried out on energy efficiency of buildings, its potentials and barriers [2], on the possibilities of the production and use of alternative and renewable energy in buildings, the expected benefits of different heating, cooling and ventilation solutions for buildings [3].

Reports about exemplary energy efficient buildings are published in different newsletters. Much development has been achieved in conjunction with different green certification systems like LEED, BREEAM or GNDB as well, there is a rapidly growing number of ‘green certified’ buildings.

The principle attitude is going under change in investment, design, implementation and building management, all turning towards building ‘green’.

Political will is also expressed like the 2020 targets of “3 × 20” in Europe: 20% decrease in greenhouse gases, reaching 20% share of renewable energy and improving energy efficiency by 20%. Despite its importance an EU Commission report says “the existing strategy is currently unlikely to achieve all the 2020 targets, and it is wholly inadequate to the longer term challenges” [4].

Buildings created today are created for the future and will be the heritage for the coming generations. It is of high responsibility what our generation leaves behind. All building professionals have to work in close cooperation to create good, nice, energy efficient and manageable buildings which in broader terms could be part of a sustainable environment. It is not only up to energy specialists or mechanical engineers, but urban designers, architects and architectural engineers, structural engineers, and last but not least conscious clients and investors as well.

Pieces of a great puzzle go under research and development to improve the global picture of building energy use and sustainability, addressing detailed, partial or holistic issues. As examples, non-transparent light-weight stud façade solutions for newbuild and retrofit are studied and developed in details in order to achieve better thermal properties [5], application of Building Information Modelling method as decision tool is established for the retrofit of the envelope of public buildings [6].

This article introduces findings from a research [7] on how the architectural and architectural engineering design could contribute to the energy efficiency of public and office buildings skinned with wholly or largely glazed façades under Hungarian (or similar) climate conditions.

2 Method of the research

The research targeted to analyse the effect of key glass façade and structural properties on energy demand of the building under typical Hungarian climate conditions.

In a first stage of the work glazing categories were identified which are typical for glazed façade applications at office and public buildings erected during the past few decades and today. On the basis of these categories mean values of key technical parameters of typical curtain wall assemblies have been set.

A fictive but typical office building has then been defined for the purpose of energy simulations.

A baseline model configuration of the building has been set and computer simulations have been run with different glazing classes. Effect of glazing key parameters on energy demand has been evaluated in detail.

Selected parameters of the building have then been modified: glazed façade ratio (5), orientation of the building (4), fixed external cantilever shading (4), moveable (controlled) external blinds (3), night-time controlled natural ventilation (3) and internal heat storage mass (4). The numbers represent the values set including the baseline value. Running each and every combination of parameters with the nine glazing classes would have meant an unrealistic number, almost 26000 simulations, which in fact would not bring much more to identify certain trends than simulations with the change of one parameter at a time compared to the baseline model. However, natural night ventilation and thermal mass were examined in combination considering their expected close interaction. As result, altogether $24 \times 9 = 216$ simulations have been run and evaluated.

The results of heating, cooling and lighting energy demands have been analysed in a comparative and graphical way to identify the tendencies and intensity of the effect of that specific parameter in relation with defined glazing classes. The analysis was carried out excluding factors of the building installation and mechanical systems as well as energy source in order to clearly identify the effect of the studied architectural tools.

3 Analysis of architectural glass products' properties

Technical properties of almost 850 builds of realistic single, double and triple glazing have been recorded in a data-base, using information available from printed data sheets and lately more from software provided by three glass manufacturers active in Europe (AGC, Guardian and Saint-Gobain).

Representing the U_g-value (centre-of-glass *u*-factor, thermal transmission factor) and the *g*-value (SHGC, solar heat gain coefficient), the two main energy-related parameters of glass in coordinate system (Fig. 1) groups of glazing can be identified.

A 0,5…0,6 wide range of *g*-values belong to the U_g value classes. These *g*-values depend on tinting and/or coating of applied glass panes. It has to be noted that U_g of IG units is a laboratory value, bowing of the unit caused by change of temperature and/or atmospheric pressure [8] or non-vertical installation [9] results a different, mostly larger value (i.e. worse insulation property).

Visualizing the light transmission (τ_v or LT) property on the same $U_g - g$ diagram by diameter of circles (Fig. 2) it clearly appears that lower *g*-values are typically coupled with lower light transmission.

Fig. 3 gives analysis between the light transmission and the *g*-value. These two factors are related to neighbouring spectra of solar radiation, the visible light ($\lambda = 380$ - $720\,\mathrm{nm}$ wavelength) and solar heat radiation ($\lambda > 720\,\mathrm{nm}$). The ratio of the two is the spectral selectivity index $S = \tau_v/g$ (or Light to Solar Gain Ratio, $LSGR = LT/SHGC$).

The selectivity of clear glazing is around 1, while glazing with tinted and pyrolythic (hard) coated panes show values mostly between 0.5 and 1. In order to let more visible light to the inside building spaces while maintaining solar protection glass industry developments brought the spectrally selective glasses, selectivity of which reaches or even already exceeds 2.

Stronger solar protection with glass – i.e. a lower *g*-value (SHGC) – can basically be achieved by absorbing or reflecting the solar heat radiation. High absorbance however is least effective due to secondary heat transport towards the inside, and usually raises the need of thermal toughening or tempering because of expected higher thermal stresses.

The relation between solar energy absorbance (α_e) and *g*-value is demonstrated on Fig. 4. In principle a glazing having higher absorbance results lower *g*-value. Adding the solar reflectance (ρ_e) to this diagram by diameter of circles (Fig. 5) it is clearly demonstrated that lower *g*-value at relatively low absorbance can only be achieved by stronger reflection (bottom left zone of the point cloud), i.e. by a higher value of energy reflectance.

Care should be taken during design in case of high reflectance of glazing. The energy reflection of glazing basically has linear relation to visual reflection (Fig. 6). Environmental effects have to be studied as high energy reflection could mean additional heat load to neighbouring buildings or façades, while visual reflection could cause glare resulting e.g. unsafe traffic conditions.

All the above analysed properties have to be taken into consideration together with guiding architectural aspects (like transparency, reflectance, outside colour appearance, colour rendering index, etc.) when selecting the proper glazing of a façade of a building.

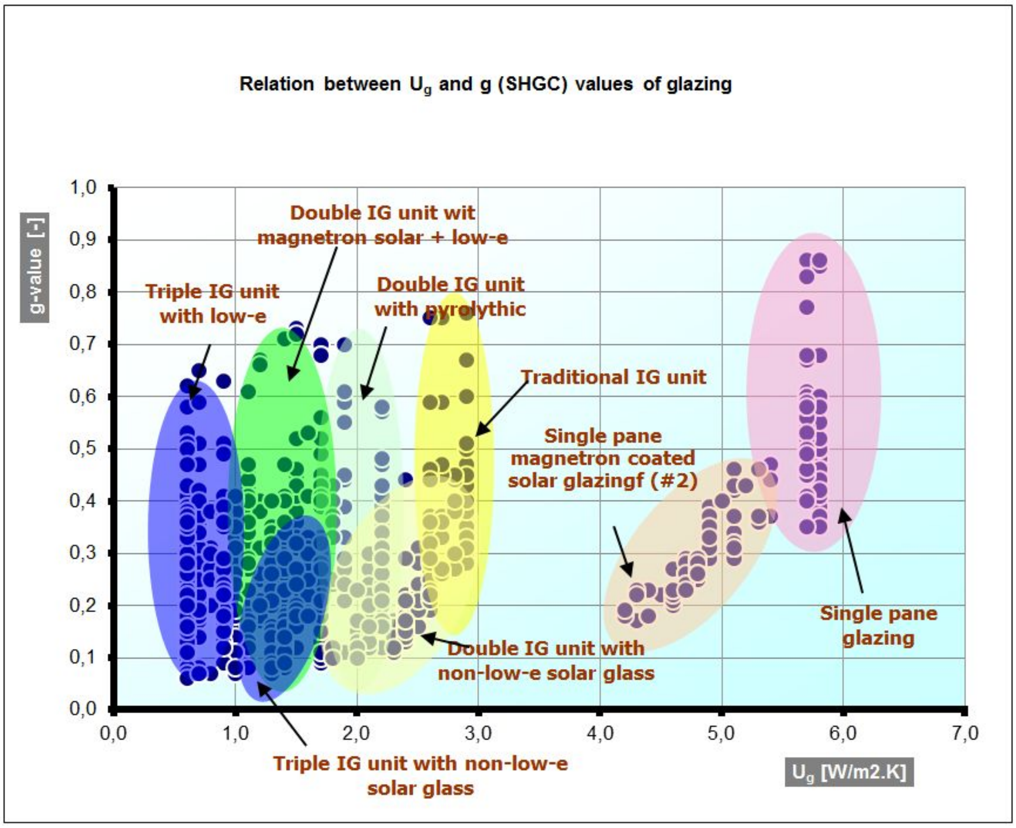

Fig. 1. Glass categories drawn by $U_G - g$ relation

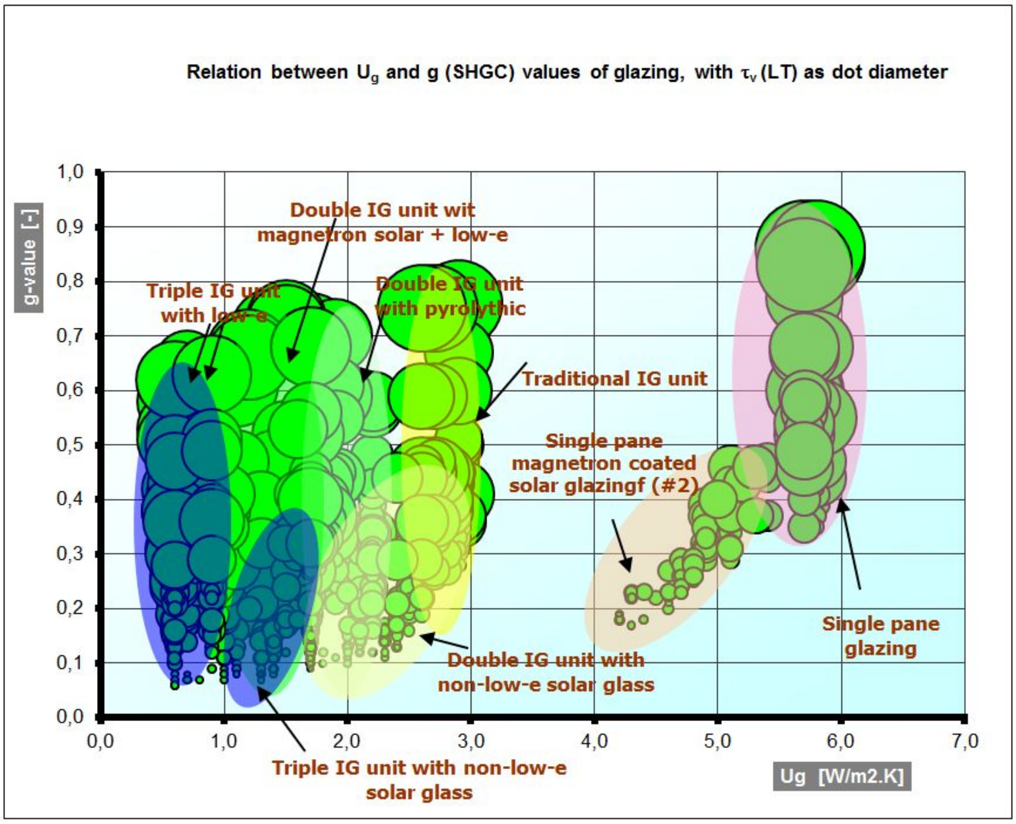

Fig. 2. Light transmission values (represented by circle diameter) in a $U_G - g$ relation

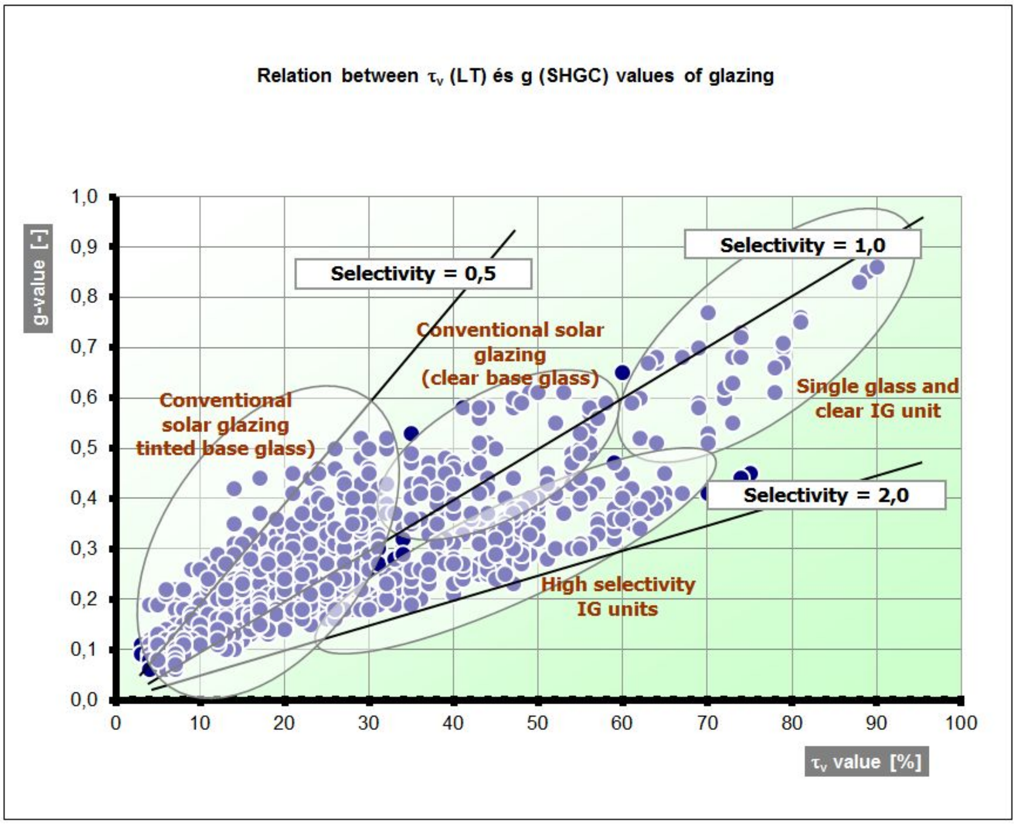

Fig. 3. Relation between light transmission and *g*-value

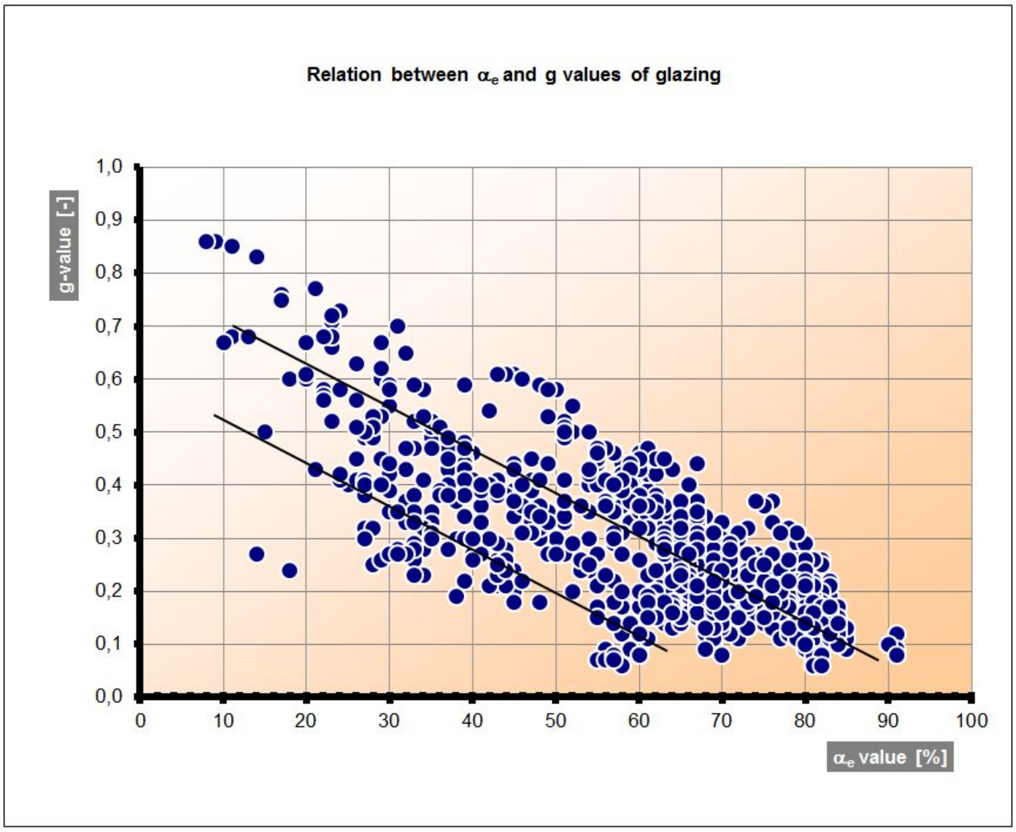

Fig. 4. Relation between energy absorbtanse and *g*-value

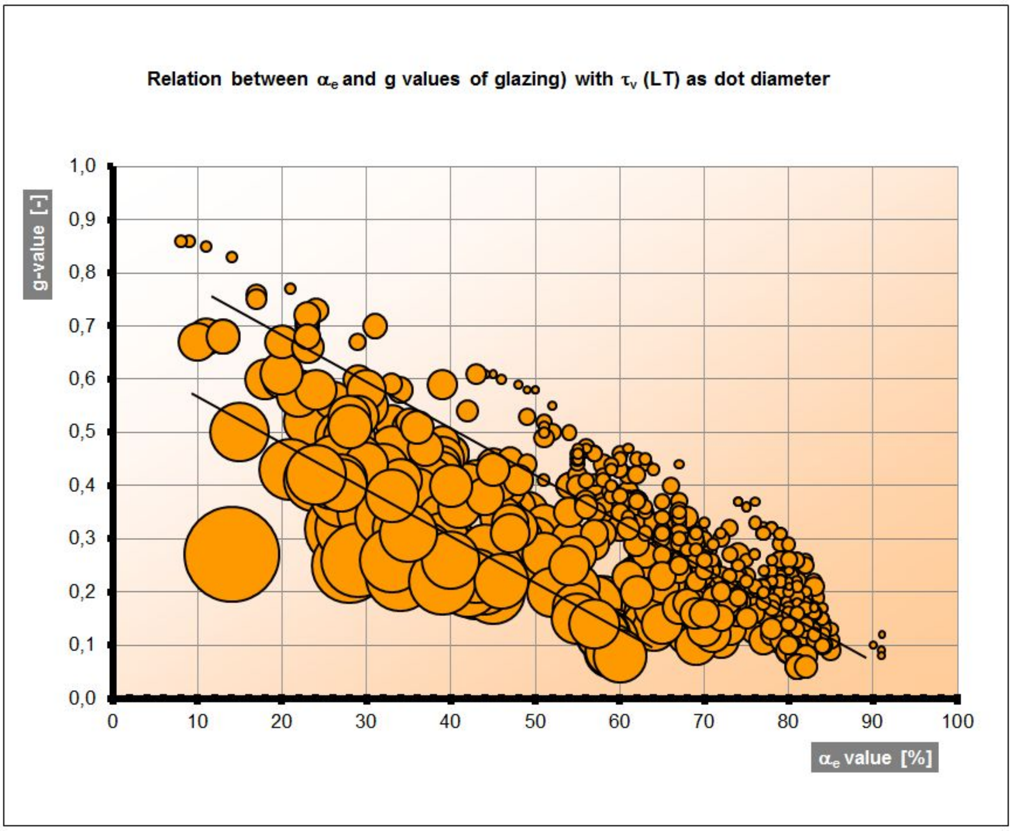

Fig. 5. Relation between energy absorbance, *g*-value and energy reflectance (marked by diameter of circles).

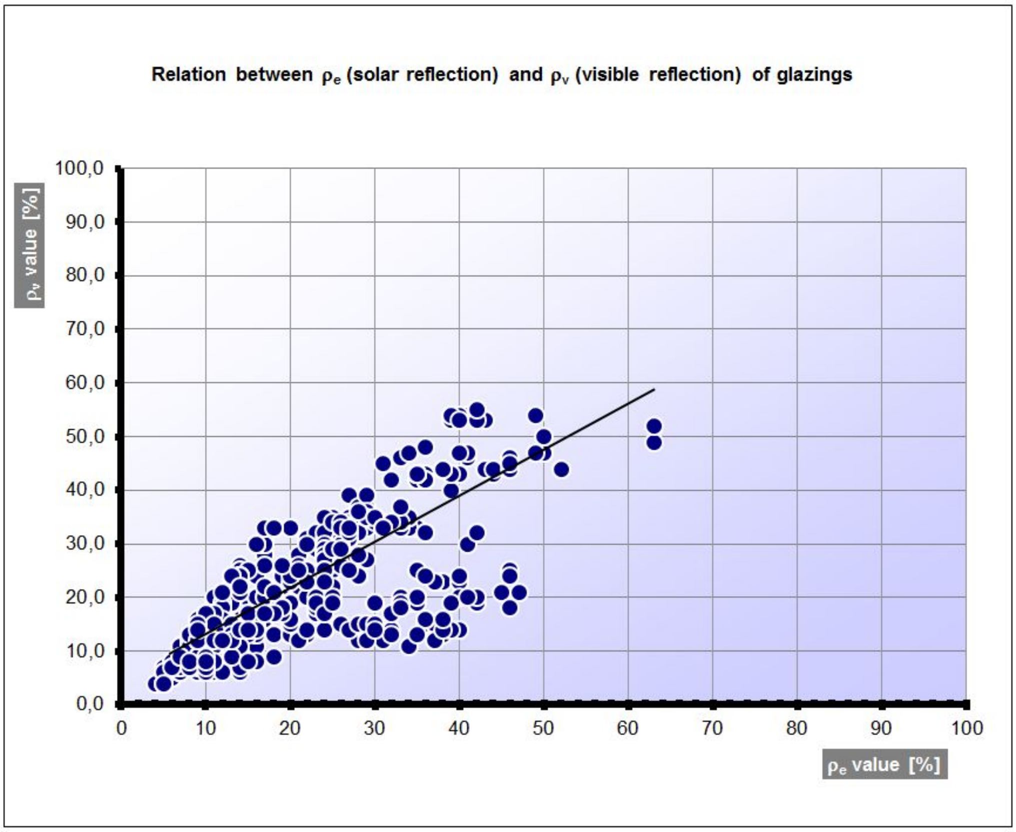

Fig. 6. Relation between energy refletance and visible light reflectance

4 Parameters and model for the energy simulations

4.1 Parameters of glass façade for the energy simulation

The relation between the U_g value (Centre-of-Glass u-factor), g-value (SHGC, Solar Heat Gain Coefficient) and τ_v (LT, visible Light Transmission) of IG units of different glass products draw up certain classes which can be differentiated using typical U_g [W/m^{2}K], g [-] and τ_v [%] value triples. Nine categories have been defined for use in the energy simulations which covers typical construction solutions of the close past and of today. These categories (in accordance with the relevant standard [10]) are identified as documented in Table 1.

Energy-related global parameters of the glazed façade depend highly on glass properties but are affected by frame and the edge-of-glass properties, geometry of design (glass/frame ratio), presence, parameters and ratio of spandrel, etc. For the purpose of the energy simulation the façade parameters documented in Table 2 have been set.

4.2 The building model for the energy simulations

A fictive but typical office building model with glass façade has been defined for the purpose of energy simulations. The key aspects were: multi-storey building with identical function on each floor to display any arising differences between floors, U-shaped plan for producing self-shading/self-reflection. Each floor has been divided into perimeter and internal thermal zones (Fig. 7).

The zone-by-zone analysis of heating, cooling and lighting energy demands give possibility to evaluate the effect of orientation, self-shading and level (vertical) position.

The model is operated according to weekly schedules, taking 5,8 W/m^2 internal heat load (15 m^2/person) and 10 W/m^2 lighting energy demand into consideration. The heating and cooling setpoints are as shown in Table 3. Climatic data was set for Hungary (weather data for Szombathely).

The simulations were carried out with EnergyPlus 8.1, in- and output supported by OpenStudio 0.9.

5 Effect of glazing types on the baseline model

The baseline model has been set with 90% curtain wall, internal yard of the U-shape facing south, 400 kg/m^2 (net floor area) thermal mass, with no outside shading and no night-time natural ventilation.

The overall heating and cooling energy demands are shown on Fig. 8. Within each category of thermal transmittance the solar glazing types require 45 - 95% more heating energy compared to clear glazing due to decreased positive effect of winter-time solar heat gain through the glass. Vice versa the cooling energy demands are much higher with clear glazing due to the higher g-value (SHGC).

The solar glasses show a clear advantage on Hungarian climate for heating + cooling energy demand, with conventional solar glazing slightly ahead (Fig. 9). Having the lighting energy demand added on top the trend turns and spectrally selective glazing proves to be best in all thermal transmittance categories, due to lower lighting energy demand thanks to better natural illumination of the interior.

Detailed analysis of the calculated heating + cooling + lighting energy demands (Table 4) proves that the most decisive factor on total energy demand is the thermal transmittance (U_W), with almost same importance of the total heat gain coefficient (g-value) and significantly smaller effect of the light transmittance (τ_v).

The simulation results have been analysed by zones and by building levels as well, for each glazing type. Fig. 10 depicts the detailed demands for glazing 2a as example – groups of bars represent thermal zones, 7 bars in a group represent floor levels of the same zone position.

The results prove that there is significant difference not only between orientations (D1 and D3 are openly exposed to south) but between floor levels as well (3 - 91% depending on zone and glazing). Heating demand is lower at the internal floors while cooling demands are smaller at lower and higher floor levels. Lighting energy demand is obviously larger at internal thermal zones (BE, BK and BN).

These differences between floors call the attention to the detailed design needs for the heating and cooling system capacity on floors which seem to be of identical thermal surroundings and conditions but require different heating and cooling power according to detailed energy simulations.

Analysing the total energy demand of 7 floors of different thermal zones (Fig. 11) it is proved that glazing type is the most decisive at exposed Southern zones (D1 and D3) while at self-shadowed zone D2 and at zones of other orientation the glazing type results smaller differences.

It can be concluded that

- floors must not be handled as identical in energy demands, detailed simulation could result different capacity needs of heating and cooling on different floors;
- glass selection for the facade during design shall be begun at exposed southern facades;
- it shall be of consideration – harmonised iteratively with the architectural concept – to apply different glazing on differently exposed facades.

6 Effect of different design variables of energy demand

6.1 Effect of glazed ratio of the facade

The proportion of the glass wall to the whole façade area has been decreased from the 90% baseline to 30% in 15% steps. The external opaque wall surfaces are considered with $U = 0.25$ W/m^{2}K thermal transmission factor.

Both the heating and cooling energy demand of the whole building (Fig. 12) decreases as the proportion of glass wall is getting smaller (the curves tend to the same point at the theoretic 0%).

Tab. 1. Glazing classes set for the simulations

	Categories of glazing used in building simulations	a			b			c		
		Clear glass			***Traditional solar glass***			***Selective solar glass***		
		U_g	g	τ_v	U_g	g	τ_v	U_g	g	τ_v
1	***IG unit of 2 conventional glass panes (no low-e)***	2.7	0.75	80	2.7	0,35	25	2.7	0,35	50
2	***IG unit of 2 panes with low-e***	1.1	0.60	75	1.1	0.25	20	1.1	0.25	50
3	***IG unit of 3 panes with low-e***	0.6	0.50	70	0.6	0.20	15	0.6	0.20	35

Tab. 2. Façade parameters set for the simulations

	Categories of glazing used in building simulations	a			b			c		
		Clear glass			***Traditional solar glass***			***Selective solar glass***		
		U_W	g	τ_v	U_W	g	τ_v	U_W	g	τ_v
1	***IG unit of 2 conventional glass panes (no low-e)***	3.00	0.68	72	3.00	0,32	22	3.00	0,32	45
2	***IG unit of 2 panes with low-e***	1.35	0.54	68	1.35	0.22	18	1.35	0.22	45
3	***IG unit of 3 panes with low-e***	0.80	0.45	63	0.80	0.18	13	0.80	0.18	32

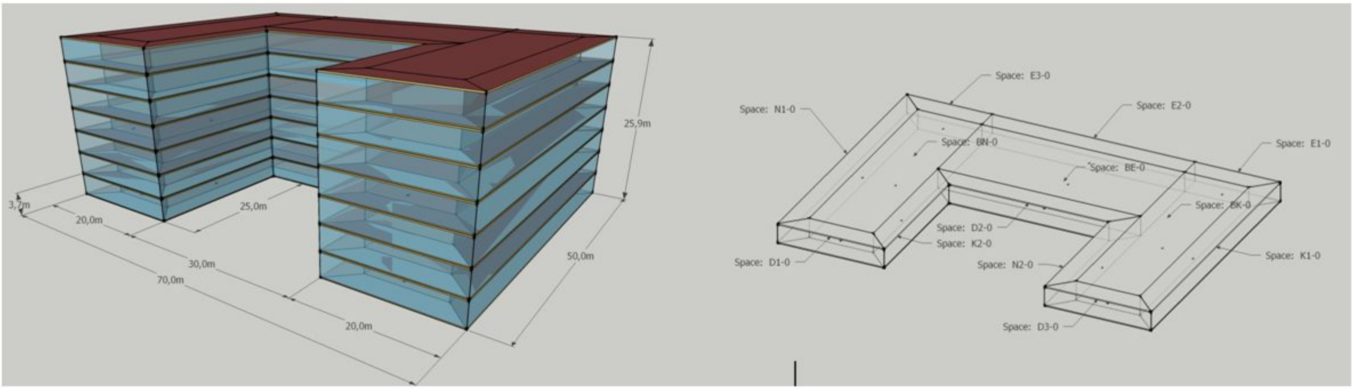

Fig. 7. The building model used for simulation and the thermal zones of a floor

Tab. 3. Heating and cooling setpoitns of the building model

Setponts	***Workdays***		***Saturdays***		***Sundays and holydays***
	06-22 h	***22-06 h***	***06-18 h***	***18-06 h***	
Heating setpoint	21°C	15,6 °C	21°C	15,6 °C	15,6 °C
Cooling setpont	24°C	26,7°C	24°C	26,7°C	26,7°C

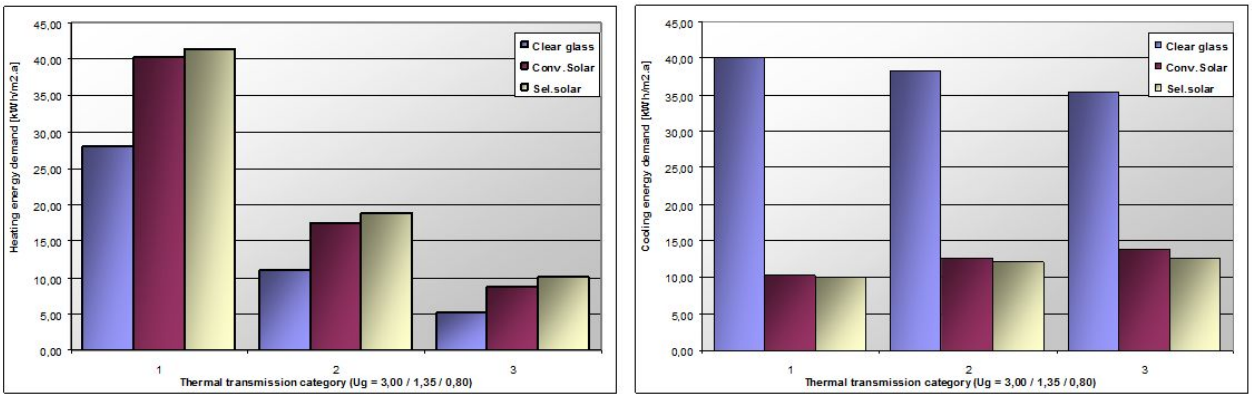

Fig. 8. Heating and cooling energy demand as function of the glazing categories

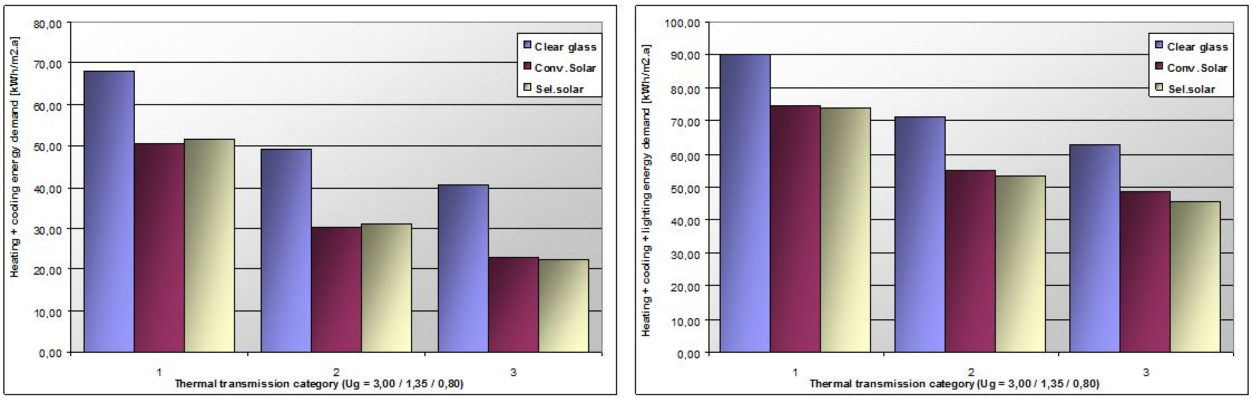

Fig. 9. The total heating+cooling energy demad (left) with the lighting energy demand added (right)

Tab. 4. The total calculated heating + cooling + lighting energy demad of the baseline model

H + C + L ***[kWh/m^2.a]***		**a**	**b**	**c**	**b/a**	**c/a**	**c/b**
cat.	**U_W**	***Clear***	***Conv.solar***	***Sel.solar***			
1	***3,00***	90,05	74,38	73,93	83%	82%	99%
2	***1,35***	71,23	54,82	53,50	77%	75%	98%
3	***0,80***	62,75	48,60	45,72	77%	73%	94%
2/1		79%	74%	72%	61%	59%	72%
3/1		70%	65%	62%	54%	51%	61%
3/2		88%	89%	85%	68%	64%	83%

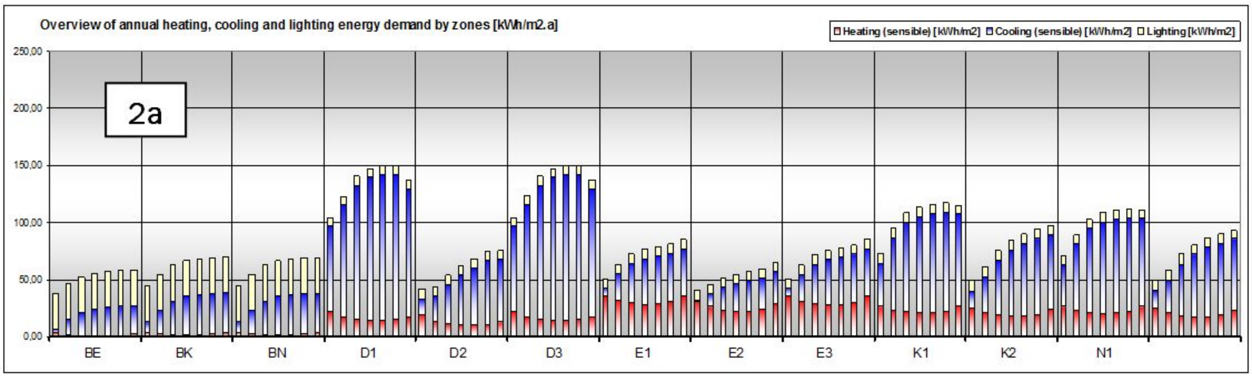

Fig. 10. Specific heating, cooling and lighting energy demands of zones with glazing 2a (bottom/red : hetaing – middle/blue: cooling – top/yellow: lighting).

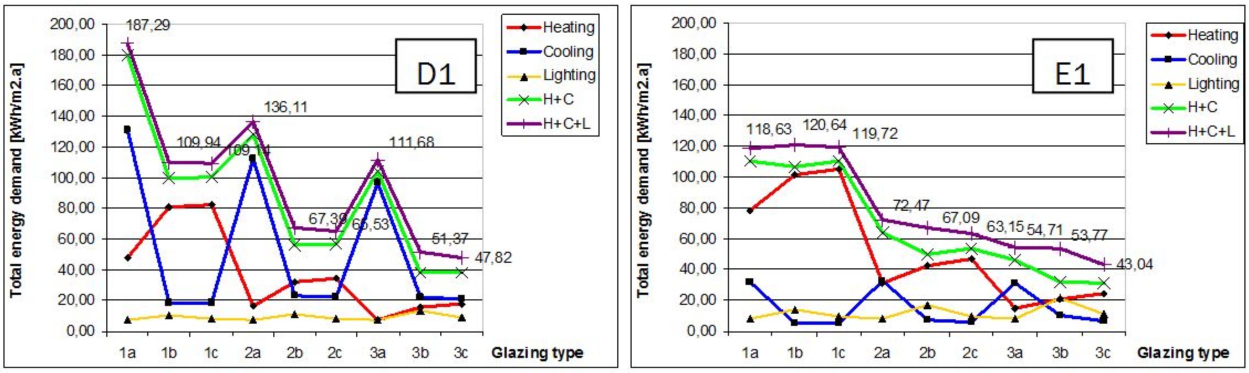

Fig. 11. Total $H + C + L$ energy demand of 7 floors of zones D1 (South) and E1 (North) as function of glazing type

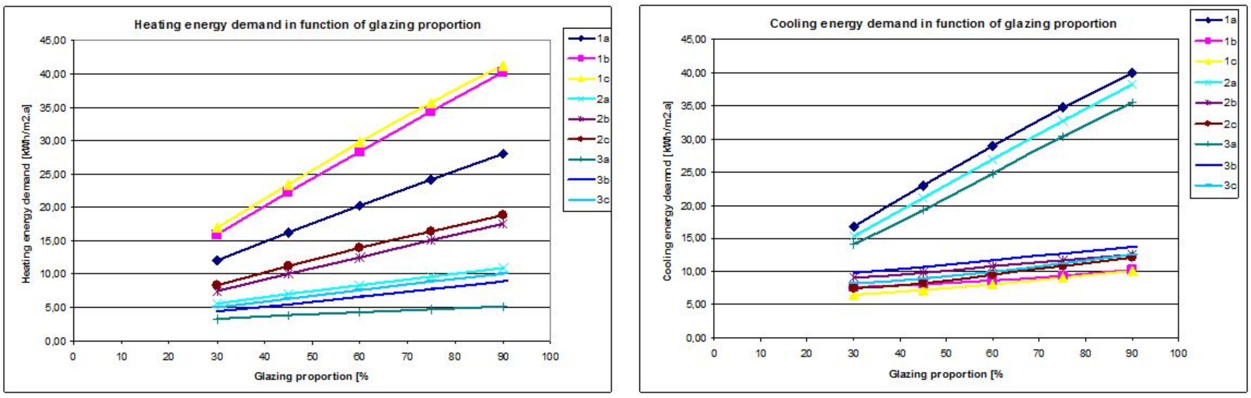

Fig. 12. Heating and cooling energy demand as function of the glass wall proportion

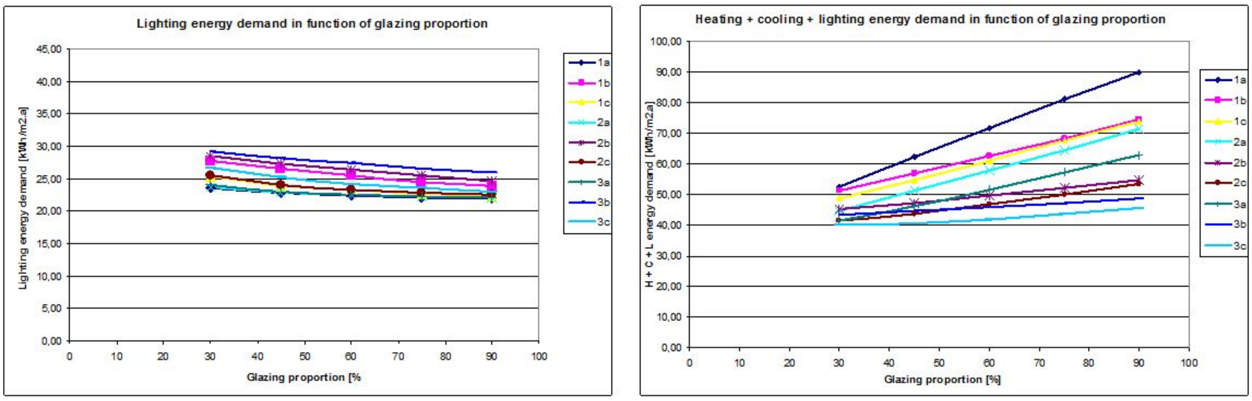

Fig. 13. Lighting and total $H + C + L$ energy demand as function of the glass wall portion

The lighting energy demand (Fig. 13) shows a progressive growth with the glass surface reduction. It results the decrease of difference in total energy demands within U_W groups (1, 2 and 3) between the clear and solar glazing, or even the solar glazing results higher calculated energy demands at 30%. The smallest energy demand is achieved with glass type 3c (triple IG unit of selective pane) in the whole 30 - 90% range.

The total drop in energy demand at 30% glass façade ratio is expected at 13 - 42% compared to the 90% proportion baseline. The smaller differences are calculated with up-to-date glazing types.

It is expected that the most intense effect could be experienced at south oriented thermal zones. Detailed examination of optimum glazing proportion as function of orientation is planned in an upcoming stage of the research.

6.2 Effect of fixed cantilever shading

It is clearly shown by the above detailed analysis that cooling energy demand is outstandingly high in thermal zones behind the exposed southern (D1 and D3), eastern (K1) and western (N1) façades under Hungarian climate. Cutting the energy demands therefore seems to be logical by reducing these cooling demands.

Fixed cantilever shading above windows is known as an effective way of solar protection for façade oriented close to South, which at the same time does not exclude gain from the wintertime low inclination solar beam. The effectiveness of this type of solar protection however is limited on western and eastern oriented façades due to lower inclination of sun beams in the morning and afternoon hours (vertical shading panels could be more efficient).

The effect of fixed cantilever shadings of 50, 100 and 150 cm projection has been studied in comparison with the baseline model. Heating and cooling energy demands are shown in Fig. 14.

The fact that heating energy demand increases by 5 - 29% with larger shading projection calls the attention to the importance of optimum projection and vertical position geometric design. The background of this increase is visually explained by a model shot taken in the late morning hours in January (Fig. 15): extended shadow appears on the eastern façade while the southern façade vision glasses receive partial shading, both reducing the solar heat gain.

The drop in cooling demand however is more intensive: 43 - 51% is achieved in case of clear glasses and 30 - 43% in case of solar glazing types. The curves group up by type of the glass panes (a, b and c).

Lighting energy demand changes similarly to heating energy demand, the increase is 2 - 7%.

Adding up the heating and cooling energy demands (Fig. 16 left) shows that advantage is kept in case of clear base glasses (23 - 33%) but is minor with solar glazing (4 - 17%). This is even more so when adding lighting energy demand on top, energy demand decrease of 17 - 21% can be achieved at clear glazing

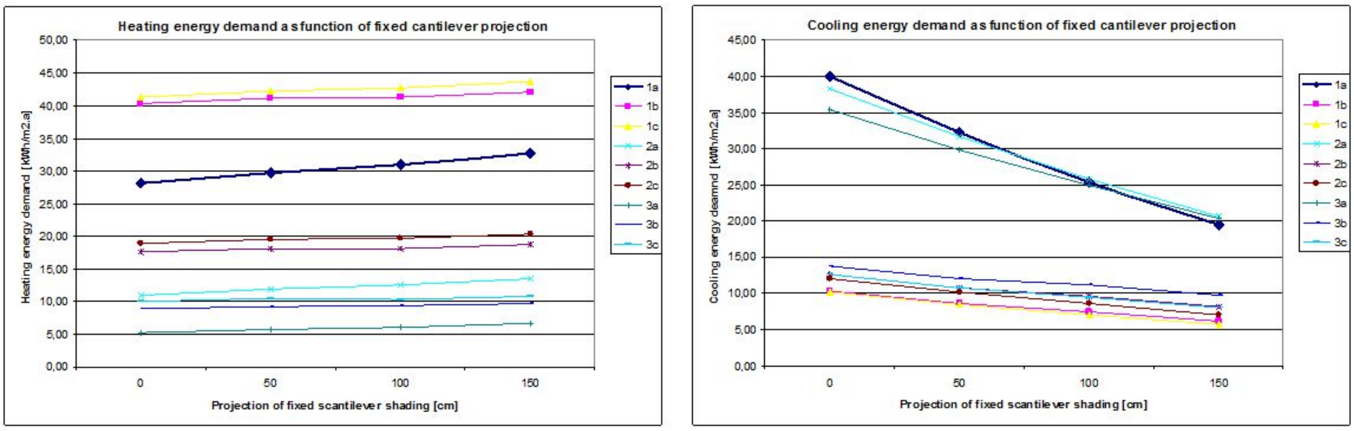

Fig. 14. Heating and cooling energy demands as function of fixed cantilever shading projection

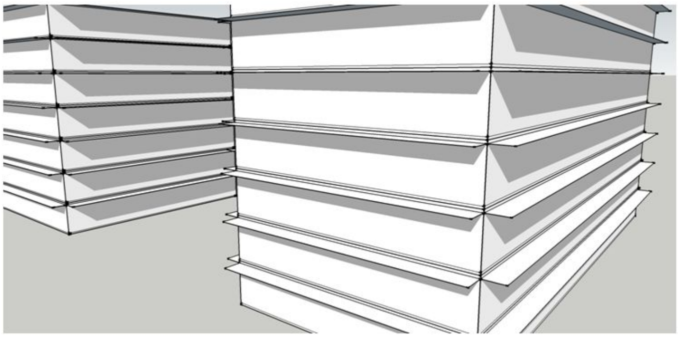

Fig. 15. Shadow projected on eastern and southern façade in a January late morning situation

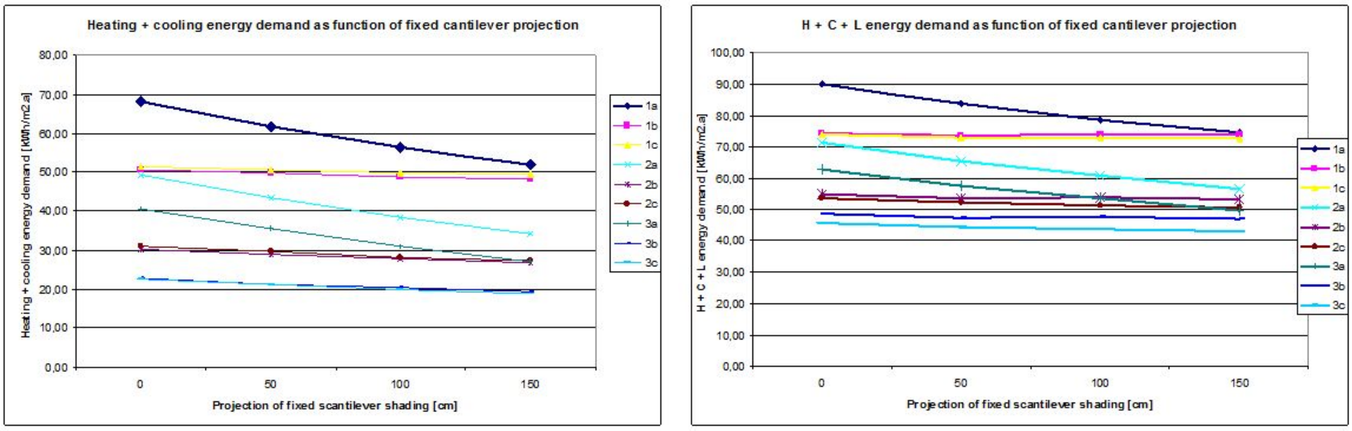

Fig. 16. Heating + cooling (left) and total $H + C + L$ energy demands (right) as function of fixed cantilever shading projection

and only 1 - 6% at solar glazing types (Fig. 16 right).

The fixed cantilever shading brings the energy demand of a building with clear glazing very close to that of solar glazing.

Having a 150 cm projection the energy demand equals a 60% proportion of unshaded glass wall in case of conventional clear insulating glass (1a) and a 75% proportion of unshaded glass wall in case of triple selective solar IG units (3c), so these solution pairs provide same results.

It has to be mentioned that apart from energy control fixed shadings could play important role in glare protection and improving thermal human comfort in zones next to the glass wall, and can also provide a platform for façade cleaning and maintenance works. These factors could further justify the application of such shading structures.

Detailed zone-by-zone study analysing the efficiency as function of orientation is planned in an upcoming stage of the research.

6.3 Effect of automatically controlled external shading louvers

The parameters analysed so far mean static solutions. The effect of glazing types and glazed proportion is independent from the season or daily path of the sun and the fixed cantilever is adaptive only in terms of the changing solar beam inclination.

The importance of effective solar protection in summer and the maximised solar heat gain in winter is proved by the simulation results discussed above. Controlled variable shading devices mean further possibilities for effective reduction of cooling demands while adaptively keeping the possibility of solar energy utilization when needed. Controlled shading plays an important role in the internal visual comfort as well. Several control strategies can be used [11], and the occupant interference with the automated systems brings some uncertainty into simulations [12].

In the recent study a system of external shading was applied on the baseline model with 45°louvres position controlled by 50 and 100 W/m^2 global radiation intensity and presence of cooling demand in the previous time step (no visual comfort factors were included).

The heating energy demands (Fig. 17 left) are slightly increased (5 - 11% at clear glazings, 1 - 2% at solar glazing types). This “loss” could be corrected by more advanced control conditions. Striking drop in cooling energy demands (Fig. 17 right) is reached in case of clear glasses (50 - 74%) but still considerable in case of solar glazing types (24 - 35%). This leads to smaller required built-in cooling capacity, reducing investment budget and running costs as well, which could improve the return of the investment of controlled external shading.

The lighting energy demand naturally grows with the use of external shading (by 3 - 8%). This could be balanced with a light shelf kind of design of the upper part of the external blinds.

The total heating + cooling + lighting energy demand (Fig. 18) shows that controlled external shading could bring 28 - 30% decrease in energy demand in case of clear glasses but the effect is almost neglectable in case of solar glazing types (2 - 4%). It has to be pointed out that controlled external shading in front of clear glazing shows equal or better results than with solar glazing solutions.

Energy demands of the baseline model and the controlled external shading solution is compared in Fig. 19 as function of glazing type. While the controlled external shading has not brought mentionable spare in total energy demands for the whole building it is clearly seen that in zones behind a façade exposed to south it reduces energy demands for all glazing types.

6.4 Effect of internal thermal inertia of the building

The thermally active mass of the building plays an important role in balancing the thermal changes and in stabilizing the temperature of the internal space, permitting less required action from the HVAC system to balance heat load or loss alterations.

The internal finishes of higher category office buildings have been guided by technological, maintenance and retrofit aspects as well as the need for short construction period. False (suspended) ceiling, false (hollow) floor, gypsum partitions became almost exclusive in office constructions of the last decades. All these are light weight but thermally insulating finishes, excluding the heavy load bearing (e.g. concrete) structure from taking part in daily thermal procedures (heat absorption, storage and emission) [13]. Different building codes give different approach to thermal mass but in general layers till $R = 0{,}15\,\mathrm{m^2K/W}$ thermal resistance can be taken into account. Table 5 shows the effective thermal mass of a few typical fit-out finishing structures.

The effect of the thermal mass of 200, 100 and 20 kg/m^2 (net floor area) has been studied in comparison with the baseline 400 kg/m^2.

Both heating and cooling energy demands (Fig. 20) become progressively higher with the decrease of thermal mass. The extra energy demand in heating is 9 - 73%, while in cooling is 17 - 60%. Lighting needs are not affected by thermal mass changes.

The total energy demand (Fig. 21) shows an energy demand increased by 16 - 25% in case of clear glazing and by 10 - 13% in case of solar glazing types. The increase is not significant till 200 kg/m^2 thermal mass but the trend becomes progressive bellow that value.

A change of design concept is required considering the typical fit-out solutions. At least heavier finishes are to be used [13], or rather load bearing heavy members have to be let uncovered, i.e. exposed in order to provide adequate active thermal mass to internal spaces. It has to be mentioned that up-to-date solutions like thermo-active building systems do require exposed concrete structures as well. PCM materials can also be combined into the system providing latent thermal mass [14].

6.5 Effect of controlled natural night ventilation

All-day natural ventilation is usually not viable in open-plan office areas which require precisely controlled air temperature

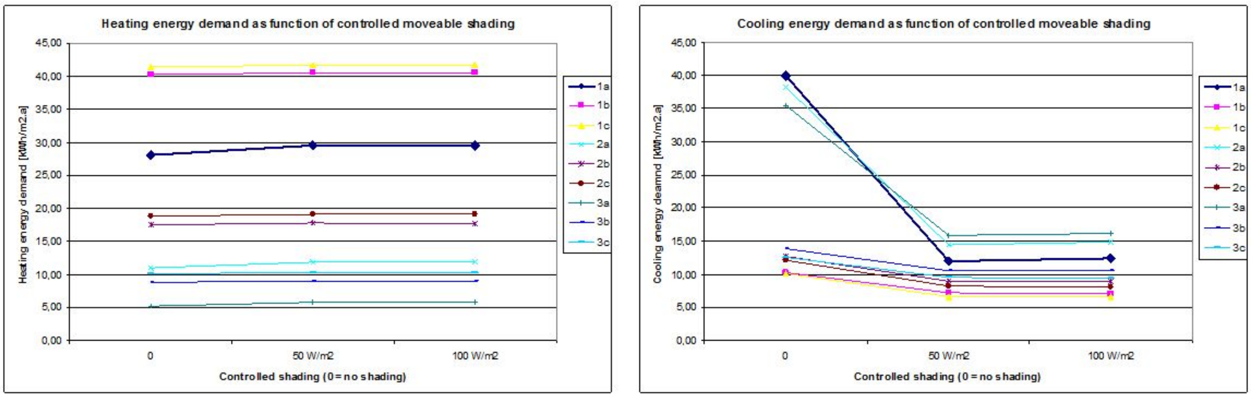

Fig. 17. Heating (left) and cooling (right) energy demands as function of controlled shading

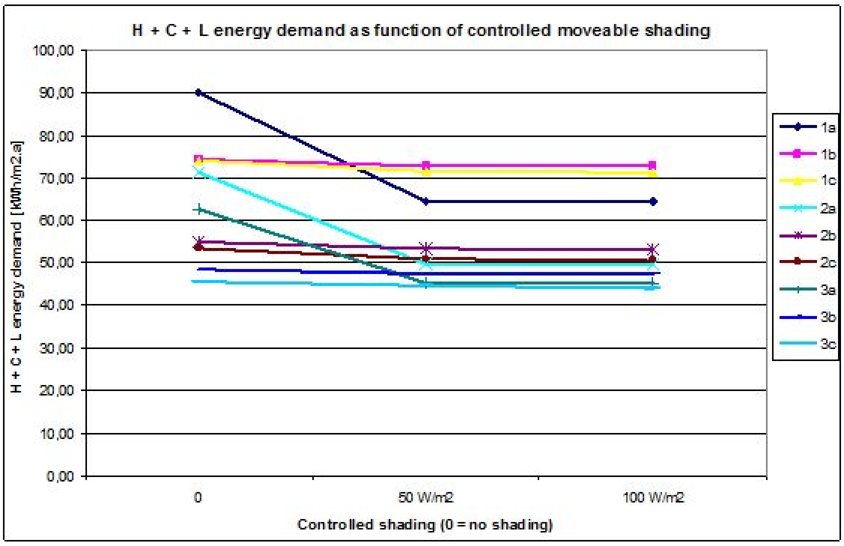

Fig. 18. Total $H + C + L$ energy demand as function of controlled shading

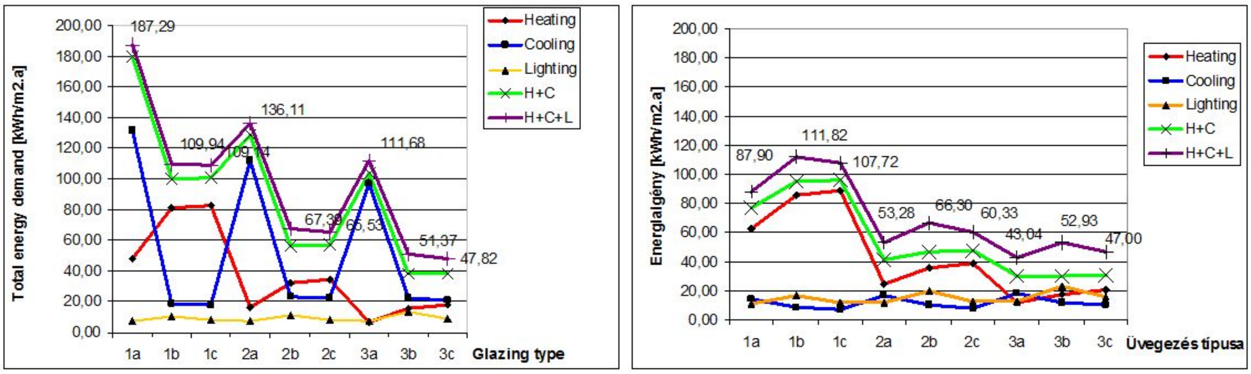

Fig. 19. Total $H + C + L$ energy demand of an exposed southern zone (D1) as function of glazing types for the baseline model (left) and with controlled external shading (right)

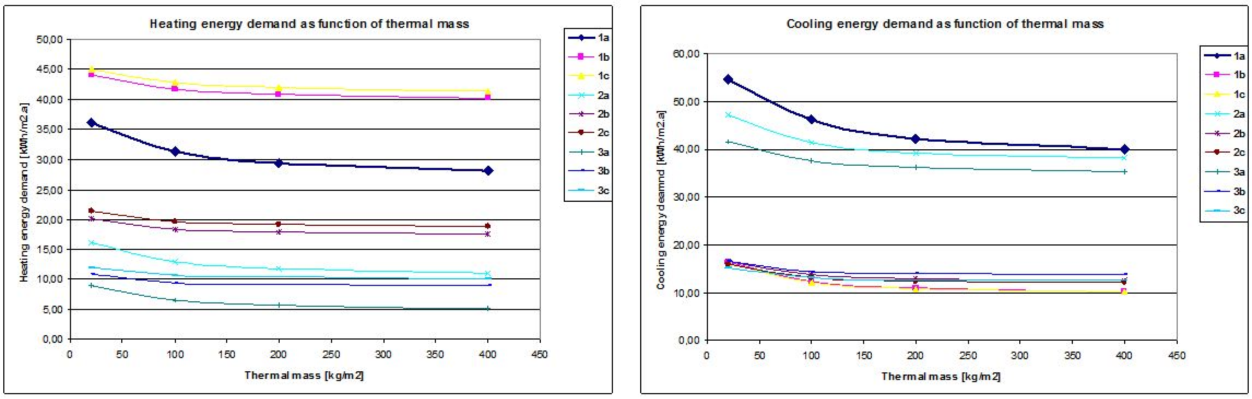

Fig. 20. Heating (left) and cooling (right) energy demand as function of thermal mass

Tab. 5. Effective thermal mass of a few typical light weight finishing (fit-out) structures (* timber has 3 times higher thermal capacity than silicate-like materials)

Material / Structure	**Density [kg/m^3]**	**Conductance λ [W/mK]**	**Thickness at $R = 0{,}15\,m^2K/W$**	**Thermal M [kg/m^2]**
Mineral fibre panel suspended ceiling	330	0,064	9,6 mm	3,2
Fitted carpet with foam base	—	0,044	6,6 mm	~0
Jointed floor (pine) – 22 mm (w/foam layer underneath)	550	0,19	(28,5 mm)	$12{,}1 \times 3^* \approx 36$
Pearlite concrete	600	0,20	30 mm	18,0
Gypsum board – actual thickness $2 \times 12{,}5 = 25$ mm	—	0,23	(34,5 mm)	18,0

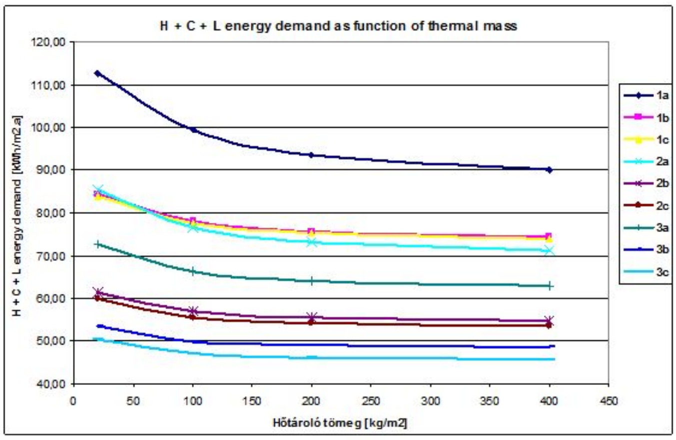

Fig. 21. Total energy demand as function of thermal mass

and humidity. Night ventilation however could be a tool in lowering cooling energy demands and required capacity of air-conditioning installation [15].

The Hungarian climate provides longer periods basically in spring and autumn when natural ventilation could result comfort in the interior, and summer night conditions are suitable for cooling the interiors at low operation costs.

Controlled natural ventilation requires automated windows and baffle panels in front of openable fields, the cost of which has to be verified in terms of return in investment and operating expenses. Natural night ventilation is found effective over the exchange rate $n = 4\,\mathrm{h}^{-1}$ [16]$^{-p159}$], therefore exchange rates of $n = 2$ and $4\,\mathrm{h}^{-1}$ has been simulated under the control conditions detailed in Table 6.

Fig. 22 and 23 shows temperature and cooling power demand results from the energy simulation for a summer week period. It is clearly seen that lower cooling power is needed and in less operating hours to maintain the set indoor temperature.

This results a 34 - 79%(!) lower cooling energy demand, with the more significant decrease in case of solar glazing types. The total annual calculated $H + C + L$ energy demand can be reduced by 15 - 26% in case of clear glazing, and by 5 - 16% in case of solar glazing types. Special attention is deserved by the fact, that 15 - 16% reduction shows up for the most up-to-date, triple IG unit with selective solar pane (3c).

7 Conclusions

Glazed façade do and expectedly will play an important role in public and office type buildings. This study targeted to identify architectural tools for their effectiveness on the reduction of energy demand of buildings under Hungarian climate conditions (findings can directly be adapted to similar continental climate.)

Energy simulations carried out using a fictive but typical building configuration with nine glazing categories proved that the selection of glazing (and its technical properties), the proportion of glazed façade in the total, external fixed and adaptive shadings and night-time controlled natural ventilation could significantly reduce the energy demand of buildings with largely glazed façades under the condition of adequate active thermal mass.

The study casts figures on the effectiveness of different architectural tools compared to a baseline model.

The trends phrased on the basis of findings could be useful in the early conceptual design stages, while the importance of detailed dynamic energy simulation is also underlined. The interaction of different parameters and conditions requires a complex approach.

Low-energy buildings utilise a large amount of solar energy

Tab. 6. Night-time natural ventilation controls in simulation

	Summer	***Winter***
Period	May 13th – October 20th	October 21st – May 12th
Min. outdoor temperature	0°C (practically no limit)	15,6°C
Max. outdoor temperature	24°C	100°C (pract. no limit)
Min. indoor temperature	19°C	
Max. indoor temperature	100°C (practically no limit)	
Ventilation hours		
- workdays	22-05 h (only at night)	
- Saturdays	18-05 h (in the evening and at night)	
- Sundays and holidays	0-24 h (all day)	

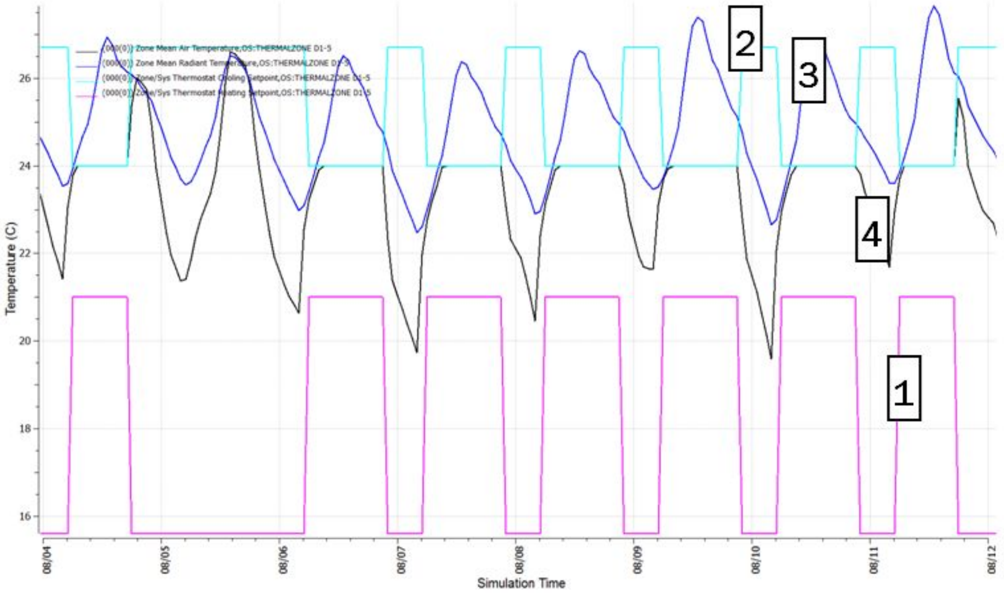

Fig. 22. Temperature diagrams of a summer week with controlled natural night ventilation (1-purple and 2-cyan: thermostat setpoints; 3-blue and 4-black: indoor sensible and air temperature)

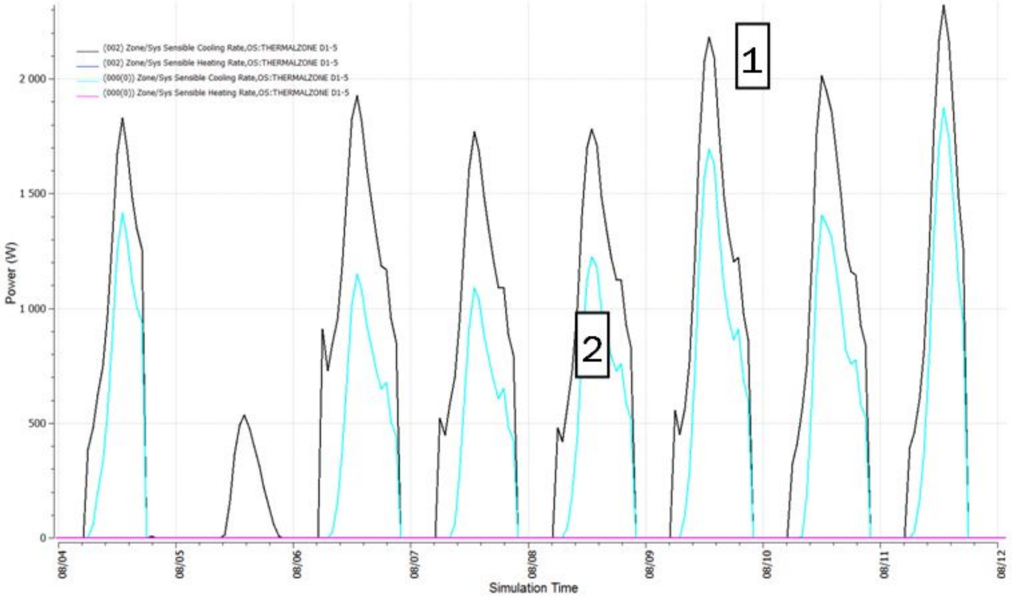

Fig. 23. Cooling power demand of the same period (1-black: no ventilation; 2-cyan: controlled night-time natural ventilation)

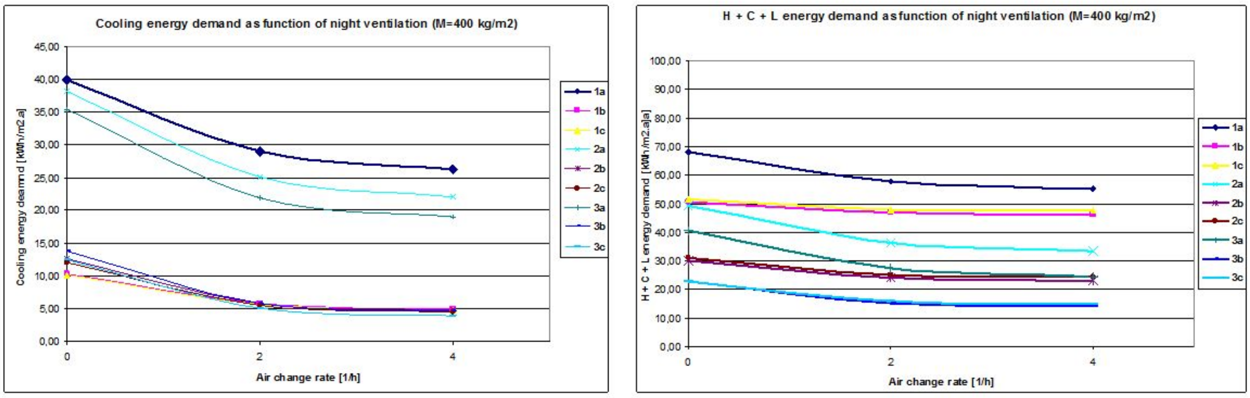

Fig. 24. Cooling (left) and total H+C+L (right) energy demand as function of controlled night-time natural ventilation intensity

(energy gains) while having a moderate energy loss. The resultant of these two opposing volumes is relatively (sometimes very) small, therefore the system is sensible. Relatively small deviations in either the energy gain or the energy loss would result in a relatively high change in the result. Exact simulation carried out on reliable and detailed data as well as consideration of different alternatives is largely recommended in order to achieve the targeted behaviour of the building in reality.

Further, the application of this set of architectural tools has to interact with comfort theory, building installation and building automation design, as well as with aspects of investment and operation economy, sustainability, etc.

Optimum solution for building owners, the users and the environment can only be worked out as a harmonised assembly of decomposed elements and systems under holistic approach and a close co-operation of related professionals.

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