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Design considerations for architectural glazing, with focus on public buildings' energy demand under Hungarian and similar climate

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Abstract

The aim of this paper is to introduce guidelines as aid for early stage architectural design of public and office buildings with large glazed surfaces in connection with the impact of some solutions on energy demand of the building. Relation between key parameters of architectural glazing (thermal transmission, solar heat gain coefficient and light transmission) has been analysed first using properties of 850 realistic builds of different glazing products recorded in the first stage of the research. Nine typical glazing categories have been specified by realistic selected triples of these parameters for energy simulation on a fictitious but typical office building. A series of energy simulations have then been run with Energy Plus 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 demand under Hungarian and similar climate conditions. Annual specific heating, cooling and lighting energy demand have been determined and studied. The simulation was made independent from choice of mechanical system (HVAC) and kind of energy sources in order to clearly analyse the effect of certain architectural tools on energy demand of internal spaces.

Keywords: Architectural glazing, glass façade, energy conservation, energy efficiency, building energy simulation, energy design

1 Introduction

The need of energy consumption cuts appears in the policy of the EU, objectives of "3×20" for 2020 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 communication [1] reports "the existing strategy is currently unlikely to achieve all the 2020 targets, and it is wholly inadequate to the longer term challenges". The steps taken towards energy efficiency improvements are especially found slow. Special attention is called on existing building stock and transport sector which hold the largest potential to make energy efficiency gains.

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A research carried out on energy efficiency of buildings, its potentials and barriers [2] states that in most EU countries “cost-effective energy savings of about 10% can be achieved by 2020 and 20% by 2030”.

Sustainability of building has a broad scale of approach.

The real-estate investment and construction sector lately pays special attention to ‘green’ building due to the continued energy crises and the growing demand for preserving the environment. A study from Colliers International [3] shows that only ‘green certified’ office buildings were and are under construction or preparation during the financially critical past years in Budapest.

Creating buildings which provide human comfort with the feasibly lowest energy demand is an important tool amongst other aspects in order to reduce the footprint of the built environment. On the other hand construction investments are long-term and of high-value, therefore the design made today has long lasting impact.

The building is a complex energy system, all components shall act in harmony in order to achieve human comfort at balanced investment budget, low energy consumption and operation cost.

Glass façade is a major part of the building skin of most public and office buildings. Energy conscious design of the building skin together with other urban, architectural and mechanical design measures is an important factor in improving energy efficiency of buildings.

This article introduces methods and considerations for the design of largely glazed facades of public buildings on the basis of findings of a research carried out lately [4].

2 Selection of architectural glazing

Glazed portion of building skin plays an important role not only in the architectural appearance, in the impression the building makes, but largely in the energy, building physics and comfort quality of the building. Decision on the final glazing product and the glazed façade construction of a number of buildings however was and still is guided by aesthetics, financial, marketing or manufacturing considerations, partly or fully excluding the aspects of energy conscious design.

It is of high importance to set criteria for the glazing and the whole glazed façade in early stages of design, as for one component of the complex energy system of the building. In accordance with the Construction Product Regulation [5] designers shall specify the performance levels of building components rather than specific product brands, and these specifications need to be enforced in construction.

This procedure requires the understanding of different parameters of glazing, the relation between those and the product types providing the expected technical parameters.

Technical properties of about 850 builds of realistic single, double and triple glazing have been recorded in a data-base, using information available from printed data sheets and 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) and the g-value (SHGC, solar heat gain coefficient) of glazings, the two main energy-related parameters of glass (Fig. 1) groups of glazings can be identified.

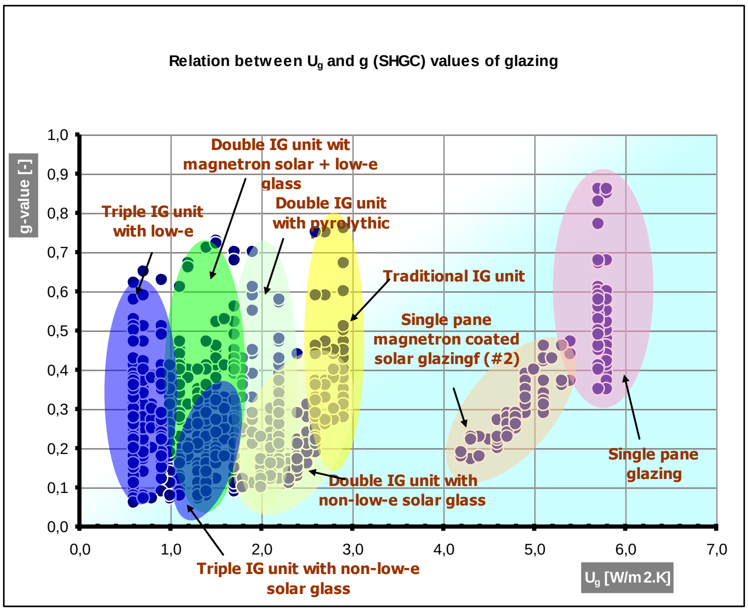

Fig. 1 Glass categories drawn by U_G – g relation

Analysis of the light transmission (τ_v or LT) and the g-value (SHGC) of glazing is given on Fig. 2. These two factors are related to neighbouring spectra of solar radiation: the visible light (λ=380-720 nm wavelength) and solar heat radiation (λ>720 nm). The ratio of the two is the spectral selectivity index $S=\tau_v/g$ (or Light to Solar Gain Ratio, LSGR=LT/SHGC).

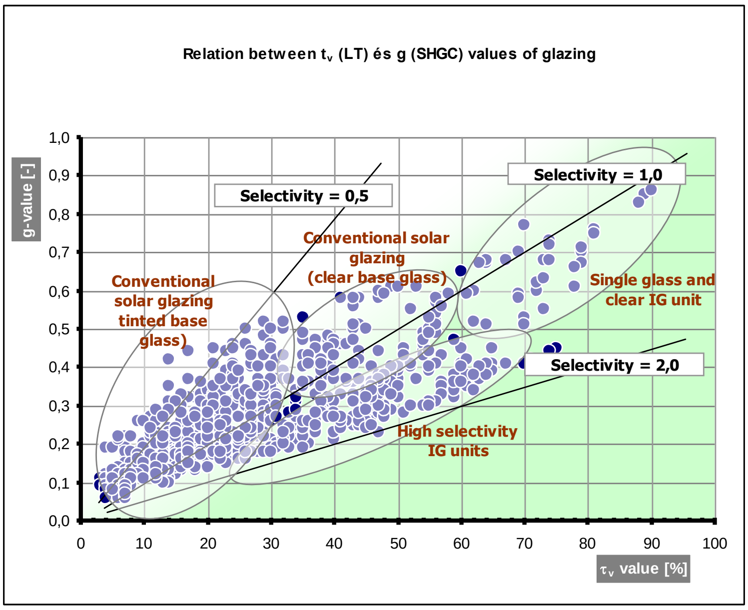

Fig. 2 Relation between light transmission and g-value

Clear glazing types are found around the selectivity of 1, while glazing with tinted and pyrolythic (hard) coated panes show lower values, mostly between 0.5 and 1. For better natural illumination of inside building spaces coupled with good solar protection spectrally selective glasses have been developed, 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 (Fig. 3). High absorbance however is less effective due to secondary heat transport towards the inside, and might raise the need of thermal toughening or tempering because of higher expected thermal stresses.

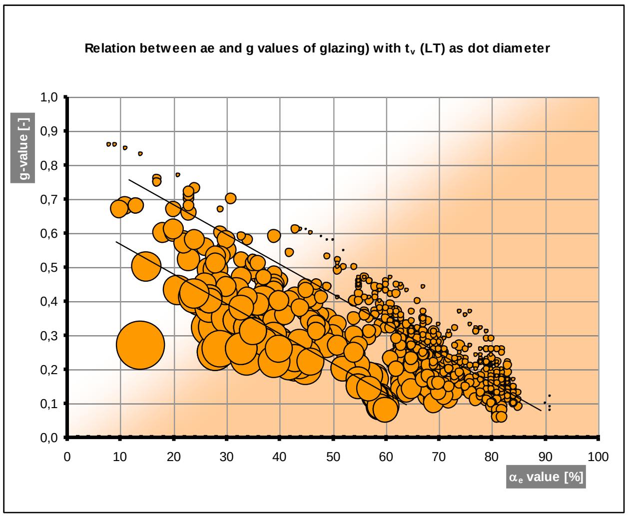

Fig. 3 Relation between energy absorbance, g-value and energy reflectance (marked by diameter of circles).

A selection method has been developed by representing the technical parameters of glazing products on a set of charts in projection (Fig. 5).

Filtering the database step-by-step for ranges of parameters glazing constructions fulfilling the expectations can be selected. Points representing products not fulfilling the given conditions disappear from all charts thus the results can visually be followed in a complex way.

Following this procedure untreatably broad performance specification can be avoided as well as impossible combination of parameters.

Range of preferred or required thermal insulation, solar heat gain, visual light transmittance, etc. shall be determined with regard to the design of the building's energy system.

3 Effect of glazing and related parameters on the building's energy demand

3.1. The baseline model for energy simulations

A research has been carried out to analyse the effect of key glass façade and structural properties on energy demand of the building under typical Hungarian weather conditions. The findings are applicable for situations under similar climate.

The effect of certain parameters has been studied with energy simulation for heating, cooling and lighting energy demands on a fictive but typical office building configuration (Fig. 4). Simulations have been run using EnergyPlus software. The analysis was carried out excluding factors of the building installation and mechanical systems in order to clearly identify the effect of the studied architectural tools.

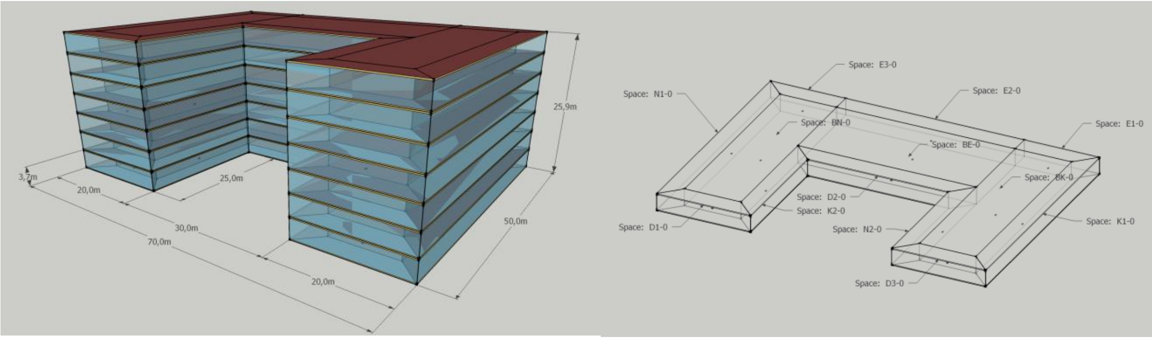

Fig. 4 The building model used for simulation and the thermal zones of a floor

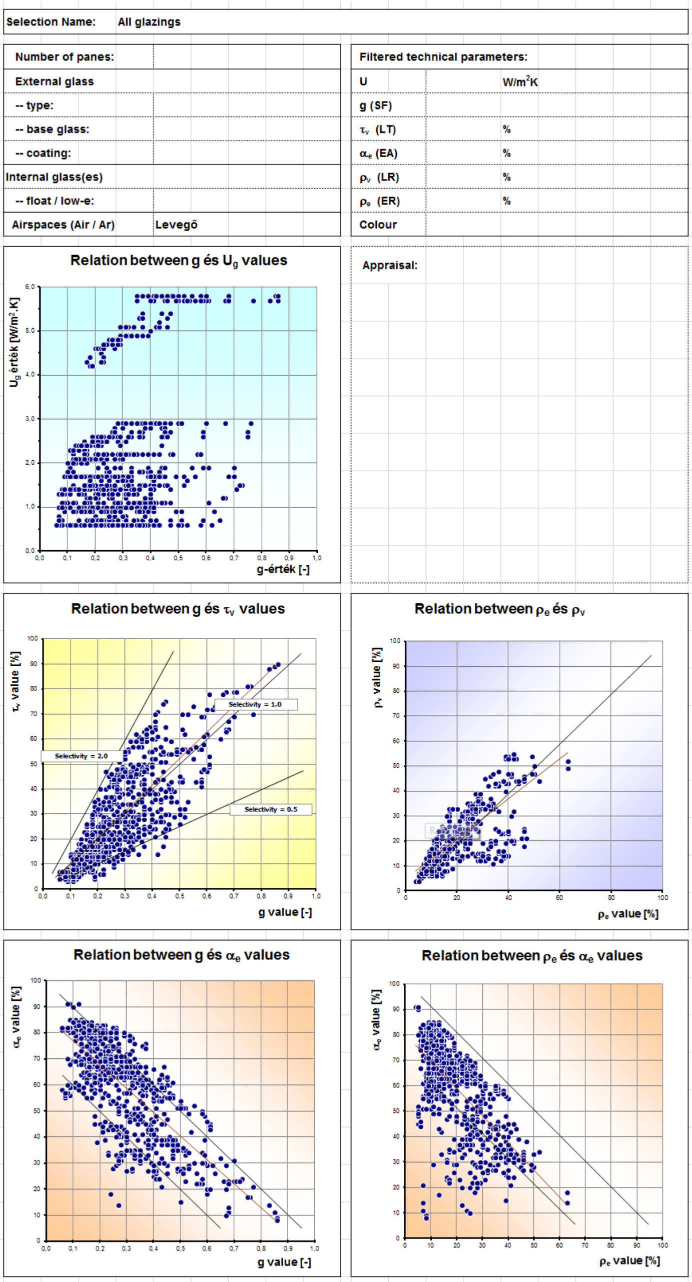

Fig. 5 Visualisation method of glazing database filtering process as aid for proper glass specification and proper product selection

A baseline building model has been set up 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. Nine glazing categories have been defined as 2 pane conventional, 2 and 3 pane low-e glazing, each category composed of clear glass, traditional solar glass (with low selectivity index) and selective solar glass products. Table 1 shows the values taken for the glazed façade.

Table 1 Façade parameters for glazing categories set for the simulations

Categories of glazing used in building simulations		***a***			***b***			***c***		
		Clear glass			***Traditional solar glass***			***Selective solar glass***		
Categories of thermal transmittance		U_W	***g***	τ_v	U_W	***g***	τ_v	U_W	***g***	τ_v
1	***IG unit of 2 conventional glass panes (with 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

The building model has been 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 2. Climatic data was set to Hungary (WMO data for Szombathely).

Table 2 Heating and cooling setpoints of the model

Setpoints	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

3.2. Effect of glazing types on the baseline model

The overall heating and cooling energy demands resulting from the simulation with the 9 different glazing on the baseline model are shown on Fig. 6 and Fig. 7 respectively. Within each category of thermal transmittance (1, 2 and 3) the solar glazing types (b and c) require 45-95% more heating energy compared to clear glazing due to the loss in the winter-time solar heat gain, while the cooling energy demands are several times lower due to the lower g-value and consequently the lower heat load in summer-time.

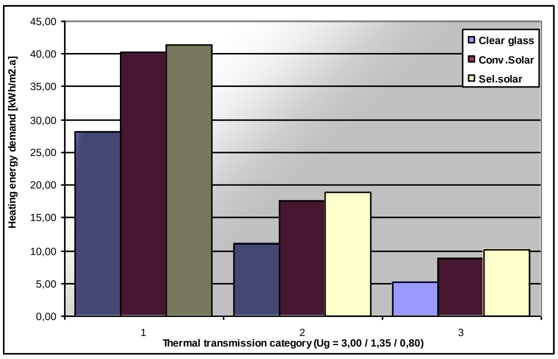

Fig. 6 Heating energy demand as function of the glazing categories

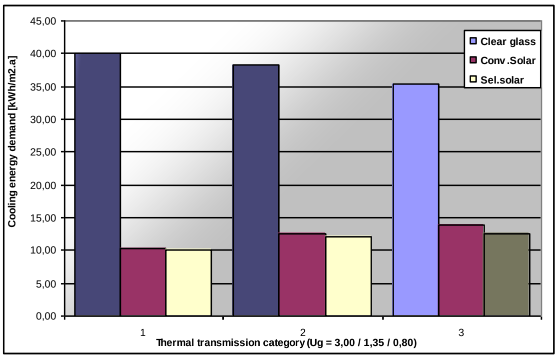

Fig. 7 Cooling energy demand as function of the glazing categories

Comparing the sum of heating+cooling energy demand the solar glasses show a clear advantage, with conventional solar glazing slightly ahead (Fig. 9).

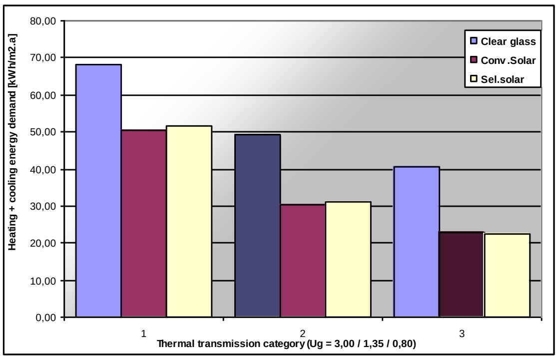

Fig. 8 The total heating+cooling energy demand

Having the lighting energy demand added (Fig. 9) the spectrally selective glazing proves to be best within all thermal transmittance categories, due to lower lighting energy demand thanks to better natural illumination of the interior.

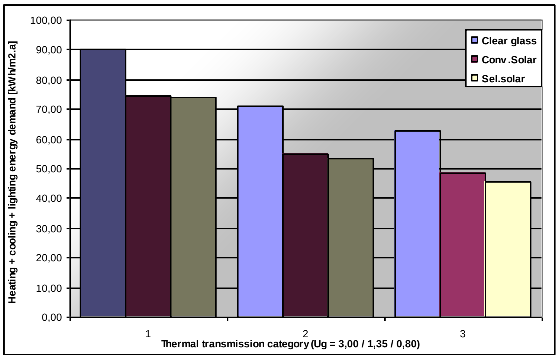

Fig. 9 The total heating+cooling+lighting energy demad

Detailed analysis of the calculated heating + cooling + lighting energy demands (Table 3) shows that the most determining 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).

Table 3 The total calculated heating+cooling+lighting energy demand of the baseline model

H + C + L [kWh/m²·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%

The total energy demand of the building sums up the energy demand of different parts of the building: external zones of different orientation and internal zones as well. When analysing the energy demands of thermal zone positions further important statements become clear. Fig. 10 shows the calculated energy demand components of a southern (D1) and Fig. 11Fig. 12 of a northern (E1) zone position (each zone position contains thermal zones one above other on 7 floors). As zones are different in area the specific energy demands are compared in [kWh/m^2.a]. The difference in g-value, i.e. using solar glazing is the most decisive factor on total energy demand in exposed Southern zones (D1 and D3), while for zones of northern orientation the glazing type (a, b, or c) has less influence within a glazing category.

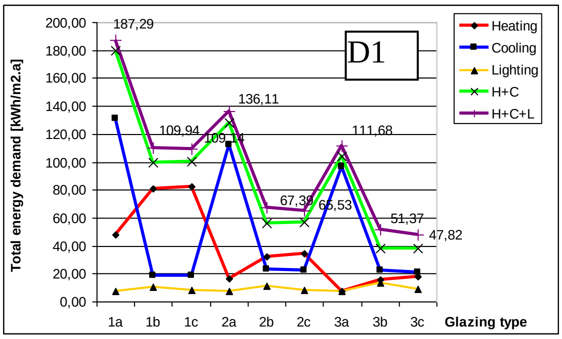

Fig. 10 Total H+C+L energy demand of 7 floors of zones D1 (South) as function of glazing type

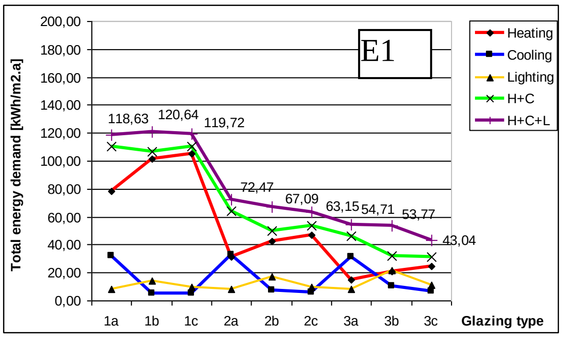

Fig. 11 Total H+C+L energy demand of 7 floors of zones E1 (North) as function of glazing type

Analysis of the simulation results by zones and by building levels also show further important findings. Fig. 12 is an example of this detailed analysis for glazing type "2a". The groups of bars represent thermal zones, the 7 bars in a group represent the floor levels of the same zone position.

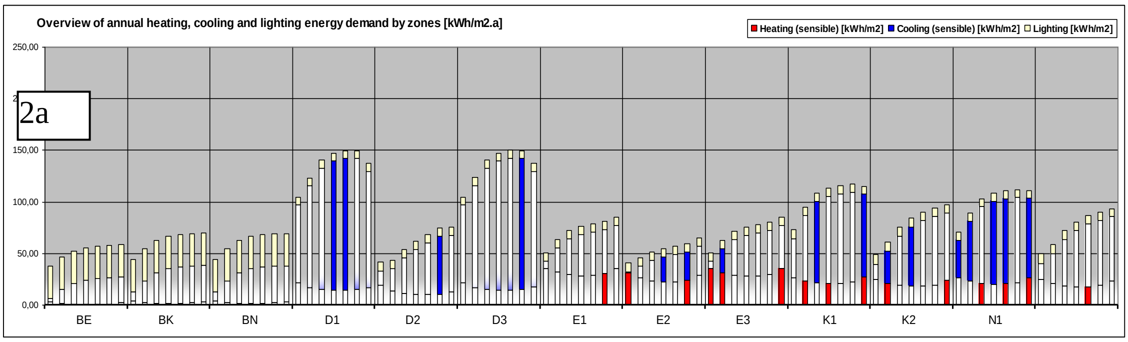

Fig. 12 Specific heating, cooling and lighting energy demands of zones with glazing 2a (bottom/red : heating – middle/blue: cooling – top/yellow: lighting).

The results prove that there is significant difference between floor levels as well. Due to the fact that floor levels are not separated by thermal insulation from each other the calculated heating demands are 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).

This difference between floors calls the attention to the need of detailed design for the heating and cooling system sizing on floors which seem to be of identical thermal surroundings and conditions but require different heating and cooling power.

The following guidelines can be phrased from the analysis of the simulation results:

- floors must not be handled as identical considering the energy demands, detailed simulation could result different capacity needs of heating and cooling on geometrically similar or identical floors;
- it shall be of consideration – harmonised with the architectural concept – to apply different glazing types on differently exposed facades.

4 Effect of different design variables of energy demand

Having the effect of key glazing parameters on energy demand evaluated on the baseline model selected parameters of the building have then been modified according the following plan:

- glazed façade ratio (5 versions),
- orientation of the building (4 versions),
- fixed external cantilever shading (4 versions),
- moveable (controlled) external blinds (3 versions),
- night-time controlled natural ventilation (3 versions) and
- internal heat storage mass (4 versions).
- Number of the versions all include the baseline model.

Running every possible combination of the above plan with all the nine glazing types would have meant and unrealistic number of simulations, with an unreasonably large volume of result data.
The result of changing one parameter at a time compared to the baseline model has been studied, only natural night ventilation and thermal mass has been analysed in combination due to the expected close interaction between the two. Altogether 28×9=252 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 trends and intensity of the effect of that specific parameter in relation with defined glazing classes. The zone-by-zone analysis gave possibility to evaluate the effect of orientation, self-shading and level (vertical) position as well.

The analysis of the effect of some key parameters is detailed as follows.

4.1. Glazed ratio of the façade without external shading

The glazed proportion of the façade makes the internal space exposed both to larger heat loss (as $U_{Window} >> U_{Wall}$) and solar heat gain. The target of this part of the research was to determine how much the glazed ratio affects the energy demand components.

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

The heating energy demand of the whole building (Fig. 14) decreases as the proportion of glass wall is getting smaller. The change is the most dramatic with glazing 1a and 1b (old solar glazings): about 2/3, while it is the smallest with glazing 3a (3-pane low-e glazing with clear glass): approximately 1/3.

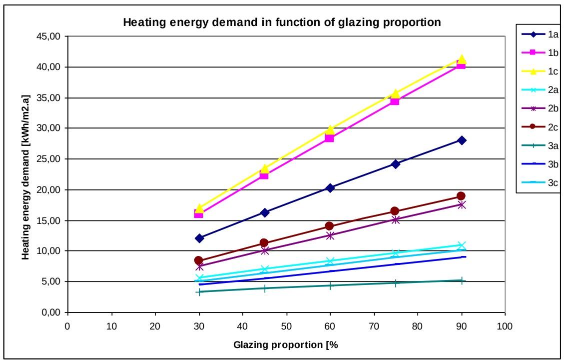

Fig. 13 Heating energy demand as function of the glass wall proportion

The cooling energy demand of the whole building (Fig. 14) decreases as well with smaller proportion of glass wall, but the change is significantly smaller in case of all solar glasses..

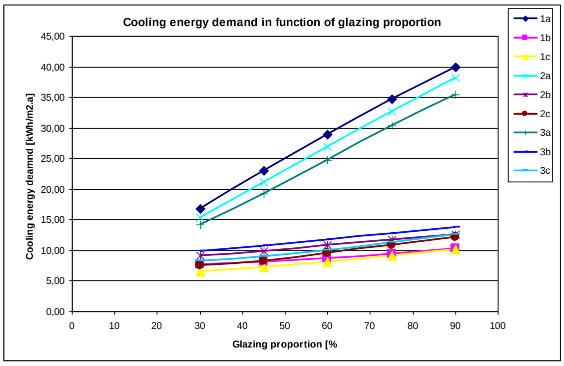

Fig. 14 Cooling energy demand as function of the glass wall proportion

The lighting energy demand (Fig. 15) shows a progressive growth with the glass surface reduction.

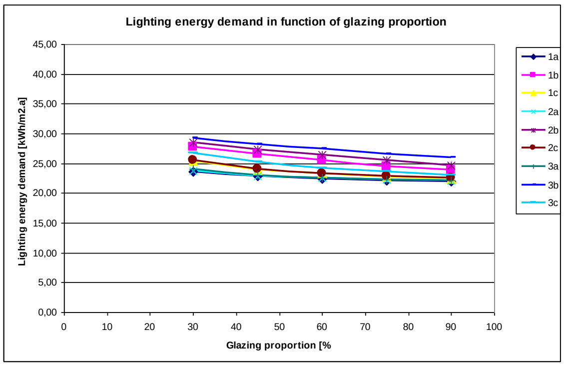

Fig. 15 Lighting energy demand as function of the glass wall portion

This results the decrease of difference in total energy demands (Fig. 16) 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 total drop in energy demand at 30% glass façade ratio is expected at 13-42% compared to the 90% proportion baseline. The smallest energy demand is achieved with glass type 3c (triple IG unit with selective glass) in the whole 30-90% range.

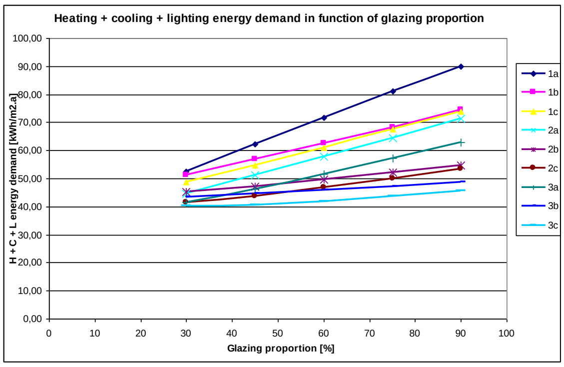

Fig. 16 Total H+C+L energy demand as function of the glass wall portion

These results show in general that the energy demand of highly glazed buildings made with conventional glazing can even be double compared to similar building with up-to-date glazing under Hungarian or similar climate. The overall energy demand grows with larger transparent façade proportion even with selective glazing, the price of full glazing compared to 30% glazed ratio is 13% increase in energy demand.

Another interpretation of these results is that much more attention is required in the glass selection process in case of large glazing proportion.

4.2. Solid overhang (fixed cantilever) shading

The above detailed results clearly show that the cooling energy demand is outstandingly high, and consequently is a decisive component of the total energy demand in thermal zones behind the exposed southern (D1 and D3), eastern (K1) and western (N1) façades under Hungarian and similar climate. Reducing the cooling demands therefore seems to be the logical way of reducing the total energy demands.

Fixed cantilever overhang shading above the glazed surface is known as an effective way of solar protection for a façade oriented close to South, which at the same time does not exclude gain form the winter time low inclination solar radiation. The effectiveness 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 [6 - p13.; 64-67].

However, as a simplified case, the effect of fixed horizontal cantilever shadings all around the building of 50, 100 and 150 cm projection has been studied in comparison with the baseline model. This solution can be found on existing buildings for the sake of a uniform architectural appearance.

The heating energy demand (Fig. 17) increases by 5-29% with larger shading projection. This calls the attention to the importance of optimum projection size and of vertical positioning compared to window fields.

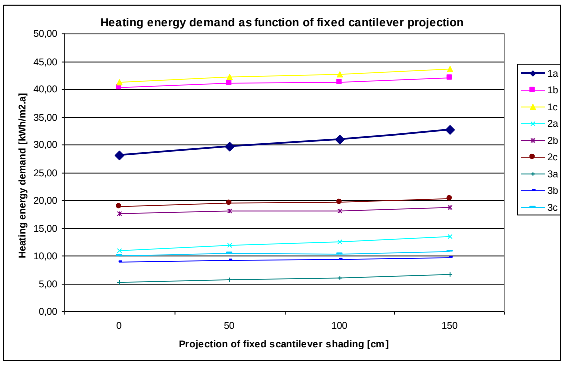

Fig. 17 Heating energy demands as function of fixed cantilever shading projection

A model shot taken in the late morning hours of a January day (Fig. 18) visualize the background of this heating demand increase: partial shading on the southern façade and almost complete shading on the eastern surfaces.

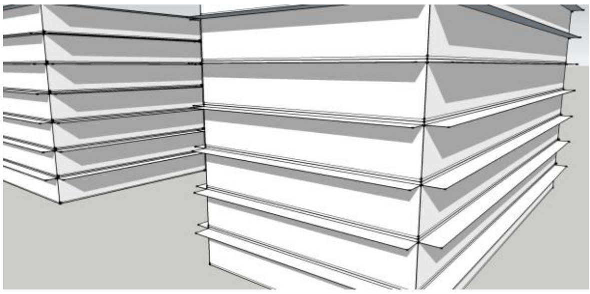

Fig. 18 Shadow projected on eastern and southern façade in a January late morning situation

The cooling energy demand (Fig. 19) is decreased more spectacularly, the drop is 43-51% 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).

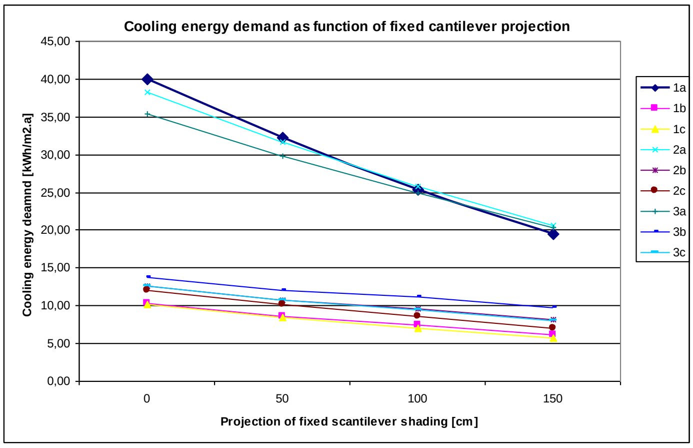

Fig. 19 Cooling energy demands as function of fixed cantilever shading projection

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

The sum of the heating and cooling energy demands (Fig. 20) shows that advantage is kept in case of clear base glasses (23-33%) but is minor with solar glazing (4-17%).

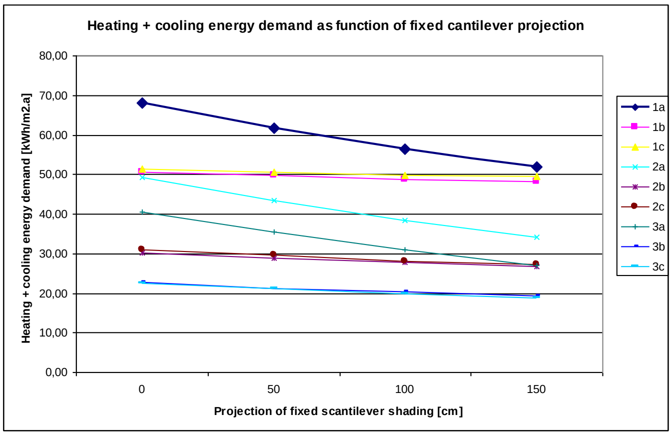

Fig. 20 Heating + cooling energy demand as function of fixed cantilever shading projection

This is even more so when adding lighting energy demand on top, energy demand reduction of 17-21% can be achieved at clear glazings and only 1-6% at solar glazing types (Fig. 21).

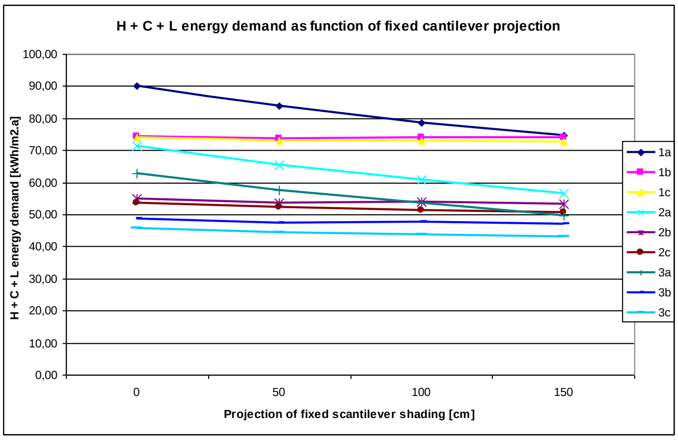

Fig. 21 Total H+C+L energy demand as function of fixed cantilever shading projection

It can be read from the results that the total energy demand of a building with fixed cantilever shading and with clear glazing is almost identical to ones with unshaded solar glasses.

The 150 cm projection of fixed horizontal shaders results an energy demand which equals to 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).

It is worth mentioning that fixed horizontal shaders might have additional values over the shading property itself. These could contribute to the non-glare interior natural lighting conditions and could serve as working platform for the external cleaning of the glazed façade.

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

4.3. Automatically controlled external shading louvers

The glazing type and the glazing proportion are static values, and the effect of fixed shading varies only with the path of the Sun. More adaptive solutions for shading expectedly result smaller losses in the winter heating season and larger spares in the summer cooling period.

Controlled variable shading devices could mean a good design option to reduce the cooling demand while keeping the solar gain when needed.

The variable shading can be operated by different control strategies [7], however predicting the results is less certain due to the possible interaction (manual control) by the user of the building [8] for the sake of different lighting conditions, view or privacy needs or other priorities.

The effect of an automatically controlled external shading has been studied. The shading criteria was to exceed 50 or 100 W/m^2 global radiation intensity and presence of cooling demand in the previous time step (no visual comfort factors were included). The louvers in the model are white and positioned in 45°.

The heating energy demand (Fig. 22) slightly increases with the shading (5-11% at clear glazings and a minor 1-2% at solar glazing types). This loss could probably be avoided with fine-tuning the control strategy.

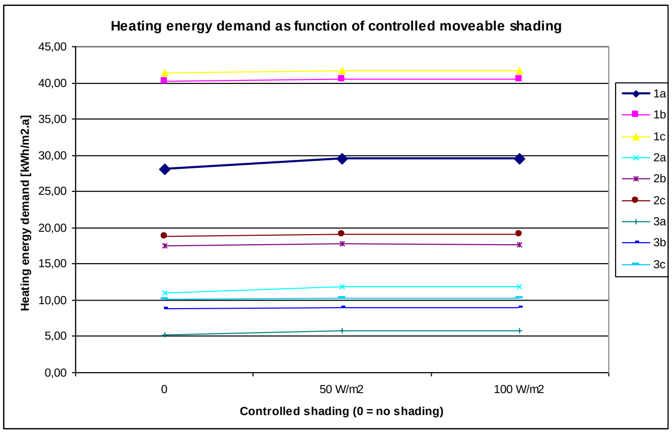

Fig. 22 Heating energy demands as function of controlled shading (0 represents no shading)

The simulation results a dramatic cut in the cooling energy demand (Fig. 23) in case of clear glasses type a) (50-74%) but still considerable in case of solar glazing types (24-35%) types b) and c).

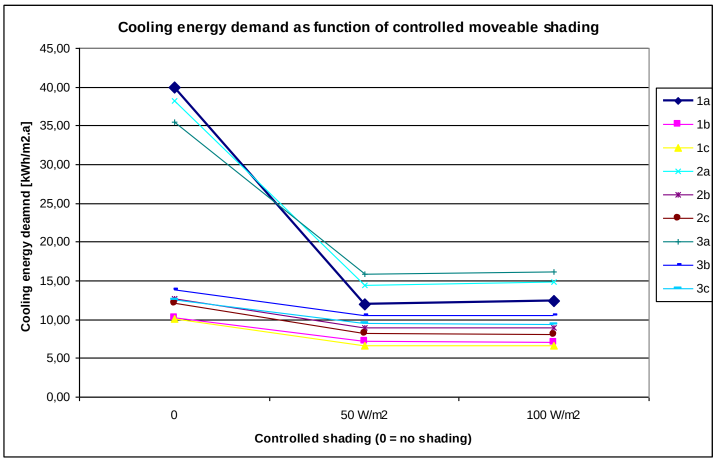

Fig. 23 Cooling energy demands as function of controlled shading

This decrease of this scale does not only mean lower running cost but – as smaller built-in cooling capacity is enough – it reduces investment cost as well. These factors together can bring a short return of the price of the automatically controlled shading installation.

There is a of course a small increase in the lighting energy demand (3-8%), this could be partly avoided by louvers fields divided for control or a light-shelf kind of design.

The total heating + cooling + lighting energy demand (Fig. 24) shows that controlled external shading cannot bring much advantage with solar glazing types but the decrease in total energy consumption is significant (28-30%) in case of clear glass types. It is also important to note that clear glazing with controlled shading shows equal or better results than solar glazing solutions do.

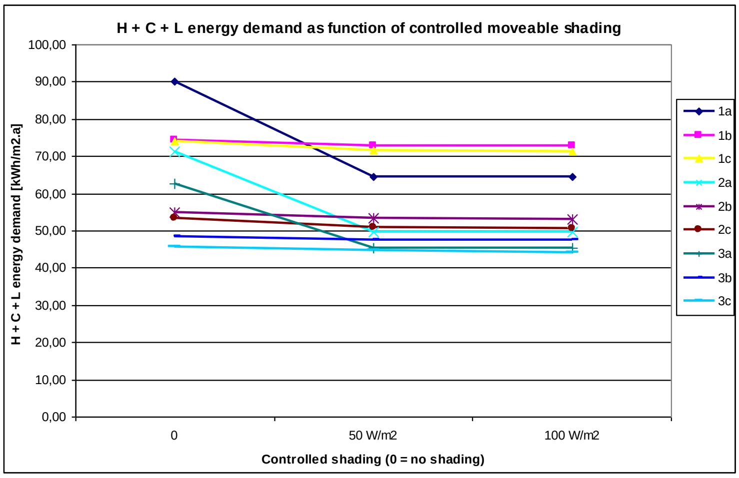

Fig. 24 Total H+C+L energy demand as function of controlled shading

Energy demands of the baseline model and the controlled external shading solution is compared in Fig. 25 and Fig. 26 as function of glazing type for a zone exposed to South. The total energy demand proves to be the lowest with clear glazing types (a) compared to solar glazings (b and c) of the same glazing category when using controlled shading louvers.

While the controlled external shading has not brought mentionable decrease in total energy demands for the whole building (Fig. 24) it is clearly seen that in zones behind a façade exposed to south it reduces energy demands for all glazing types (Fig. 26).

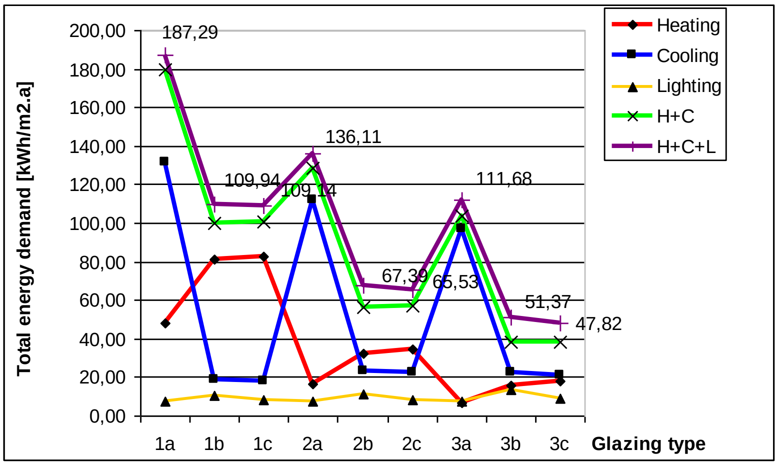

Fig. 25 Total H+C+L energy demand of an exposed southern zone (D1) as function of glazing types for the baseline model

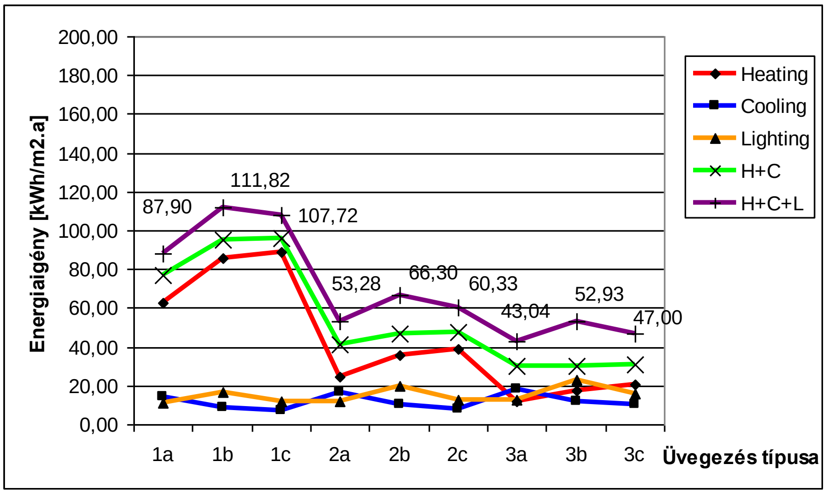

Fig. 26 Total H+C+L energy demand of an exposed southern zone (D1) as function of glazing types for controlled external shading model

4.4. Internal thermal mass of the building

Storage and recovery of heat energy can largely contribute to temperature stability of building and to less interaction required from the mechanical (heating and cooling) systems of the building.

Evaluation of higher category office buildings erected in the past few decades shows that due to guiding factors like hiding installations, providing space for floor cabling, using easily convertible internal divisions and finishes in order to easily follow demands of the tenants, etc. the active thermal mass has virtually disappeared. Suspended ceilings, false or hollow floors, light-weight partitions, curtain walls are typical, all of small weight, and partly made of thermally insulating materials.

Different definitions and calculation methods of thermal mass exist but as rule of thumb layers till the depth of $R=0.15\ m^2K/W$ thermal resistance can be taken into account as active for daily

thermal cycles. Thermal capacity of most silicate based construction materials is around 0,84-0,95 kJ/kg.K. The following table (
Table 4) shows a few typical values of these structures.

Table 4 Effective thermal mass of a few typical light weight finishes (* thermal capacity of timber is about 3 times larger)

Material / Structure	Density [kg/m^3]	Conductance λ [W/mK]	Thickness at R=0,15 m^{2}K/W	Thermal M [kg/m^2]
Suspended ceiling (mineral fibre)	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)	12,1×3≈36*
Pearlite concrete	600	0,20	30 mm	18,0
Gypsum board – actual thickness 2×12,5 = 25 mm	---	0,23	(34,5 mm)	18,0

The baseline model of the simulation was defined with a conventional 400 kg/m^2 thermal mass (specific for net floor area). In order to study the effect of smaller thermal mass on the energy demand simulations have been run with 200, 100 and 20 kg/m^2 values.

Both heating (Fig. 27) and cooling (Fig. 28) energy demand becomes significantly higher with the decrease of thermal mass. The calculated growth in energy demand in heating is 9-73% and in cooling is 17-60%. Changes in thermal mass obviously have no effect on lighting energy demands.

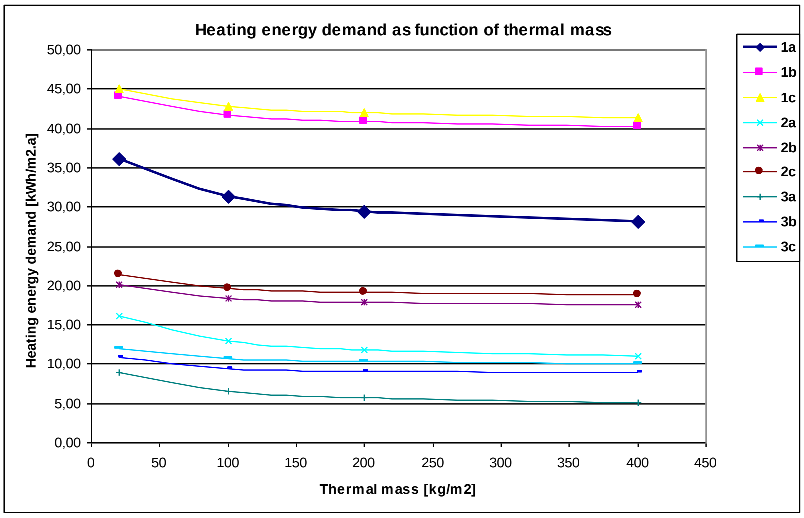

Fig. 27 Heating energy demand as function of thermal mass

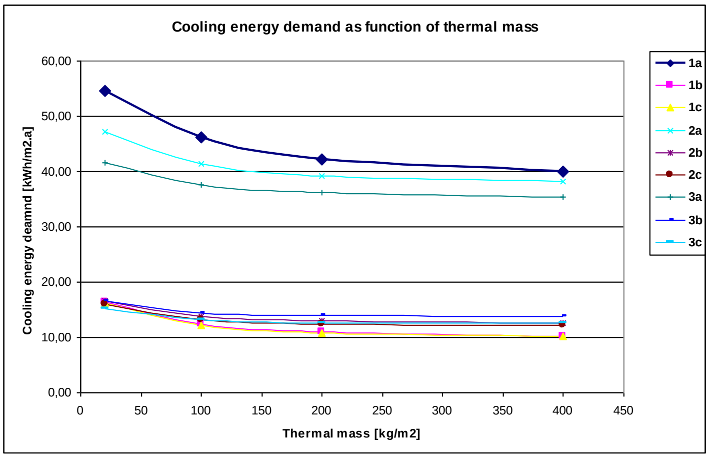

Fig. 28 Cooling energy demand as function of thermal mass

The total energy demand (Fig. 29) increases by 16-25% in case of clear glazing and by 10-13% in case of solar glazing types. It is clearly visualized that this increase is becoming progressive under 200 kg/m^2 thermal mass.

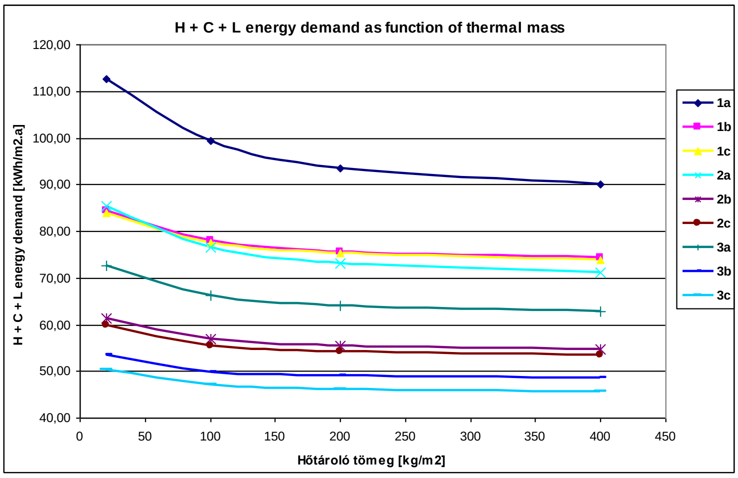

Fig. 29 Total energy demand as function of thermal mass

The positive effects of larger thermal mass of conventional building structures have long been utilized but seemingly been forgotten for the sake of some modern concepts and technologies.

Results of the simulation shows that the design concept of light-weight finishes needs to be revised and heavy components of the building have to be let exposed (floor structure on the first degree, but parapet wall can also be mentioned). This requires conceptual changes in interior design and customer demand as well, becoming more conscious of energy issues.

Thermo-active building systems and PCM components (phase change materials) [9] also utilize the principle of larger internal active thermal mass in a sophisticated way.

4.5. Night-time controlled natural ventilation

A further tool of energy efficient solutions is natural ventilation, which can be limited in open space, higher category and down-town public buildings due to draft, strict requirements for temperature and air humidity and air and noise pollution respectively. However, spaces overheated by daytime solar gains and internal heat loads by the function can effectively be cooled and prepared for the next day by controlled natural night ventilation [10]. The Hungarian and similar continental climate has longer periods of the year especially in spring and autumn which provide thermal comfort of the interior by natural ventilation and summer nights are mostly cool enough to lower the temperature of buildings' body.

The structural solutions for controlled ventilation are complex and costly, requiring automated windows, baffle panels and sophisticated building management systems. Natural ventilation is found to be effective over a rate of n=4 h^{-1} [11 - p159]. In order to study the effect of natural night ventilation simulations with exchange rates n=2 and 4 h^{-1} have been carried out under the control conditions given in Table 5. The research has covered the combination of night ventilation and thermal mass cases. For reasons of extent the effect of controlled night ventilation is introduced in this article only for 400 kg/m2 thermal mass.

Table 5 Night-time natural ventilation controls set for simulation

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

Fig. 30 shows how internal sensible and air temperatures change in a summer week period compared to thermostat setpoints determined by office temperature requirements.

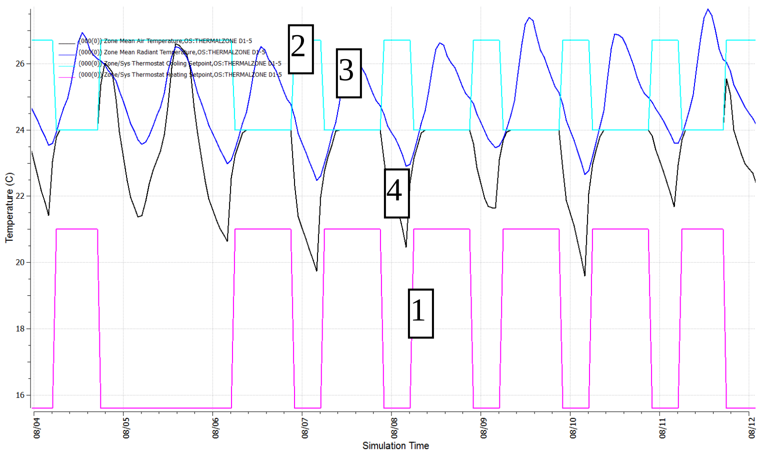

Fig. 30 Temperature diagrams of a summer week with controlled natural night-time ventilation (1-purple and 2-cyan: thermostat setpoints; 3-blue and 4-black: indoor sensible and air temperature)

Fig. 31 visualizes the cooling power demands for the same summer week period, showing the significantly lower demand in case of night ventilation feature.

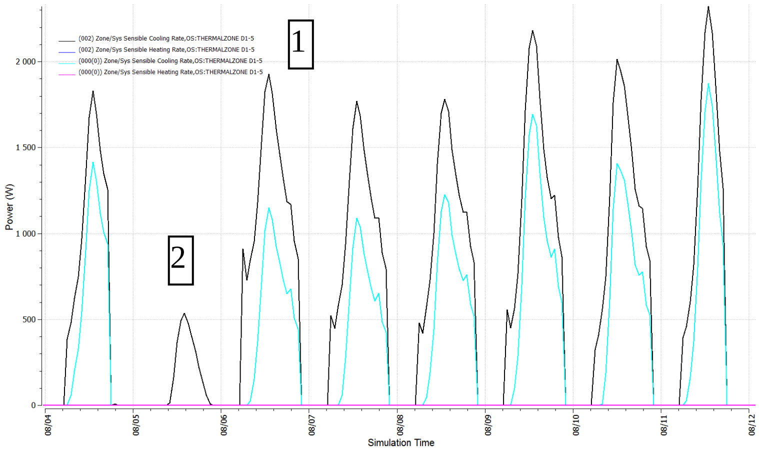

Fig. 31 Cooling power demand of the same period (1-black: no ventilation; 2-cyan: controlled night-time natural ventilation)

Comparing the energy demands the required cooling energy is 34-79%(!) less with night ventilation (Fig. 32). The more important benefit is experienced with solar glazing types.

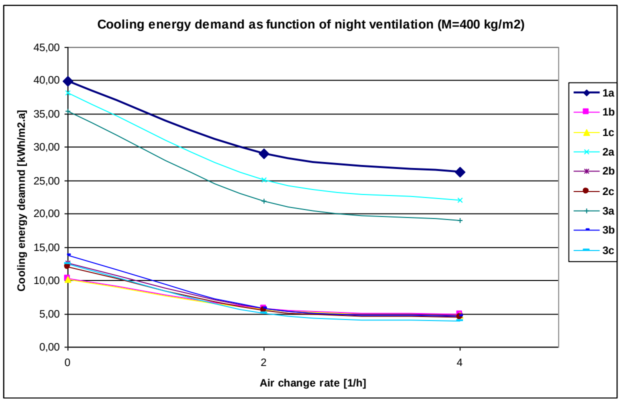

Fig. 32 Cooling energy demand as function of controlled night-time natural ventilation intensity

The total calculated heating+cooling+lighting annual energy demand can be reduced by 15-26% in case of clear glazing, and by 5-16% in case of solar glazing types (Fig. 33). 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).

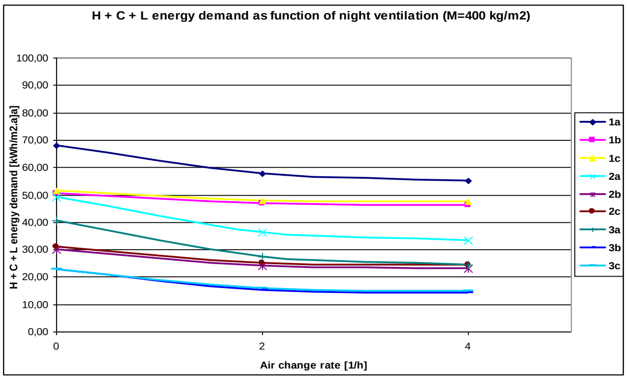

Fig. 33 Total H+C+L energy demand as function of controlled night-time natural ventilation intensity

It is also recognised that n=2 h^{-1} already brings important changes in the energy demand, which can be reached in average relatively easily by natural ventilation.

5 Conclusions

Glazing, this architecturally ever exciting transparent material for building skin, plays an important role in public and office type buildings' architecture.

Internal climate and running cost of buildings with fully glazed facades is highly affected by the energy balance related to the transparent building skin. Heating and cooling energy demand of such building can be controlled by architectural and building constructional tools. Decisions on glazing, shading, ventilation and thermal mass solutions have consequences not only on the annual heating, cooling and lighting energy demand but the sizing of the heating and cooling installation.

Components have been analysed in the paper separately, mentioning a few interactions as well. It is clear from the simulation results that no best or worse configuration exists, looking for the optimum solution requires the case-specific study of several design options and further their combination. Effectiveness of solutions is also climate specific.

Controlled solar energy gains and moderate energy losses result low energy buildings. This equilibrium is sensitive; therefore computer energy simulation can lead to reliable comparison of different options. The study introduces figures on the effect of changing certain design parameters compared to a selected baseline model, confirming how significant these values can be. These values can be interpreted on Hungarian and similar climates.

Reductions due to changes in annual energy demand and required size of mechanical installation can then be analysed together with the investment cost of the certain architectural or building constructional solutions and final decision can be concluded by the Client and the architect & engineering team. Optimum solutions for developers, building owners, the users and last but not least the environment can only be worked out as a harmonised combination of decomposed elements, under a holistic approach and close cooperation between professionals.

Acknowledgements

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