ANALYSIS OF IMPACT OF SELECTED GLASS UNITS FOR ENERGY CONSUMPTION AND THE RISK OF OVERHEATING IN THE SCHOOL BUILDING USING SIMULATION

Miloslav Bagoňa[1], Dušan Katunský[1], Martin Lopušniak[1] and Marian Vertaľ[1]
[1]TU Košice, Faculty of Civil Engineering, Kosice, Slovakia
Vysokoskolska 4, 042 00 Kosice, www.svf.tuke.sk

ABSTRACT

The insulation glass unit as a part of a window plays a key role in the design of low energy buildings. The paper focuses on a selection of glass units and the analysis of their contribution to the design of a low-energy school in Slovak climate conditions. The analysis was performed using "Designbuilder" software. The glass units were used in simulations with an emphasis placed on maximizing heat gains while minimizing heat losses in winter and minimizing heat gains in summer. Results show heating demand is adequate but a relevant problem is caused by summer overheating which needs to be addressed.

INTRODUCTION

Insulation glass unit (IGU), which is normally part of either a window, door or facade construction, is a key factor influencing the energy balance (Fang et al., 2007) and the state of the internal environment of buildings (Sanyogita et al., 2009, Kalousek et al., 2006). The number of manufacturers of IGU and their range of products is currently high. The appropriate IGU selection process is sometimes complicated or even problematic due to requirements that we place on the IGU. For example: large solar heat gains versus low losses in winter or minimizing solar gains in summer while permitting internal daylight illumination. This difficulty may rise even further by adding requirements that the IGU should fulfill. Examples could include additional acoustic, security, fire safety etc.

Simulation is currently the best tool for the analysis and verification of the design and evaluation of IGU. It permits results from several types of IGU, as well as taking into account the dynamics of the external environment (Taylor et al., 2009). Application of dynamic calculations allows for a more precise analysis of the appropriateness of the IGU's proposal. Considering the wide number of possible combinations of glass, it is necessary to carry out the selection of appropriate types of IGU before simulation. The selection of IGU has to reflect the local requirements (for example standards) as well as the local climatic conditions. Appropriate selections lead to shorter simulations and reduction in analysis time. Such a procedure is particularly appropriate for the early stages of building design.

A primary requirement for the refurbishment was to reduce the energy intensity and to improve the indoor environment. Our job was to analyze the effects of the selected IGU in accordance with the primary requirements for the refurbishment of the building. The selected types of IGU reflect the technological progress, current status and market supply in Slovakia. Whereas the transparent constructions are an important area of the envelope, selected types of IGU were subjected to computer simulation.

BUILDING

Original design and present state

The school was built in 1966. During its lifetime no structural repairs were carried out. For this reason, the building is in a state of disrepair. The most serious shortcomings include the mould rise, condensation of water vapor on building surfaces, excessive infiltration through air leaks and joints, summer overheating and high energy demand (165 MWh).

The original structure was designed for conditions that previously did not require energy savings. Comparisons of the heat transfer coefficient of existing structures with the design standard requirements (Slovakian) for the current structures are specified in Table 1.

Table 1
Thermal properties of the original structures and their comparison with actual standard requirements regarding thermal protection

Structure	U - W/(m^{2}K)	
	Original design	Standard requirement
Envelope	1.36	0.32
Roof	2.61	0.2
Slab on ground	1.2	0.4
Windows	2.9	1.5
Doors	3.7	2.0

The building was originally designed for normal learning (writing, reading) at an elementary school level. The building will continue to serve its current function after refurbishment. Individual classrooms capacity is set at 20 to 25 students per class.

Concept

A comprehensive refurbishment concept was proposed so that the building would be considered to be a new construction because the current technical condition of the building is in disrepair.

Figure 1 Floor plan, 1st floor and 2nd floor

However, it was not our intention to design a building that only meets the current requirements for thermal protection of buildings. The aim is to design a concept that goes beyond current requirements for thermal protection of buildings.

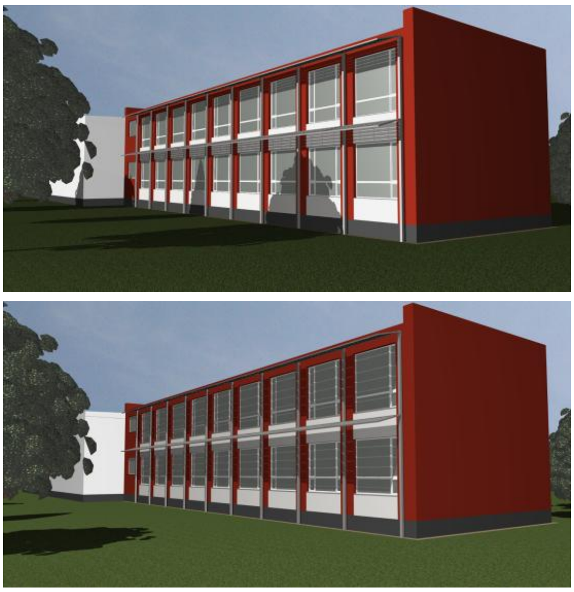


Figure 2 Main facade 1st December 12:00; 1st May, 12:00

The concept of the building's refurbishment was proposed in accordance with the principles and requirements for the design of passive houses - PH, (Feist, 1993). The recommended values of thermal protection for PH are considered for all heat exchange structures (Table 2). This concept of the building creates conditions for fulfilling the vision of a nearly zero net energy building - nZEB (Kurnitsky et al., 2011). Implementation of this vision is expected within the EU by 2020.

The refurbishment of a school building is the object of the design. The building is designed as a free-standing two floors building without a basement. The floor plan is rectangular (Fig. 1). The main façade (southeast) incorporates shading structures with built-in photovoltaic panels. This structure also serves as protection against overheating in summer (Fig. 2).

The minor façade (northwest) is minimalistic with window openings as the dominant feature (Fig. 3). Both side facades are without windows.

Figure 3 Minor facade

Structures

The original envelope will be insulated from the outside with 200 mm thick thermal insulation. The new structures of the envelope are designed from porous concrete blocks 250 mm thick insulated with 200 mm thick insulation.

Table 2
Thermal properties of designed structures and their comparison with requirements for PH

Structure	U - W/(m^{2}K)		Area m^2
	Design values	PH requirement	
Envelope 1	0.17	0.15	310.8
Envelope 2	0.13	0.15	211.9
Roof	0.12	0.1	397.3
Slab on ground	0.126	0.15	397.3
Windows	0.8*	0.8	156.3
Doors	0.8*	1.0	14.4

*This value is indicative. Because the IGU has changed the final value U_w is the result of the calculation procedure according to EN ISO 10077 for each window and IGU.

The roof will be designed with 300 mm added insulation on the outside. Thermal insulation of 200 mm thickness will be added to the original slab on the ground.

All original windows will be replaced with new ones. The design value for the new window frame is U_F < 0.79 W/(m^{2}K). IGU for windows is discussed further.

HVAC

The building will be heated by hot water radiators. The effectiveness of the heating system is 90%. Heating water for the heating system is proposed by using electricity and is situated in the technical room which is located situated on the second floor.

Mechanical ventilation with a heat recovery averaging 80% efficiency is proposed as part of the refurbishment of the building.

The photovoltaic panels installed on the roof as well as the shading structure should contribute to the improvement of the overall energy balance.

GLAZING

Requirements for selection

The selection factors for the building design and selection process were based on the determination of the current requirements of this type of building. Selection factors are as follows:

- Low energy demand of buildings, mainly due to the building being located in a cool climate region with frequently low temperatures during the winter;
- Ensure the sufficient transfer of solar energy into the building during the winter;
- Maximize the transfer of the visible spectrum of sunlight into the interior of the building.

For the given three selection factors the following quantifiable physical properties of IGU were selected:

- Energy demand - the evaluation variable is the heat transfer coefficient of the IGU U_G W/(m^{2}K), from which the set requirement of the selection process was $U_G \leq 0.9$ W/(m^{2}K).
- Passive solar gains - the evaluation variable is the solar factor g (%), from which the set requirement of the selection process was g ≥ 50% (requirement for PH is g > 50%);
- Daylighting - the evaluation variable is the light transmittance through IGU τ_V (%), from which the set requirement of the selection process was $\tau_V \geq 65$ (%).

Selection

When making the selection, we focused IGU that reflect the technological progress but also availability of the Slovak market. By choice we included double, triple and quadruple IGU. To explain the idea may indicate whether the change in the design and use of double IGU over triple or quadruple IGU glass systems brings advantages or disadvantages in the field of building physics and whether this global trend is beneficial in temperate climates with cold zones.

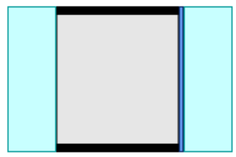
Determination of IGU parameters

We used CALUMEN II software to calculate input values of thermal, energy and optical properties of the selected IGU which were incorporated into the simulation program. This algorithm recommended by EU standard to calculate the following characteristics. To calculate the heat transfer coefficient U_G W/(m^{2}K) algorithm according to EN 673 was utilized.

For the calculation of the solar factor g (-), the visible light transmission through IGU τ_V (%) and other additional properties an algorithm from EN 410 was used. Selected IGU have the following basic characteristics.

Specimen #1 (Table 3): double IGU with a total thickness of 18 mm composite 4-10-4 with a krypton filled, Low-emissivity layer positioned 3rd. This system was designed to test the threshold solution of the IGU for a PH standard - which indicates its U_G-value. Advantage includes low permeability structural demands on the systems frame.

Table 3 Technical, thermal and optical properties of specimen #1

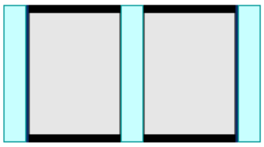
Position	Glass 1	Glass 2
Gas		Krypton 95%, 10 mm
Coating		Planitherm ONE
Glass	Planilux 4 mm	Planilux 4 mm
U_G	0.91 W/(m^{2}K)	
τ_v	71%	
g	50%	
Spacer	TGI	

The minimum requirement that qualifies for passive houses must conform to values of U_W 0.8 W/(m^{2}K). The resulting values of U_W < 0.8 W/(m^{2}K) will not satisfy with this IGU. This is considered a threshold solution.

It is labeled G1 for the purposes of this paper.

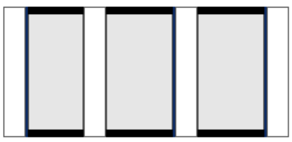
Specimen #2 (Table 4): triple IGU with a total thickness of 44 mm composite 4-16-4-16-4 with an argon filled; Low-emissivity layer positioned in the 2nd and 5th layer. Reasonable price and acquiring appropriately balanced the overall parameters which met the requirements. For the purposes of this paper, it is labeled as G2 solution.

Table 4 Technical, thermal and optical properties of specimen #2

Position	Glass 1	Glass 2	Glass 3
Gas		Argon 95%, 16 mm	Argon 95%, 16 mm
Coating			Planitherm ULTRA N
Glass	Planilux, 4 mm	Planilux, 4 mm	Planilux, 4 mm
Coating	Planitherm ULTRA N		
U_G	0.57 W/(m²K)		
τ_v	70.9%		
g	50%		
Spacer	TGI		

Specimen #3 (Table 5): quadruple IGU with a total thickness of 50 mm composite 4-10-4-12-4-12-4 with a krypton filled; Low-emissivity layer positioned 2^{nd}, 5^{th} and 7^{th}. This system is at the opposite range and counters the. In order to qualify for the g - value and τ_V low-iron glass is used in this option to maintain light transmittance at highest levels For the purposes of this paper, it is labeled as G3.

Table 5 Technical, thermal and optical properties of specimen #3

Position	Glass 1	Glass 2	Glass 3	Glass 4
Gas		Krypton 95%, 10 mm	Krypton 95%, 10 mm	Krypton 95%, 10 mm
Coating			Planitherm MAX	Planitherm MAX
Glass	Diamant 4 mm	Diamant 4 mm	Diamant 4 mm	Diamant 4 mm
Coating	Planitherm MAX			
U_G	0.35 W/(m²K)			
τ_v	66.8%			
g	58%			
Spacer	TGI			

SIMULATION

Boundary conditions

Boundary condition data for the simulation were considered from IWEC's database for the site in Košice. The location is characterized by an outside air temperature difference $\Delta\theta_e$ = 54.3 K, the maximum value $\theta_{e,max}$ = 31.2°C and the minimum value $\theta_{e,min}$ = - 23.1°C.

In terms of global radiation, the following characteristic values $I_{g,m}$ = 165 W/m², $I_{g,max}$ = 1004 W/m² are presented. Courses of the external temperature and global radiation are shown in Figure 8.

Calculation

DesignBuilder simulation software was used for computer simulation. The building was designed as a two-zone model. This concept is also consistent with mechanical ventilation and heating design, which was proposed for the building.

The specified building operating mode corresponds to the real operation of the building. The School building is characterized by the presence of students from 8:00 to 15:30 weekdays. The presence of students also formed the only internal heat source (94.5 W/person) considered in the simulation. The school year lasts ten months. For the calculation, only holidays in the summer months of July and August were considered.

For the building ventilation is n = 18 m³/p. This value was set according to the national standard. The proposed number of occupants (predominantly children at ages of 6 to 15) is 150 + 6 teachers. For such a defined number of people a threshold value for ventilation, n = 1.2 1/h is established.

The building design also incorporates the opening of windows. However, for simulation purposes only the proposed modes of ventilation were considered, as they enable better mutual comparison of results. Operating modes of ventilation are shown in Figure 9. Three modes of operation are considered for the operation of ventilation:

- Mode 1: n = 1.2/(0.3 – standard requirement) 1/h; October, November, December, January, February, March, April, May,
- Mode 2: n = 1.2 1/h, June, September,
- Mode 3: n = 0.3 1/h, July, August, Weekdays.

Two operating modes are considered for the operation of heating with the required state of the internal environment:

- Mode 1: θ_{ai} = 20°C, September, October, November, December, January, February, March, April.
- Mode 2: θ_{ai} = no requirements, May, June, July, August

The compact HVAC definition model was applied for the simulation of HVAC systems.

For simulation has been conceived air-tightness of the building n_{50} = 0.6 1/h, (requirement for PH).

RESULTS

The simulation results focused on two fields. The first chosen field was the evaluation of the impact of IGU on the risk of overheating. The second field involved the analysis of the impact of selected IGU on the heat demand.

Summer overheating

June was selected for evaluation as the critical month since the building is not used in July and August. The interval at which the indoor air temperature $\theta_{ai,max}$ (°C) was exceeded was used as a criterion for the evaluation. An evaluation indicator is the frequency of the set limit temperature exceeded in unit hours. The following values were chosen for the maximum indoor air temperature: $\theta_{ai,max}$ = 25°C, $\theta_{ai,max}$ = 26°C and $\theta_{ai,max}$ = 27°C. Those temperatures correspond to the most reported and required indoor air temperatures in summer.

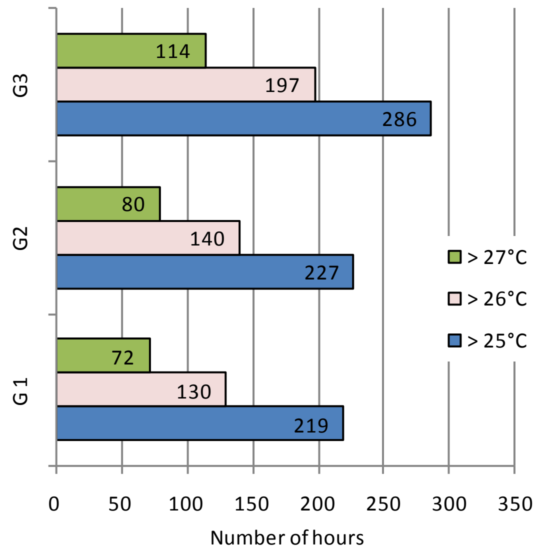


Figure 4 Number of hours over limited values 25°C, 26° and 27°C in June

For each IGU solution the setting values of $\theta_{ai,max}$ for each exceeding frequency is shown in Figure 4. Courses of internal air temperatures for G1 solution and G3 solution are shown in Figure 10. From the picture it is clear that the worst solution is IGU G3. Even in the best case (G1) exceeded 25°C by as much as 30% of the time. This result cannot be accepted as satisfactory.

In this analysis the solar factor was one of the selection process factors. The proposal for PH requires g > 50%. This requirement comes from maximizing solar gains, which help reduce energy demand. The concept of PH was intended primarily for family houses, respectively residential buildings. However, the concept is currently used for types of buildings other than housing. This affects the design requirements as well as requirements for the indoor environment. The operation of the school building is a good example. In the case of the school we expect to operate between 7:00 to 17:00 Monday to Fridays. Population density is estimated at 0.2 person/m^2. This high concentration creates a large internal gain. As simulation results show (Fig. 5) the internal heat gain from the occupants is greater than that caused by solar gain through the glazing. In the case of the family house the opposite holds true. The combination of large internal gains and gains from solar radiation logically leads to overheating in summer. The tendency to obtain sufficient solar gains for residential buildings is offset in the school due to the internal heat gain as result of high occupancy. As a consequence the reduction of the original prerequisite of g > 50% could lead to minimizing the risk of overheating.

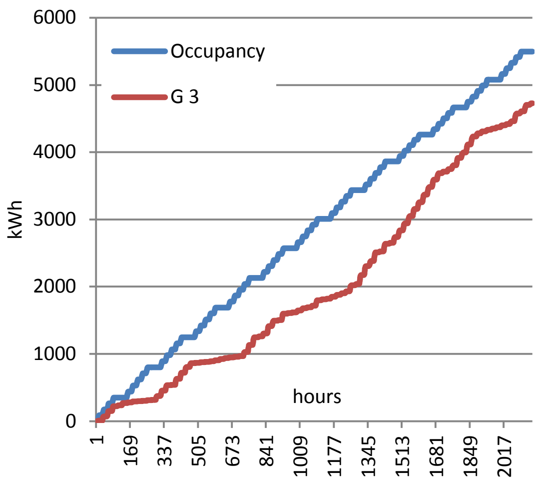


Figure 5 Occupancy gains (kWh) and solar gains from G3 IGU (kWh) for January to March

Probably, none of the other types of IGU (with significantly lower solar factors) could avoid radical changes in indoor air temperature courses in summer. Lowering the solar factor will reduce cooling demand. It will also help to design an IGU with better U_G, which assists in the reduction of heat loss in winter. This would act as partial compensation for reduced solar gain.

It follows that it is more suitable to treat the summer overheating problem using other means like the modification of IGU. Unwanted heat gains need to be treated by an appropriate design of shading structures or an appropriate operation of the HVAC system.

A suitable proposal of a shading structure can lead to a satisfactory reduction in summer overheating (Lopušniak, 2010). This only applies when $\theta_{e,max}$ < 28°C (Lopušniak, 2007). This is not because the shading in itself is insufficient but that high day time temperatures typically result in high night time temperatures and the building is no longer able to cool itself sufficiently for the next day. Buildings such as PH have excellent thermal insulating properties, which do not permit natural cooling at night. Reducing overheating at high ambient temperatures is feasible only by use of appropriate HVAC systems. However, when dealing with shading structures it is necessary to address its role in conjunction with the proposal and the assessment of daylight.

Heating demand

From figure 6 and 7, it is clear that the most preferred solution is G3. This IGU provides maximum solar gain for the smallest thermal loss. The result follows a reflection of the best quality properties for IGU from required evaluation criteria. The difference between the best and worst solutions is 37%.

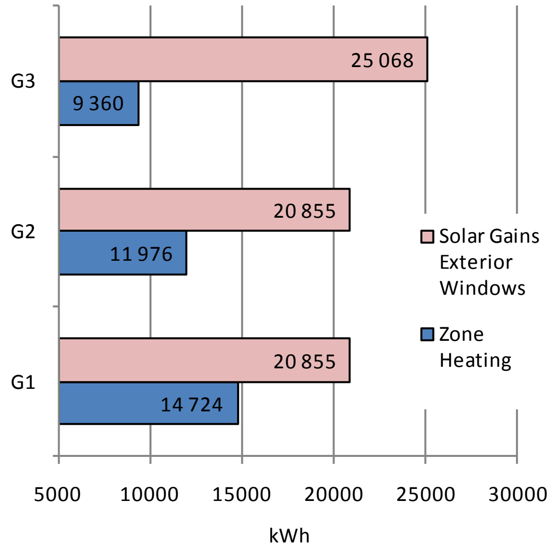


Figure 6 Zone heating requirement and Solar gains through windows in annual regime

In real terms, this difference represents € 1,095 per year (Table 6) over the cost of energy for heating. The financial contribution of the solution clearly points out the economic disadvantage in terms of invested money for heating costs. There are other aspects besides cost efficiency to take into consideration. It is necessary to accept a complex file of the requirements.

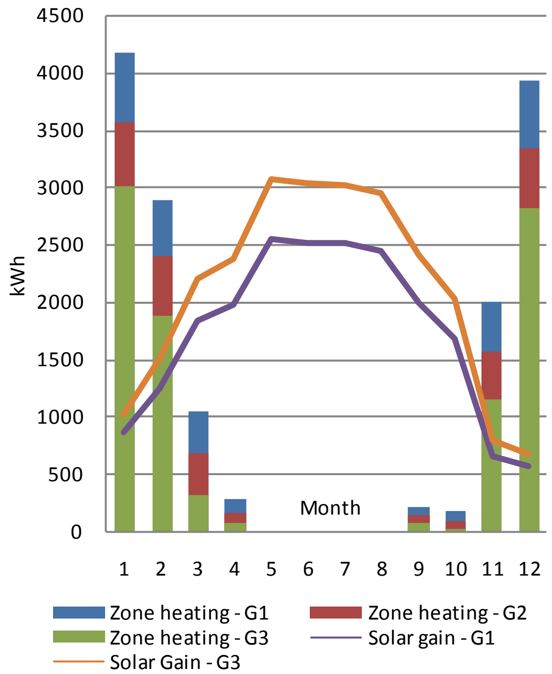


Figure 7 Zone heating demand and Solar gains through windows in monthly regime

For example, double IGU often causes condensation on the inner surface of the glass in Slovak conditions (Bagoňa, 2005). This phenomenon is considered unacceptable. That is why the use of triple IGU is a very common in practice. If we were to include the economic requirements into the selection process the end result would probably differ from the actual selection.

Taking all of the data into account G2 (specimen 2) achieved optimal results for the solution. The result is a balanced solution between energy savings, the risk of overheating, economy efficiency and other requirements applied to the IGU. The G2 is a complete solution that meets predefined criteria.

Table 6 Comparison of cost for annual heating demands and the cost of selected IGU

IGU	Energy demand in kWh	Price for energy for heating in €	Price for IGU in €
G1	20613	3069	6352
G2	16766.55	2508	6069
G3	13104.05	1974	21078

CONCLUSION

The paper presented the analysis of the impact of IGU on the internal environment and the heating demand of the school building. IGU itself was chosen based on predefined requirements. Only IGU that meet these requirements have been subjected to simulation. The three selected IGU's represent the technological progress as well as the availability and marketability of the Slovakian market. The following results can be stated based on defined operating modes and presented results:

- All selected IGU meet the conceptual design school requirements in terms of heating demand.
- The difference between the worst and the best solution in terms of heating demand is 37%.
- Triple IGU or quadruple IGU should be considered for more difficult requirements (passive houses) in Slovak climate conditions.
- The marginal additional energy savings provided by quadruple glazing do not justify the additional expense of the glazing.
- No solutions satisfied the risk of overheating in the critical month (June) for a given operating mode.
- All of the solutions exceeded the limit temperature $\theta_{ai,max}$ (°C) frequency in hours by more than 10%.
- The worst case temperature limit for $\theta_{ai,max}$ = 25°C has been exceeded 60% of total time.

- Simulation results show that the requirement g > 50% for this type of building is inappropriate.
- The recommended solution for the next phase of the project is to use triple IGU as a balanced solution.
- The recommended solution for the next phase of the project is to design better shading structure and to design a suitable ventilation system (alt. cooling) for the June.
- For shading design of structures as well as for changes in IGU properties it is necessary to analyze the quality of daylight.

ACKNOWLEDGEMENT

This paper was created thanks to the financial support from the EU Structural Funds, through the Operational Program R&D and project OPVaV-2008/2.2/01-SORO "Architectural, engineering, technological and economic aspects of the design of energy efficient buildings, codenamed ITMS: 26220220050; which is financed by EC funds.

NOMENCLATURE

U	W/(m²K)	Heat transfer coefficient for opaque structures
U_F	W/(m²K)	Heat transfer coefficient for window frame
U_G	W/(m²K)	Heat transfer coefficient for IGU
U_W	W/(m²K)	Heat transfer coefficient for window
g	%	Solar factor (Total solar energy transmittance)
τ_v	%	Light transmittance
$\Delta\theta_e$	K	External air temperature difference
θ_e	°C	Exterior air temperature
$\theta_{e,max}$	°C	Maximal exterior air temperature
$\theta_{e,min}$	°C	Minimal exterior air temperature
$I_{g,m}$	W/m²	Mean global solar irradiance
$I_{g,max}$	W/m²	Maximal global solar irradiance
n	1/h	Air change rate
θ_{ai}	°C	Internal air temperature
n_{50}	1/h	Air change rate at the pressure difference 50 Pa
$\theta_{ai,max}$	°C	Maximal internal air temperature

REFERENCES

Amstock, J.S. 1997. Glass in Construction, New York, USA.

Bagoňa, M. 2005. Interaction of Frame and Glass Systems in Future development of Window Construction, PhD Thesis, Kosice, Slovakia.

Calumen II – software, Saint-Gobain Glass 2007. Version 1.0.0.

DesignBuilder V 2.3.6.005. 2009.

EN 673, 1997. Glass in Building, Determination of Thermal Transmittance (U value), Calculation Method, Brussels, Belgium.

EN 410, 1998. Glass in Buildings, Determination of Luminous and Solar Characteristics of Glazing, Brussels, Belgium.

EN ISO 10077, 2000. Thermal Performance of Windows, Doors, and Shutters, Calculation of Thermal Transmittance, Brussels, Belgium.

Fang, S., Chen, Y. 2007. Evaluation on Energy Efficiency of Windows in Different Climate Zones of China, Beijing, China.

Feist, W. 1993. Passive Houses in Central Europe, Thesis, University of Kassel, Germany.

Kalousek, M., Bečkovský, D. 2006. Thermal Comfort of Lightweight Building in Summer Time, Lisbon, Portugal.

Kurnitsky, J. et al. 2011. How to Define Nearly Net Zero Energy Buildings nZEB, Istanbul, Turkey.

Lopušniak, M. 2004. Summer Overheating in Large Space Industrial Hall Type Buildings, PhD Thesis, Kosice, Slovakia.

Lopušniak, M. 2010. Comprehensive Analysis of the Shading Structure for Low Energy House, Kosice, Slovakia.

Sanyogita, M., Rajan, R. 2009. Impact of Window Design Variants on Lighting and Cooling Loads: Clues for Revisiting Local Building Regulations, Glasgow, Scotland.

Taylor, P., Duponchel, H., Bannister, P. 2009. The Impact of Glazing Selection on Daylighting and Energy Performance for an Office Building in Canberra, Glasgow, Scotland.

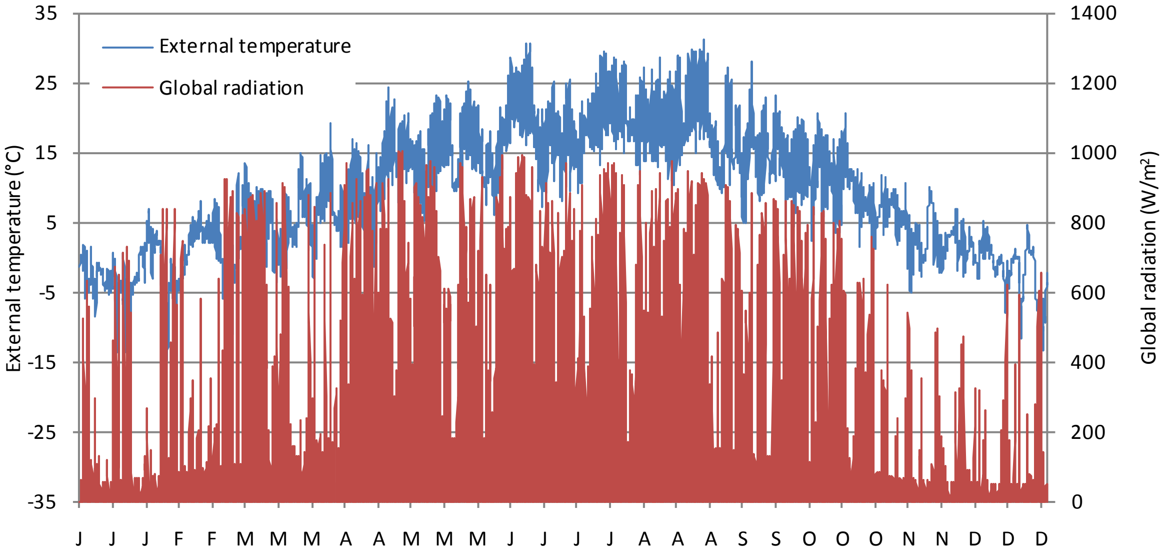


Figure 8 Courses of external temperature (°C) and global radiation (W/m^2) , IWEC, Košice

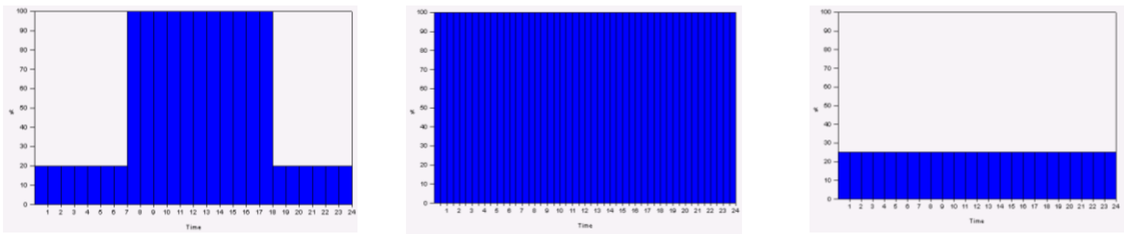


Figure 9 Ventilation modes, from left to right: Mode 1, Mode 2, Mode 3

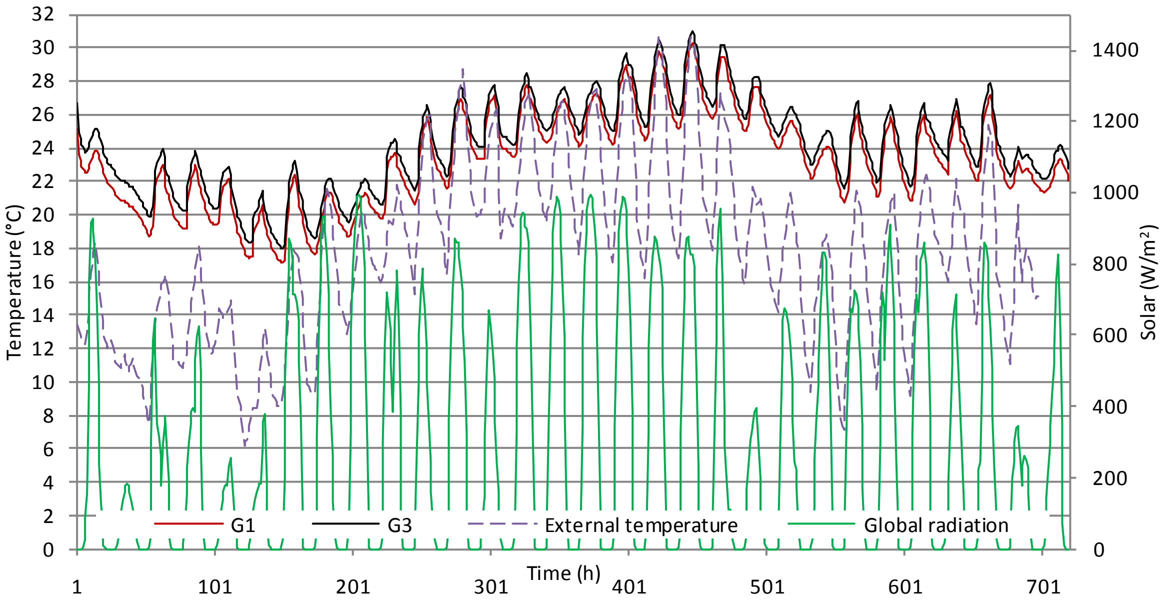


Figure 10 Courses of internal air temperature (°C) for G1 and G3 solution,
Global radiation (W/m^2) and External temperature (°C),