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SIMULATION BASED COMPLEX ENERGY ASSESSMENT OF OFFICE BUILDING FENESTRATION

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Abstract. The number of office buildings with highly fenestrated facades is currently increasing in Lithuania and neighboring countries. Highly fenestrated facades reduce energy consumption for lighting and simultaneously increase energy consumption for heating, cooling, air conveying and may cause thermal and visual discomfort. Pursuing to reduce negative effects of the highly glazed facade, special glasses are frequently used. However, such windows usually increase demand for lighting energy. Therefore, when making early decisions about glazing the building, it is important to have a complex evaluation of energy demand related to the specific case.

The paper presents the results of analysis made using energy simulation tools. The obtained results have shown that when shading is not applied, the north is the most energy efficient orientation to glazing for an air conditioned office building in cool climate zones like Lithuania. The most energy efficient window-to-wall ratios (WWR) for the south, east and west oriented façade are 20%, whereas for the north it makes 20–40%. However, such WWR values do not satisfy standard requirements for day lighting.

Keywords: office building, glazing, heating, cooling, lighting, energy demand, simulation.

1. Introduction

Transparent parts of the facade are one of the essential constructive elements of the building and at the same time a weak part from the point of view of energy efficiency because despite the characteristics of the glasses used, their heat transmittance (*U*-value) is always higher than the coefficient of up-to-date wall constructions. Intensive solar radiation may cause thermal or visual discomfort (Menzies and Wherret 2005; Šeduikytė and Paukštys 2008).

Properly oriented, energy efficient windows are one of the key elements both for newly built and retrofitted buildings (Kaklauskas *et al.* 2005, 2006). Therefore, when designing facades, the most important architectural factors, considering energy consumption, thermal and visual comfort are the following glazing characteristics: fenestration, glass type, the coefficient of thermal transmittance and orientation.

Pursuing to reduce energy consumption, some countries have official recommendations on how to select glazing characteristics. The USA Ashrae 2004 despite of the climatic region recommends reduce fenestration on the east and west oriented facades as much as possible and increase southern fenestration for heating dominated climates for small office buildings. Canadian recommendations (PWC 2002) are similar to those of the USA. For Belgian climate, Gratia and De Herde (2003) concluded that in case it is impossible to envisage a shading device on southern glazing, it is preferable to place the greatest glazed surfaces on the northern side. Hence, in some cases, the above mentioned recommendations differ.

Recommendations concerning the fenestration of the facade also differ. ASHRAE (2004) recommends WWR from 20% to 40%, whereas Norwegian standard for building energy performance NS 3031:2007 (2007) defines that the glazing area must not exceed 20% of the heated floor area. The recommended fenestration area in Canada is calculated due to the dimensions (i.e. geometry factor) of the room. These calculations usually give WWR close to 30% (PWC 2002).

Lithuania, similarly to some other neighboring countries, has no official norms regulating office building glazing characteristics with an estimation of their complex impact on energy demand. There are two standards for thermal and spectral glazing characteristics in Lithuania: the first one regulates the value of heat transmission (STR 2.05.01:2005), the second – the minimum values of the total solar heat gain coefficient and minimum fenestration satisfying requirements for daylighting (STR 2.05.20:2006).

Estonian building energy performance standard requires evaluating overall building energy consumption (complex assessment) (Laaniste 2008), and there also standard EVS 894:2008 (2008) for minimum WWR according to daylighting demand exists. However, solutions to efficient energy glazing are left to be worked out by a designer.

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Apart from constructive elements, the building consists of its occupants and plants. There is a very complex interrelation between them. Therefore, a building should be regarded as being systemic (many parts make the whole), dynamic (parts evolve at different rates), non-linear (parameters depend on the thermodynamic state) and, above all, complex (myriad intra- and inter-part interactions) (Clarke 2001). The high modeling integrity of the building can be reached by using simulation programs only.

At the same time, architects and constructors need recommendations concerning the proportions of the building elements without making complicated simulations.

Since simulations require complicated computer programs, there is a lack of comprehensive research regarding the impact of glazing characteristics on building performance. Thus, the presented paper partly fills this gap.

As most office buildings are rectangular and have repeating elements, energy demand is modeled for one typical element (office room) of a certain orientation facade.

2. Calculation Model

Calculations are performed for the created model of the rectangular office building (Fig. 1).

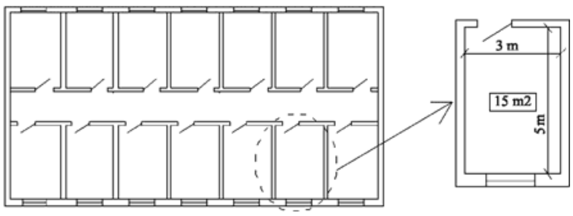

Fig. 1. A plan of a typical floor and office room

The assumption that solar heat gain through the roof is insignificant, compared to that through windows, enables to discern an office room as a typical one related to heat regime in a certain orientation facade.

Office rooms in the building are of a popular size – 15 m^2 and 3 m height, which also satisfies hygiene requirements for a workplace equipped with a computer (HN 32:2004). The size and proportions of the room correspond to architectural and daylighting requirements. This approach follows Norwegian standard NS 3031:2007 when calculating building energy performance it requires dividing offices into separate zones according to exposure to the sun.

The analysis of the office room of a certain facade allows simplifying calculations and generalizing their results for the whole facade of the analyzed orientation.

3. Methods

To find the most effective energy fenestration, analysis is performed in the following way:

1. According to Lithuanian standard STR 2.05.20:2006, the calculation of minimal fenestration satisfying requirements for daylighting is performed.
2. The creation of the building model (geometry, constructions, occupants‘ activity, comfort conditions, HVAC and lighting systems, their characteristics and operation schedules) and glazing alternatives in DesignBuilder program which is an interface of simulation engine EnergyPlus;
3. Simulation of alternatives with EnergyPlus (see Table 1).
4. Importing results from DesignBuilder to Microsoft Excel, processing and analyzing them.

Table 1. Characteristics of the selected glazing alternatives

Glazing No.*	U, W/m^{2}K	τ_1	g	τ_1/g
1	1.6	0.75	0.73	1.04
2	1.4	0.79	0.62	1.27
3	1.4	0.59	0.46	1.28
4	1.4	0.60	0.34	1.74
5	1.4	0.74	0.43	1.73

*further glazing type will be defined by the number (No. 1, No. 2, etc.).

This article is designed with reference to Lithuanian Republic Building Regulations and Hygiene Norms based on European Norms and Standards.

3.1. Calculation of the Minimum Required Fenestration

In the offices with continuous work, adequate visual comfort must be provided. Daylight is one of the important factors influencing human‘s psychological comfort.

Taking into account the above mentioned requirements for daylighting, requirements for window design are established in Lithuanian standard STR 2.05.20:2006. Each room depending on its dimensions and their relation, glazing characteristics, the placement of windows and other factors will have different minimal required fenestration A_{sv} (m^2) satisfying requirements for daylighting. After the values of the coefficient for the analyzed case have been embedded, Eq. (6) of STR 2.05.20:2006 becomes simpler:

$$A_{sv} = 4.72 \cdot \frac{k}{\tau_1}, \tag{1}$$

where τ_1 – light transmittance; k – the correction coefficient of orientation.

Eq. (1) is valid only when lighting level on the working plane is 500 Lux. Knowing that office work will need less preciseness, lower lighting levels can be chosen. The highest lighting level – 500 Lux is assumed in the calculation model while designing air conditioning systems according to LST EN 13779 the default used value is 400 Lux. A lower lighting level requires a lower daylight factor and fenestration:

$$A_{sv} = 3.77 \cdot \frac{k}{\tau_1}. \tag{2}$$

According to Eq. (1), minimum required fenestration for the analyzed case depending on light transmittance can be defined from Fig. 2.

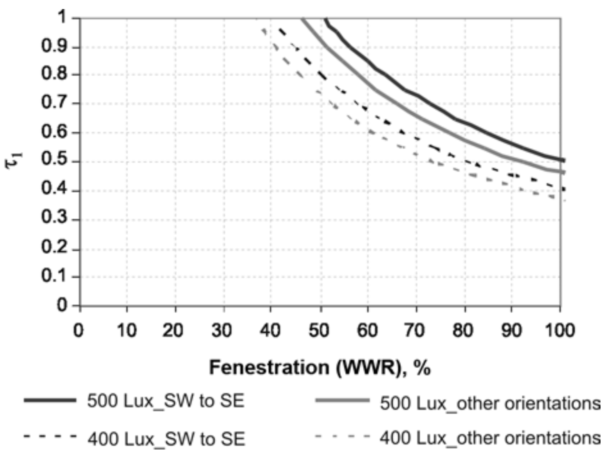

Fig. 2. Dependency of minimum required fenestration on glazing light transmittance

Fig. 2 also shows the dependency of minimum required fenestration on the glass light transmittance coefficient when lighting level is 100 Lux lower, i.e. equals 400 Lux. In this case, minimum required fenestration (WWR) can be 10–20% less.

3.2. Glazing Characteristics

In point of energy and daylight, the main characteristics of glazing, next to fenestration and orientation are heat transmission coefficient (*U*), solar heat gain coefficient (*g*) and light transmittance (τ_1), which in general depend on the type of glass used and window construction. The frame is not as important as the glass part of the window (Almeida Ferreira Tavares and de Oliveira Gomes Martins 2007).

STR 2.05.20:2006 establishes requirements for using solar control glazing. When window orientation is northeast to northwest, solar control glazing should be used if WWR is more than 30% and for other orientations – when WWR is more than 20%. When WWR is higher than the one indicated, the average glazing solar heat gain coefficient *g* should not be greater than that calculated according to Eq. (3):

$$g = 0.7 \cdot \frac{S_o + \sum \Delta S}{f \cdot F_c \cdot F_F}, \qquad (3)$$

where F_F – the coefficient evaluating the glazed part of the window; when it is not known, it can be assumed equal 0.8; F_c – the coefficient evaluating the influence of shading devices; S_o – the value of the base solar transmittance of glazing, $S_o = 0.18$; ΔS – affixes to the value of base solar transmittance.

For the analyzed case, according to Eq. (3), the maximum allowed values of coefficient *g* are calculated for different fenestration, orientations and a shading type (without shading, internal shading and external blinds) (Fig. 3). The standard does not give a detailed list with coefficients evaluating the influence of shading devices.

Variously named window types can have very similar characteristics. Therefore, when choosing a window, it is advisable to look at separate characteristics of glazing. The selection of glazing for this analysis was performed seeking to have glazing with different characteristics, including light transmittance, solar heat gain coefficient and heat transmission coefficient. When choosing glazing type, two limitations were followed:

- heat transmittance should satisfy standard requirements (STR 2.05.01:2005);
- glazing light transmittance should not be lower than 0.5 otherwise the requirements of standard STR 2.05.20:2006 for the analyzed room will not be met (Fig. 2).

Based on Eq. (1), the calculation of minimum required fenestration is calculated for different glazing (Table 2).

Table 2. Minimum required fenestration for different glazing

Glazing No.	Minimum required fenestration			
	Orientation SE, S and SW		Other orientations	
	m^2	%	m^2	%
1	6.90	68	6.27	61
2	6.59	65	5.99	59
3	8.76	86	7.96	78
4	8.68	85	7.89	77
5	7.03	69	6.39	63

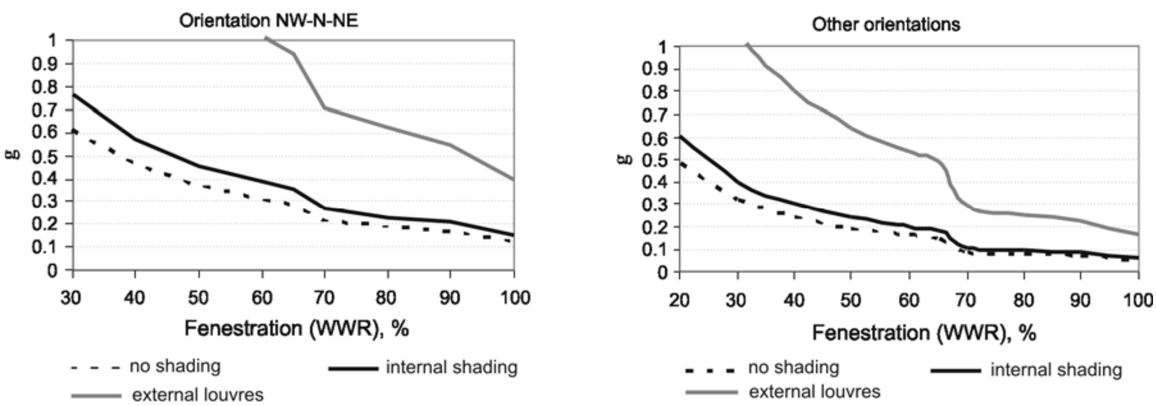

Fig. 3. Requirements for solar heat gain coefficient *g* depending on the glazing area, orientation and used shading devices

The higher values of solar heat gain coefficient *g* are more beneficial in cold climates. The energy and daylighting efficiency of glazing is characterized by τ_1/g. When this relation is less than 1, glazing does not ensure sufficient daylighting and if relation is more than 1.55, such glazing is considered as very efficient. The quality of daylighting is also characterized by relative aperture rate $\tau_1\left(A_{windows}/A_{floor}\right)$ and if this value is between 0.15 and 0.30, daylighting is considered to be effective. The choice of the relative aperture rate is one of the most sensitive parameters on the global energy needs of an office building (Franzetti *et al*. 2004). Despite the value of this factor, balance should always be found between visual and thermal comfort (ASHRAE 2004).

3.3. Computer Model of the Room

The creation of the building model (geometry, constructions, occupant activity, comfort conditions, HVAC and lighting systems, their characteristics and operation schedules) in DesignBuilder program enables to perform further calculations.

The analyzed building is made of lightweight constructions. Its heat transfer coefficient meets standard requirements (STR 2.05.01:2005) and equals 0.243 W/m^{2}K. The assumed outside air infiltration is 0.2 h^{-1}.

Since the analyzed element is a typical office room, it is assumed that other rooms have the same heat regime and there is no heat exchange between them, i.e. internal partitions are adiabatic.

Occupants, computer equipment and lighting systems have the same activity schedules typical for offices – weekdays from 8:00 to 17:00. Despite that the realistic occupation of the office building is not constant and fluctuates individually in each office room, it is assumed, that in the analyzed case, the type of work requires constant occupation during working hours and the room has two occupants. During working hours, HVAC systems maintain comfort conditions: for warm season – 24ºC and for cold season – 21ºC. For unoccupied hours during the heating season, the heating system maintains 3K lower (18ºC) temperature (LST EN 12831:2003) and the cooling system is always off. Preheating time (required to rise temperature to 21ºC) is 1 hour. The minimal supply of the fresh air is 10 l/s per person (STR 2.09.02:2005). The ventilation system has a heat recovery unit with 70% efficiency, the heating system – local heating devices, a heat generator – gas fired boiler. The coefficient of the performance (COP) of the chiller is 2,5.

The highest assumed lighting level required for offices makes 500 Lux (HN 98:2000), the selected efficient lighting system with linear control according to the fixed lighting level and specific lamp power is 3 W/m^2 /100 Lux (LST EN 13779:2007). Office equipment internal gains are 4 W/m^2.

3.4. Analyzed Glazing Alternatives

The constructed model is simulated with different glazing alternatives changing glazing characteristics like area, orientation and glazing type. Simulations are performed by simulation engine EnergyPlus. In total, 100 alternatives are simulated.

The model is programmed to calculate energy demand for heating, cooling, ventilation and auxiliary energy used to power HVAC systems pumps and fans.

The results of simulations are imported from interface Design Builder to Microsoft Excel and then processing is performed.

4. Results

After processing simulation results, the analysis of the influence of orientation on energy demand for each glazing type is performed. It has been found that depending on fenestration, heat gain through southern glazing is from 50 to 100% higher than that through the northern one. The influence of orientation rises within the increased fenestration.

Despite the fact that heat gain through glazing is very important, the final optimization of glazing characteristics should be performed evaluating the overall energy demand. Glazing influences energy demand for heating, cooling, lighting, HVAC pumps and fans. Meanwhile, energy demand for hot water and computer equipment does not depend on glazing, and therefore this energy is not estimated.

Building energy demand is often calculated without taking into account the fact that heat (produced not from electricity) and electricity (in case it is not renewable) is the energy of different quality and adding it directly in general is incorrect and in many cases (as the one analyzed) can vitiate the results (Biekša *et al.* 2006). In order to avoid such situation, energy is converted to primary energy, assuming that electricity PE factor equals 3.00 (Kalz *et al.* 2009) and heating PE factor – 1.12.

An example of how dependence on fenestration and orientation changes the structure of energy demand is shown as glazing No. 3 in Fig. 4. For other glazing types, the obtained results are analogical.

It can be seen (Fig. 4) that primary energy demand for heating in all cases constitutes only a small part of the total energy demand. Heating constitutes the biggest part when 100% of the glazed facade is oriented to the north and the smallest part when 100% of that is oriented to the south.

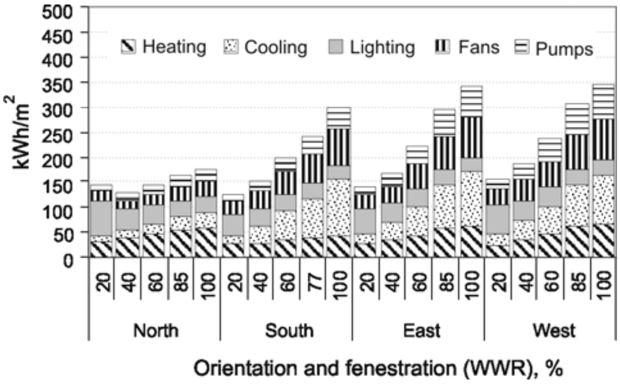

Fig. 4. The structure of the annual primary energy consumption

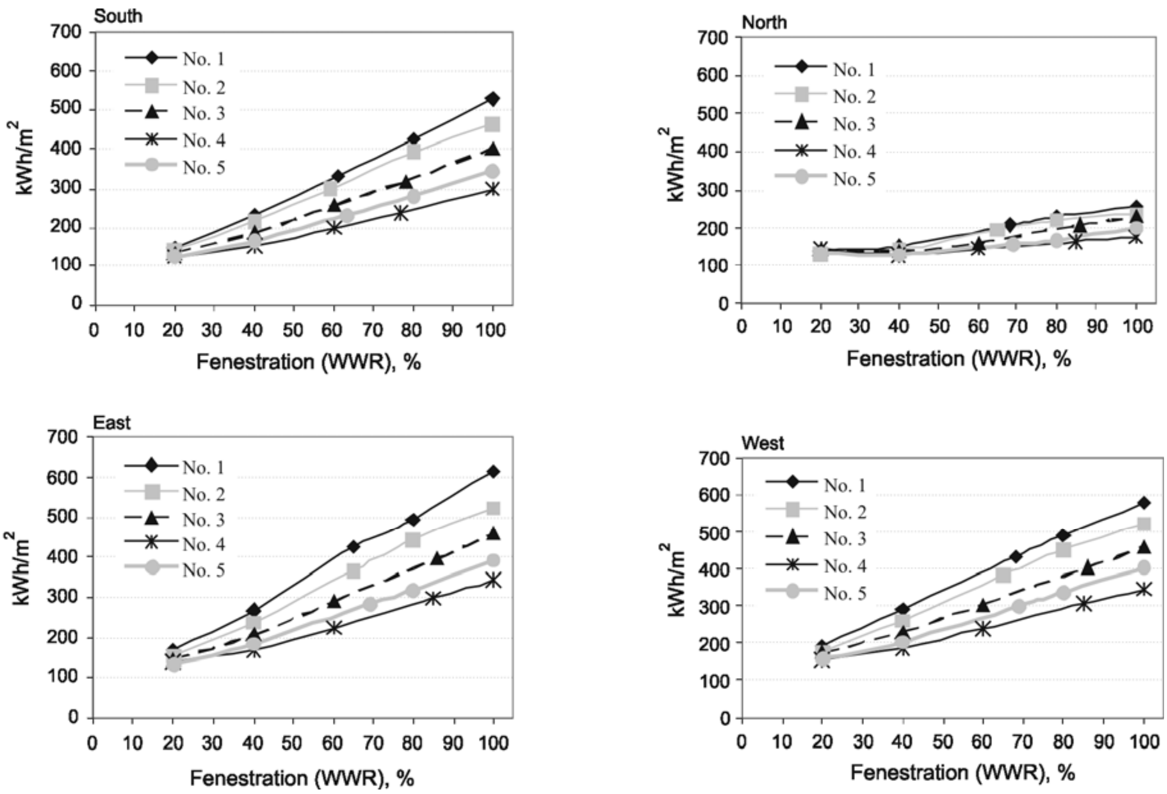

Fig. 5. Dependence of building annual energy consumption on glazing characteristics

Cooling energy demand is much more dependable on orientation and fenestration than heating demand. The part of energy for cooling can substitute from 9 to 47% of the total energy demand. The biggest part of energy for cooling is consumed when the facade is south oriented and the smallest one – when north oriented and this part is increasing along with growing fenestration.

A higher fenestration level causes a reduction of energy demand for lighting. The part of lighting energy constitutes 5–49%. It is obvious that the highest energy demand for lighting is observed when fenestration is equal 20% for the north facade while the lowest one makes 100% fenestration for the rest of orientations.

The total primary energy demand is highly increased by electricity needed to power HVAC pumps and fans. The performed surveys show that this kind of energy (often called "parasitic") and can amount 20–60% of the total energy consumed in office buildings (Westphalen and Koszalinski 1999). In the analyzed case, such energy makes 22–44% and is directly influenced by increasing fenestration.

Pursuing to identify the optimal characteristics of glazing, the analysis of the total primary energy demand is performed (Fig. 5). The performed calculations have showed that for each orientation and glazing type, the dependency of energy demand on fenestration is analogical as with the rise of fenestration, energy demand also rises. Fenestration increase from 20% to 100% for the south, east and north facade can increase energy demand approx. 3–3.5 times for clear glazing (No. 1) and 2.2–2.5 times for glazing with multifunctional coatings (No. 4). Meanwhile, for the northern facade with fenestration increase from 20% to 40%, energy demand for some glazing types is even decreasing because of lower energy demand for lighting (Fig. 5). For northern orientation, an increase in fenestration to the maximum can raise energy demand 1.8 times for clear glazing and accordingly – 1.2 times for glazing with multifunctional coatings.

It is noticeable for all orientations that the higher is the relation between glazing light transmission coefficient with total solar heat gain coefficient τ_1/g, the lower is energy demand. Therefore, the lowest energy demand is for glazing with multifunctional coatings (No. 4).

5. Discussion

The performed simulation of energy demand for the office building confirms that different research results concerning fenestration and optimal facade orientation depend on many factors, including intensity and changes in solar radiation, the type of the building, the selected model of building operation and thermodynamic limits of the system. It also depends if energy demand is calculated in terms of final or primary energy. All these factors should be considered assessing and applying recommendations for increasing building energy performance.

Lithuania is situated in the cool climate zone with a short duration of high outside temperatures, and thus the occupants can open windows for the purpose of airing. Therefore, in non energy efficient residential buildings, both air conditioning and mechanical ventilation are not common while office buildings are usually built in the zones of enlarged noise and pollution. For this reason, even when the outside temperature is suitable for natural ventilation, windows remain closed and comfort conditions can be maintained only by the air conditioning system.

The dominating tendency for improving the thermal insulation of building elements decreases the part of heat losses in heat balance but increases the part of energy needed for cooling. Normally, cooling equipment uses electricity, thus 3 times more fuel is consumed in producing 1 kWh of electricity (if electricity is not renewable) than producing 1 kWh of heat in a gas boiler. This requires additional fuel to be consumed both directly for air cooling and for air conveying.

Summarizing the analyzed results, it can be predicted that in most cases, energy efficient WWR for office buildings in Lithuania and the neighboring countries with the same climate conditions is 20% for the south, east and west oriented facades and 20–40% – for the north. Energy efficient WWR values do not satisfy standard hygienic requirements for daylighting. Higher fenestration decreases energy demand for lighting which does not compensate the increased energy demand for ventilation and cooling. Therefore, to maintain the desired lighting level, it is beneficial to prolong operation hours of the lighting system.

Energy demand for lighting during occupation hours is mostly determined in November, December and January. Therefore, the prolonged operation of the lighting system during the rest of the year does not make any essential changes in energy balance.

6. Conclusions

1. The analysis of energy demand has shown that in most cases, energy efficient WWR for the conditioned office building in cool climate zones like Lithuania is 20% for the south, east and west oriented façade and 20–40% for the north.

2. The most energy efficient fenestration does not satisfy standard requirements for daylighting, and therefore recommended WWR must be equal to the minimum required by daylighting standard.

3. It is defined that the most energy efficient orientation for glazing the conditioned office building when solar shading is not applied is the north while east and west orientations are the worst.

4. The final choice of glazing for a cool climate zone has to be made according to the relation of glazing light transmittance (τ_1) with solar heat gain coefficient (g).

5. For highly fenestrated conditioned office buildings of any orientation, cooling energy demand is 2 to 3 times higher than that for heating (except north oriented). Cooling energy in office buildings increases the total energy consumption unlike in the unconditioned residential buildings where higher fenestration on the southern facade decreases energy demand for heating as well as the total energy demand.

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MODELIAVIMU PAGRĮSTAS KOMPLEKSINIS ADMINISTRACINIŲ PASTATŲ ĮSTIKLINIMO ENERGINIS VERTINIMAS

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S a n t r a u k a

Pastaraisiais metais Lietuvoje ir kaimyninėse šalyse daugėja administracinės paskirties pastatų, kurių dauguma išorinių atitvarų yra skaidrios. Didesnis įstiklinimo plotas lemia mažesnius energijos poreikius apšvietimui, tačiau didina šildymo ir vėsinimo sistemų energijos poreikius, sukelia šiluminį bei vizualinį diskomfortą. Neigiamai didelių skaidrių atitvarų įtakai sumažinti naudojami tamsinti ir kitų specialių charakteristikų stiklai, tačiau tai savo ruožtu didina energijos poreikį apšvietimui. Todėl, priimant sprendimus dėl pastato įstiklinimo, svarbu prieš tai kompleksiškai išnagrinėti konkretaus sprendimo įtaką pastato energijos poreikiams.
Straipsnyje pateikiama modeliuojant gautų rezultatų analizė. Rezultatai parodė, kad vėsaus klimato šalyse, kurioms priklauso ir Lietuva, kondicionuojamų administracinių pastatų fasadų, kai nenaudojamos apsaugos nuo saulės priemonės, energiškai efektyviausias įstiklinimas yra į šiaurės pusę. Energiškai efektyviausias santykinis fasado įstiklinimo plotas pietinės, rytinės ir vakarinės orientacijos fasadams yra 20 %, o šiaurinės – 20–40 %. Tačiau tokie įstiklinimo plotai neatitinka norminių natūralaus apšvietimo reikalavimų.

Reikšminiai žodžiai: administracinis pastatas, įstiklinimas, šildymas, vėsinimas, apšvietimas, energijos poreikiai, modeliavimas.

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