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Energy consumption of buildings depends on the daylight

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Abstract. In order to reduce energy consumption in heated buildings and thus fossil fuels, there is a need for proper modernization of existing buildings and new construction with reduced energy demand. The size and the insulation of windows have a decisive influence on the amount of heat loss. The study looks into the impact of decreased power consumption through optimal use of sunlight through the selection of the size of windows, type of windows, and adjusting the light intensity using an automatic control of lighting according to the amount of sunlight reaching the room. The research related to the differences between the six types of windows in relations to the energy consumption of the building.

1 Introduction

It is estimated that the department of building consumes half the energy produced. The most important thing during the heating season is to provide the building with heat gains form the sun. The amount of solar radiation in Poland is low, but in the winter per square meter south oriented facades of the building located in Warsaw falls about 385 kWh of energy. This is the amount of heat corresponding to the quantity of energy obtained combustion of 38 liters of fuel oil.

In addition to obtaining solar energy by using special devices such as solar panels, it can be used it in its pure, unaltered form also, setting the appropriate building in relation to parts of the world and improving participation of glazed surfaces in stalls external walls.

It is possible to obtain in this way increase heat gains from the sun and a larger share of solar energy in the lighting of rooms. This affects the final energy balance of the building by reducing the the demand for heat which is usually obtainable from the heat source or situated in a building, which receives heat using traditional fuels such coal, gas or fuel oil. The use of daylight systems or intelligent lighting control by reducing artificial lighting decreases energy use of the building for electricity by about 15%. This is important for the evaluation of the effective use of solar energy in the construction industry, in particular in passive houses, or a zero-energy houses, [5].

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2 The energy balance of buildings and daylight

Energy balance is the difference between the profits of heat energy in the building and its losses. The energy efficiency of the house is a ratio of the amount of energy saved as compared to the amount of energy consumed or forecast. Efficient use of energy means reducing the energy consumption of production, operation and running of services. The building refers to the energy needed for heating, cooling, ventilation and air-conditioning or electricity consumed by the device. In order to eliminate or at least reduce consumption of non-renewable fuels in Poland in 2020 in line with the recommendations of the Climate Package of 2015 years, it is planned to reduce greenhouse gas emissions by 20% and improving energy efficiency by 20%. Public buildings also define the energy needs for lighting purposes, [2].

2.1 Design of daylight lighting in the rooms

While designing the lighting in the room, it is crucial to include factors that affect the intensity of solar radiation, as shading of the building, type of glazing, inclination of windows, location in relation to parts of the world, location, time of year and time of day. The size of the average intensity of solar radiation, depends on the the location of the building relative to parts of the world for individual months. Location of the room on the south side positively affects the heat balance of the building, especially during the coldest months: January, February and November compared to the rest of the orientation of the building.

2.1.1 The windows in the building

The flow of power through the window has the biggest impact on the balance of energy in building. The most important matter in designing daylight rooms is the selection of the size and the type of windows. The characteristics of energy-efficient window frames are determined not only by the heat transfer coefficients, but also by the parameters describing the properties of the glazing, such as the ratio of the total solar energy transmittance and light transmittance. It is important to remember that this parameter is different for the window frame, window, and the entire window. Insulation window improves increasing the number of windows in the profile and filling the space between the noble gases, eg. argon or krypton or coating glass coatings selective. It shall also apply to the so-called. warm frame, or inter-frame polymer which improve the thermals of the window (reduction in the linear coefficient of heat transfer at the connection to the frame of the glass package).

2.1.2 Heat losses through the windows

In terms of energy (heat loss by penetration), the window is characterized by the heat transfer coefficient U_w; W/(m^{2}K), depending on the insulation frame, glazing and heat transfer coefficient of linear thermal bridge at the junction of the glass from the window frame. Heat losses through the opacified partition (like wall) during winter are approximately 25%. In winter, a small area of vertical windows (less than that due to daylight) in which the share exchange heat through the windows of the south is less than 30% in the monthly balance, and in the windows on the north side is about 35%. When the surfaces of the windows is above the applicable minimum surface due to the daylight part of the heat demand for space heating due to heat loss through the window significantly increased to over 60% in the case of the southern windows, and over 70% in the case of the northern windows, [5].

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In conclusion if surface of a window is big, specially if this window is on the roof, it affects the need for cold or heat in this room which grows along with the surface of windows and tilting from the vertical (at site level).

3 Energy consumption for heating and consumption for the lighting of buildings

3.1 The final indicators of consumption for energy of building

3.1.1 Indicator of the primary energy - EP

Indicator of the primary energy determined for the annual consumption of the building on non-renewable primary energy falling on 1m^2 rooms with controlled temperature (cooled or heated). It is determined by formula, [1]:

$$EP = Q_P / A_f \tag{1}$$

$$Q_p = Q_{p,H} + Q_{p,W} + Q_{p,C} + Q_{P,L} \tag{2}$$

Q_p- non-renewable primary energy to heat annual consumption for heating and ventilation ($Q_{p,H}$) energy consumption for cooling rooms ($Q_{p,C}$) energy consumption for heating water ($Q_{p,W}$) energy consumption for the electricity power needed for operation of technical systems which are associated with those purposes. The public buildings are also referred to energy consumption for lighting ($Q_{p,L}$).

3.1.2 Index of usable energy - EU

Index of usable energy describes the energy required for different needs associated with the use of the building; this is a monthly balance of gains and losses of heat energy for heating, cooling and heating water to appoint by formula, [1] (building energy consumption for heating building):

$$EU = Q_u / A_f \tag{3}$$

$$Q_u = Q_{H,nd} + Q_{W,nd} + Q_{C,nd} \tag{4}$$

$$Q_{H,nd} = \sum_i (Q_{ht,i} - \eta_{H,i} \cdot Q_{gn,i}) \tag{5}$$

Af – surface of room with controlled temperature, $Q_{H,nd}$ – annual energy consumption for usable energy for heating and ventilation $Q_{H,i}$ - dimensionless utilization coefficient of heat gains in the coming months, $Q_{ht,i}$ - heat losses in the following months, kWh/month, $Q_{gn,i}$- heat gains in the following months, kWh/month.

3.1.3 Index of the final energy- EK

The indicator for the final energy is the annual energy per m^2, needed to provide cooling, heating, ventilation and lighting facilities, hot water preparation and taking into account losses in technical systems. Calculated by, [1]:

$$EK = Q_k / A_f \tag{6}$$

$$Q_k = Q_{k,H} + Q_{k,W} + Q_{k,C} + Q_{k,L} \tag{7}$$

$$Q_{k,H} = Q_{H,nd} / \eta_{H,tot} \tag{8}$$

$Q_{k,H}$ - annual energy consumption for the final energy for heating and ventilation,

$\eta_{H,tot}$ - average seasonal total efficiency of the heating system of the building (from the production of heat transfer in the room).

$$\eta_{H,tot} = \eta_{H,g} \cdot \eta_{H,s} \cdot \eta_{H,d} \cdot \eta_{H,e} \tag{9}$$

$\eta_{H,g}$ - the average seasonal efficiency of producing heat transfer medium of energy supplied to the borders of the building (the final energy). The value depends on the type of heat source (boiler, pumps, heaters or other). It falls generally in the range {0.5-1.0}, $\eta_{H,s}$ - the average seasonal efficiency of the heat accumulation in the capacitive elements of the heating system of the building. This value is assumed to be depending on the presence and the type of the installed buffer. These values are in the range {0.91-1.00}, $\eta_{H,d}$ - the average seasonal efficiency of the transport of heat transfer medium within the building, $\eta_{H,e}$ - he average seasonal efficiency of regulation and the use of heat in the building.

3.1.4 Energy consumption for lighting

The energy consumption for lighting evaluated in public building is calculated by:

$$Q_{pL} = w_{el} \cdot E_{kl} \tag{10}$$

w_{el} - correction factor for the media electricity, E_{kl} - aggregate annual energy consumption for lighting building [kWh/year]:

$$E_{kL} = E_{Lj} \cdot A_f \tag{11}$$

A_f - the surface area of each room of the building; m^2, E_{Lj} - annual unit energy consumption for every room of a building; kWh / m^{2}year, according to PN-EN 15193: 2010 is an indicator of LENI, [1, 5].

$$E_{Kj} = \{F_c \cdot \frac{P_j}{1000} \cdot [(t_D \cdot F_0 \cdot F_D) + (t_N \cdot F_0)]\} \tag{12}$$

F_c - factor related to the reduction of light intensity to the required level, F_O - coefficient taking into account the absence of members in the workplace, F_D - coefficient taking into account the use of daylight, P_j - power unit lighting luminaires base, W/m^2, t_D - time of use light per day, h/r, t_N - time of use of the lights during the night; h/r.

4 Intelligent lighting control systems

Building Management System (BMS) contributes to the increase in the comfort of usage, safety and rational use of energy, with the economic aspect. The use of daylight and modern electrical installations, provided with systems for building automation (BMS) can lead to a reduction of electricity consumption for lighting purposes up to 80%, and in terms of the total consumption of electricity and heat, can bring savings of 30% and more, [3].

4.1 Intelligent lighting control system with daylight

The first level of integration can be distinguished for the indoor lighting. The control takes into account the artificial lighting alone or the takes into account artificial lighting and its control by external information like day lighting, occupancy, etc. This system complements the system of electric light sources, so that electric lighting is complementarity with the intensity of daylight to the required level. This is done through controls of the luminous flux "dimmer". They may be devices controlled manually or automatically. In the second case, the control system controlling electric lighting must interact with the sensor measures the illuminance level. The "intelligent system" of this type provides automatic adjustment of the size of the luminous flux of electric light sources to the changes in the share (level) of daylight, while maintaining a given level of brightness contributing to the reduction of electricity consumption of the building.

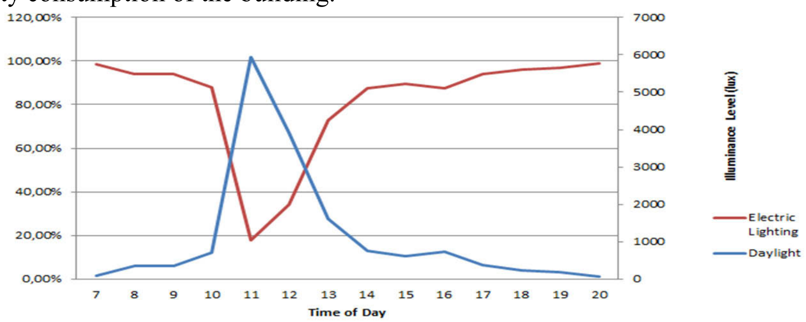

Fig. 1. The result of daylight automatic control is energy savings for 23 July 2016 (Clear sky).

The energy savings were calculated by taking the highest point of electricity used for the day, and then subtracting anytime the actual value was lower to find the difference. The differences are then totaled and averaged to find the overall saving percentage for each day. The measurements were made for 15 (fig.2) and 23 (fig.1) July 2016.

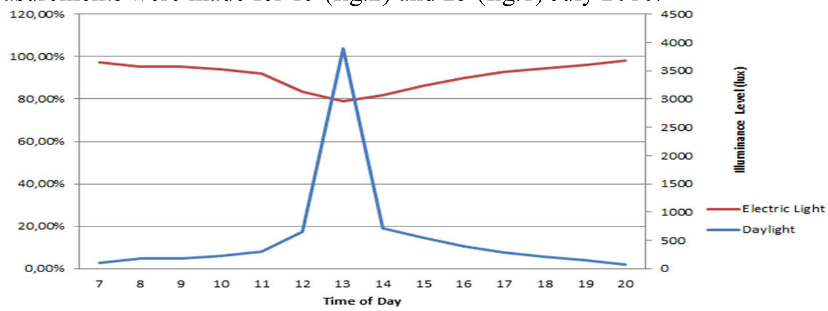

Fig. 2. The result of daylight automtic control is energy savings for 15 July 2016 (Overcast sky).

4.2 HDR Images as an innovation of the use of the daylight for systems of automatic lighting control

In order to map the sky luminance of the light used HDR images. The process involves taking the picture LDR (Fig. 3) of the sky through objective "fisheye" and transforming it into the HDR image. Then, on the HDR image is applied to the mesh distribution of the sky equal to 145 Tregenza`s pieces. At the end, the average together luminance values part of the mesh like that show Figure 4.

Fig. 3. Example of LDR sky image

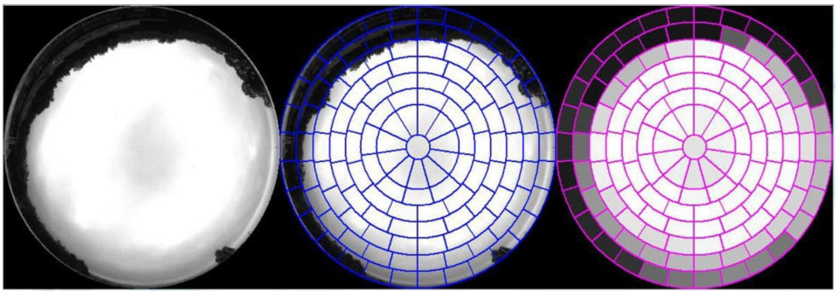

Fig. 4. Luminance distribution in Bialystok 11-th of July a) HDR sky image, b) with Tragenza mesh, c) with mesh and averaged luminance.

Through the analysis of HDR images from the test room, it can be concluded that it affects the electricity consumption through the daylight. Obtained results allow determining the appropriate size and number of window openings depending on the location of the building, which, in turn, reduces the electricity consumption for artificial lighting, as well as allows analyzing the energy balance of the building. Optimizing these two issues significantly reduces the used electricity and thermal energy for heating and cooling the building.

5 Research and analysis of the results

The effect of the selection of characteristics of window and its effect on the energy balance of the building. The assumption was a room with dimensions of 3.27 x 3.04 x 2.77 m with one window with dimensions of 1.74 x 1.45 m. Wall with a window set on the south side of the best sunshine in a year. The window was tested in variants according to the Polish standards in Figure. 3:1. Window box triple, 2. windows loom single glazed window 3. double-glazed unit in single-chamber 4. single-glazed window with glass composite twin-chamber 5. the window composite double glazed window 6. composite triple glazed (one single-chamber glass unit).

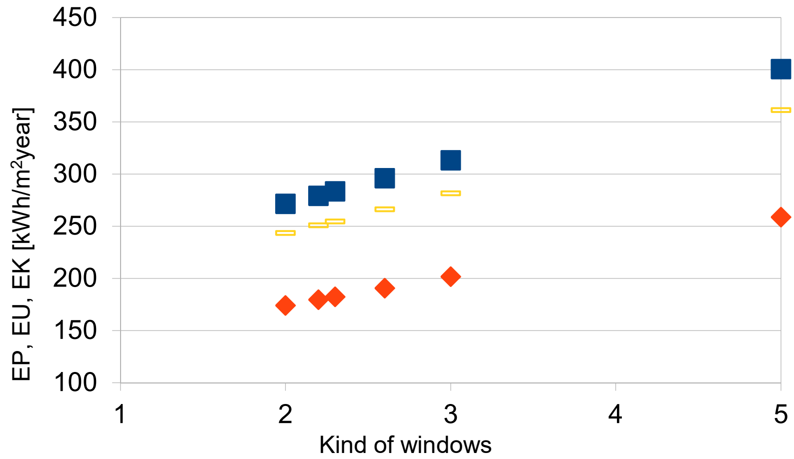

Fig. 5. Indicators energy consumption for EP, EK and EU depend on kind of window.

The lowest value of the energy consumption of the room for every kind of window in the case of energy the usable, the largest and the primary energy. Graphs EP, EK, EU and have the same shape and in each case the largest energy consumption (approximately 35% more than other kinds) in the case of a window 2 which is a single glazed. The lowest power consumption is in the case of windows box 1 triple and 6 composite triple glazed (one single-chamber glass unit).

5.1 Energy losses and gains, depending on the selection of a window

The effect of energy gains, for this room from sunlight is shown in Fig.6.

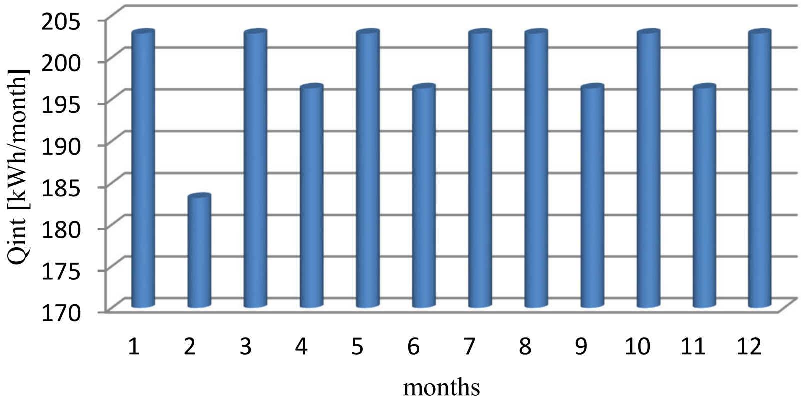

Fig. 6. Heat gains from sunlight (daylight).

It is easy to notice that the heat gains coming from sunlight are rather high and steady throughout the year. Only in February the value of heat gains is low. High values of more than 200 kWh / month are received not only in the summer months like July and August, but also during the winter months like December and January. The effect of heat energy losses for this kind of room depending window system is shown in Fig.7.

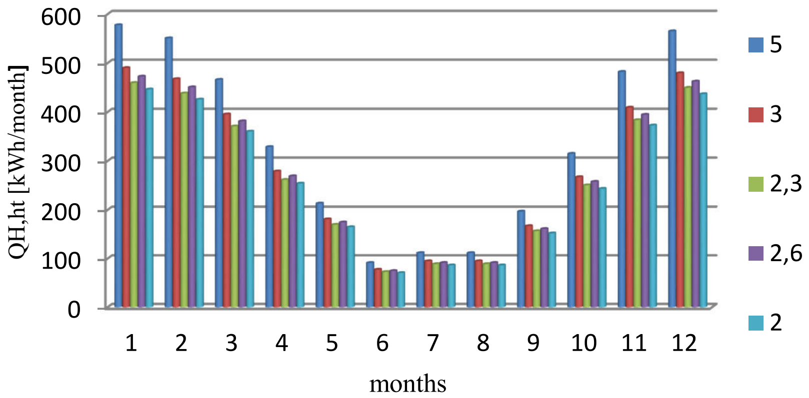

Fig. 7. Losses of heat energy depend on the kind of a window.

The greatest loss of heat coming from the windows appears in the winter months (January-March and November-December) and the smallest in the summer months from June to August. In this case, the worst results were obtained, regardless of the month, in window 2, while the other windows have values closer to each other. Fig.8 analyzed the annual heat demand for the test windows.

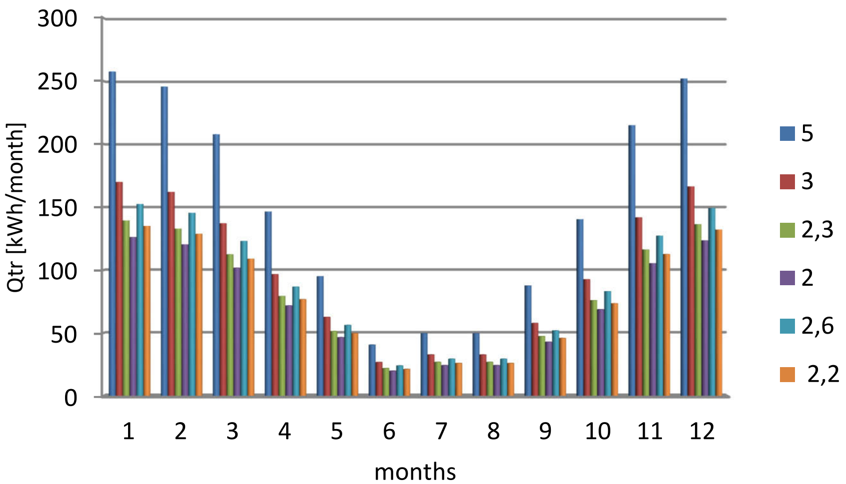

Fig. 8. The annual energy consumption for heating the test room depends on the kind of a window.

The graph shows the results of calculation of the heat demand of the room depending on the change in the type of windows, [1]. Single-windows greatly increase the heat demand of the building (as 50% greater than the other) which is very disadvantageous. The demand for heat is the lowest in the case of the window in the system 1, and comparable to much larger window, type 4 single-glazed window with glass composite twin-chamber and 6. Windows type 3 double-glazed units in single-chamber and 5 composite double glazed windows to higher demand by about 10% higher than the windows kind 1, 4 and 6.

5.2 Energy consumption for lighting of a room

Table 1 shows the results of calculations of demand for the lighting of a room depending on the applied controls: manual control and automatic (as in the case of an intelligent lighting management system).

Table 1. Energy consumption demand for lighting control, in depends on manual or automatic.

	manual control (kWh/m^{2}year)	automatic control (kWh/m^{2}year)
E_l	1,51	1,24
E_{kl}	135,87	111,28
E_{pl}	407,61	333,83

In the test room it adopted normative duration of lighting for classrooms with a value of 1800h / year. The use of light for manual control is 10% higher than in the case of automatic control. Usage of a light sensor daylight using HDR declined the operation time of lighting during the day by adapting accordingly their intensity and reducing electricity consumption for lighting, [5]

6 Summary

In order to optimize the energy balance of the building and the use of the phenomenon of free heat gain, we should take into account the impact of lighting sunlight at the design stage.

The energy consumption during the year is changing: it is the highest during the summer while the lowest during winter. Heat gains through windows are relatively similar throughout the year, hence a greater impact on energy losses through the buildings which have windows. Loss of heat and energy through the window openings is the greatest in the winter.

The size and the insulation of windows have a decisive influence on the amount of heat loss. The study of cubic kind of windows depends on their design. It noted the influence of selection of appropriate properties joinery building on the gains and losses of heat during the year.

The most economical use of energy in the building is the type of windows Type 1. window box triple or Type 4. single-glazed window with glass composite twin-chamber or Type 6. composite triple glazed (one single-chamber glass unit). The least favorable in increasing energy demand is Type 2. single glazed loom window. Type 3. windows double-glazed unit in single-chamber and Type 5. window composite double glazed window have on average about 10% larger energy consumption compared to windows Type 1, 4 and 6.

Considering the construction of windows and their function (partition transparent), windows are ones of the main elements of the building, which has a significant impact on its thermal characteristics. As a result, it can be concluded that the selection of windows in the building during the upgrade to a better and more efficient performance affects to a fairly large extend the overall energy demand, which in large residential buildings and offices reduces the overall consumption of thermal energy of the building. The windows are very important

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when planning energy-efficient refurbishment. The windows largely determine the heat balance of the building, not only the loss but also the profits (sourced in a passive solar energy). Transparent partitions are responsible for an average of 15-25% of heat loss. Therefore, the important thing is the imposition of appropriate standards for the selection of windows for the building renovation and new buildings, not only in terms of the efficiency of heat transfer through the window but also for the whole structure. Further cost reductions can be achieved (due to maximize of use a daylight to illuminate the room) by using automatic lighting control systems.

By controlling the light intensity during the on and off switching, the lighting system allows for optimal use of natural light, which not only reduces the consumption of electricity for lighting by 10-15% but also increases user's comfort. The use of daylight sensors captures real luminance sky dome using HDR images which contributes significantly to the energy consumption for artificial lighting on intelligent systems.

All these measures result in reduced demand for heat in buildings, and the use of non-renewable fuels and heating oil. Reducing the energy consumption of buildings affects not only the building itself, but the whole environment.

References

1. CIE Standard General Sky Guide: Technical Report (2015).
2. D. Chwieduk*, Wytyczne Tworzenia Koncepcji Energetycznej Budynku*, Budownictwo, Rok 109, Zeszyt **3**, 2-B/2012
3. S. Darula, R. Kittler, H. D. Kambezidis, A. Bartzokas, *Guidelines for more realistic daylight exterior conditions in energy conscious designs*, National Observatory of Athens Institute of Environmental Research and Sustainable Development and Institute of Construction and Architecture Slovak Academy of Sciences Bratislava, Athens (2000)
4. E. Klugmann-Radziszewska, *Odnawialne Źródła Energii Przykłady Obliczeniowe*. Gdańsk, (2009)
5. E. Piotrowska, M. Zajkowski: Modernizacja infrastruktury budynków a ich właściwości środowiskowe i energetyczne, V Międzynarodowa Studencka Konferencja Naukowa : Inżynieria Środowiska Młodym Okiem, Białystok, 2016
6. E. Piotrowska: Modelowanie natężenia oświetlenia dziennego w programie DIALux, Zastosowania Komputerów w Elektrotechnice : ZKwE'2016 : XXI Konferencja Naukowa, Poznań, 2016