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INFLUENCE OF THE DEPTH OF THE FRAME ON ROOM ENERGY BALANCE ACCORDING TO ENERGY CONSUMPTION

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Abstract: The article discusses the impact of the size of the shading caused by natural obstacles as the depth of the frame on the heat balance of the room, thus the selection and size of air conditioning equipment. Taking into account this phenomenon on the design stage, we are able to avoid wrong device selection, and thus reduce cost of whole installation. A thorough analysis of the affection of shading in passive construction through the use of shading elements, is an opportunity to reduce the flow of solar energy in the summer and thereby improve the energy consumption of the building.

Keywords: heat increment, cooling capacity, solar radiation

1. INTRODUCTION

It is common practice that during the counting of heat gains through transparent partitions is not taking into account the depth of shading caused by frames (areas transverse to the plane of the wall at the opening of the window or door).Without taking into account this natural obstacle to solar radiation, affect the calculation of the balance of profits sensible heat to the room, which significantly influences on the choice of air-conditioning equipment, their power, and the cost of investment. The reason shading can also be various types of shading roof, which advisability of use results from the need of reduction of direct impact of solar radiation on the increase in air temperature in the room. High temperature creates a discomforting conditions for people in room, noticeable especially on large areas of glazing (60%). Roofing should

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be designed to create in summer greatest possible shading of windows (especially from the south), and during the winter, to allow access to solar radiation as greatest as possible. An example of analysis of the annual cooling energy demand (kWh) for different sizes of area of glazing (30, 60%) for the three types of building partitions (Reinforced concrete 0.6 m, 0.19 m Styrofoam, Porotherm 0.3 m + insulating. 0.15 m), is shown in Fig. 1 and 2.

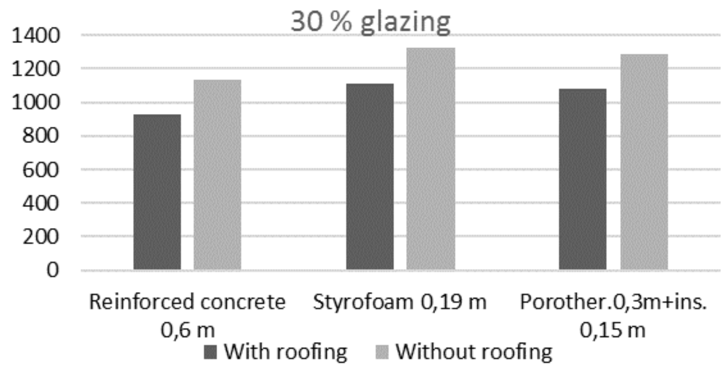

Fig. 1. Annual energy demand for cooling energy for the three types of walls (glazing 30%) with and without roofing

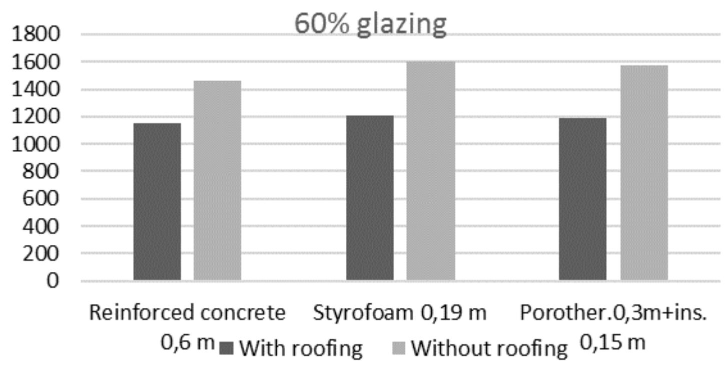

Fig. 2. Annual energy demand for cooling energy for the three types of walls (glazing 60%) with and without roofing

Fig. 1 and 2 shows that for analized partitions at 30% of glazing, roofing regardless of the type of wall reduces the energy balance of the room by about 17%. But for 60% of glazing, decrease in energy demand was 24%, as well as the need for air-conditioning energy (Kucypera and Nowak, 2009).

2. THE METHODOLOGY OF THE RESEARCH PROCESS

The method of analysis was to determine the energy balance of the room for several types of frame depth - from 0.3 m to a depth of 0.0 (window flushed with the outer wall). By doing that, overall balance of heat gains for all rooms was created. In addition for selected loads, air balance due to the sensible heat gains was calculated. Then calculated the required theoretical power of cooler was calculated. The calculations were based on the formulas given in the literature.

The method of calculating heat gains from the sun, taking shading into account:

$$Q_{OK} = F\left[\Phi_1 \cdot \Phi_2 \cdot \left(R_S \cdot J_C + R_C \cdot J_R\right) + K\left(t_Z - t_P\right)\right], W \tag{1}$$

where

F – windows in the wall surface; for the room, m^2,

Φ_1 – factor related to the participation of the glass in the window surface,

Φ_2 –factor related to the type of glass, number of windows, devices for protection from solar radiation,

J_C,J_R –the temporary value of the total solar radiation and scattered solar radiation (depending on the exposure direction and time of day), penetrating into the room through the double glass window made of normal glass for July 23, W/m^2,

R_S– the ratio of area which is absorbing solar radiation to whole area in the wall surface,

R_C– the ratio of shady area to whole area in the wall surface,

k – heat transfer coefficient for the window, W/m^2·K,

t_p– inside room temperature, °C,

t_z – outside air temperature, °C

The method of shading calculation (Malicki, 1980):

The width of the shade vertical strip on the window caused by the recesses *a* and *d*:

$$I_c = (d + a) \cdot tgB - e, m \tag{2}$$

Horizontal shadow belt height, produced by the recesses a and c:

$$h_c = (c + a) \cdot \frac{tgH}{\cos B} - b, m \tag{3}$$

where

a, b, c, d, e - see Fig. 3.

B - The solar azimuth of a vertical wall (shown in Tab. 1.)

H - height of the sun (shown in Tab.1.)

Shaded surface is calculated from the formula:

$$F_c = H \cdot I_c + (L - I_c) \cdot h_c,\ m^2 \tag{4}$$

Sunlit surface of the window is determined from the formula

$$F_s = H \cdot L - F_c,\ m^2 \tag{5}$$

The ratio of the shaded area to the area of window, in the wall surface is:

$$R_s = \frac{F_c}{H \cdot L} \tag{6}$$

In contrast, the ratio of the area which is absorbing solar radiation to the area of window, in the wall surface is:

$$R_c = 1 - R_s \tag{7}$$

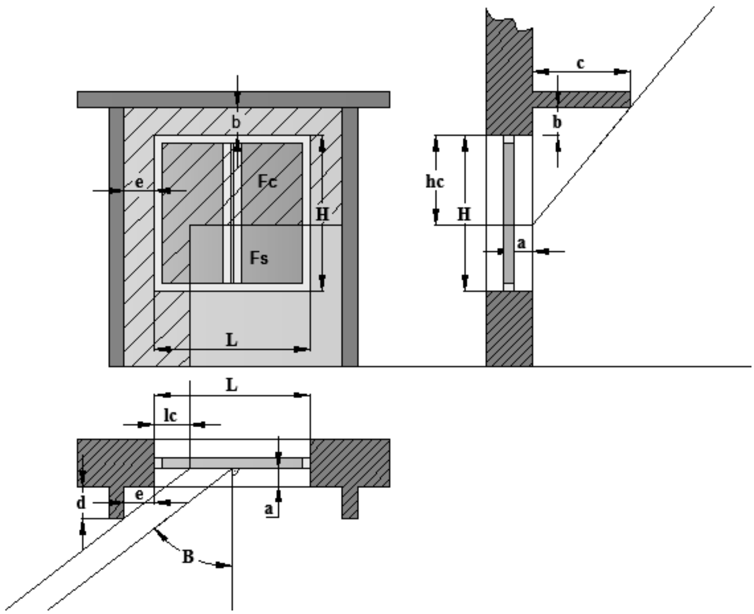

Fig. 3. Shading caused by recesses, *B* - azimuth of the sun, *H* - height of the sun, *Fc* - shaded area, *Fs* - the area which is absorbing solar radiation, *L* - width of the window, *H* - height of the window, *hc*-height of the area which is absorbing solar radiation, *lc* - width of shading, and *a,b,c,d,e* - the size of the recesses

Table 1. The height H of the sun, the sun azimuth B [degrees], for Krakow

Solar time	8	9	10	11	12	13	14	15	16	17	18	19	20
H – position of the sun	37	46	54	60	62	60	54	46	37	27	18	9	
B – solar azimuth of vertical wall	98	11 1	129	152	180	208	231	249	262	274	285	296	

3. DESCRIPTION OF THE MODEL

Building, for which the air-conditioning system is designed, is located in Krakow in the second climatic zone for the summer period where the clarity of the atmosphere determined (for the city of Krakow) is, as P4. The building has 2 floors. Calculations was carried out for the first floor, where surface of air conditioned the rooms is 184.5 m^2. During determining the heat balance of the rooms heat gains derived from the people, heat gains from infiltration and lightning was taken into account. Transparent and opaque partitions are also included in the calculation. In addition, gains of heat from electrical equipment located in rooms was also included (Tab. 2). For the calculation of heat gains from people, assumed that the work performed by members of the household is considered to be light physical work (coincidence factor $\varphi = 0.8$). Infiltration is assumed to be 0.2 air changes per hour in the room. Energy-efficient lighting with power of 25 W / m^2 was installed (0.95 coincidence factor). Designing indoor air temperature is 24 °C, its relative humidity – 50%. For the parameters of the outside air, respectively 30 °C, 45%. In rooms where air conditioning is designed air exchange system top-top is used. Tab. 2 presents a brief description of rooms with number of people and devices installed in the rooms. Tab. 3 shows the characteristics and thermal conductivities of building partitions in presented building. Daily characteristics of solar radiation used in calculation was presented in Tab. 4.

Table 2. Characteristics of analyzed room

N.	Type of room	Height	Total surface	Number of people	Volume of room	Installed devices
		m	m^2	os.	m^3	W
1	Sitting-room	3.3	44.1	10	145.5	Televisor 150 W
2	Room nr 1	3.3	26.0	4	85.8	Televisor 150 W
3	Hall	3.3	39.9	0	131.7	-
4	Room nr 2	3.3	30.4	2	100.4	Computer 100 W
5	Bathroom	3.3	12.9	0	42.6	-
6	Room nr 3	3.3	18.9	2	62.4	Computer 100 W
7	Room nr 4	3.3	12.3	2	40.5	Computer 100 W

Table 3. Characteristics of chosen types of particles

Type of particle	Type	λ W/m^2K
Bearing walls	Medium thickness	0.25
Partition walls	Lightweight design	0.4
External windows	Plastic, double glazed, with no shading devices	1.2

Table 4. Daily solar radiation in W/m^2

Orientation	8	9	10	11	12	13	14	15	16	17	18	19	20
N	117	136	150	158	160	158	150	136	117	110	142	91	0
E	582	566	480	336	160	158	150	136	117	93	66	35	0
S	199	328	441	515	542	515	441	328	199	93	66	35	0
W	117	136	150	158	160	336	480	566	582	540	377	156	0
Scattered	117	136	150	158	160	158	150	136	117	93	66	35	0

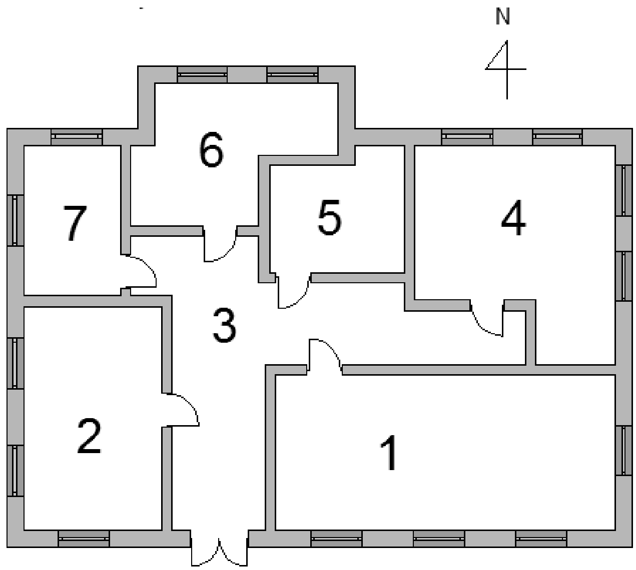

Fig. 4. Diagram of the air-conditioned rooms

The results of the analyzes are presented in the form of graphs, showing the percentage ratio of the shaded window surface (blue) to the surface of window exposed on solar radiation. This directly affects on sunlight stream which comes to the interior. However, the most important information is a graph showing the percentage change in the heat balance for all rooms, and graph of theoretical demand for radiator power and its percentage change with increasing depth of the frames. The following graph (Fig. 3) is shown how the ratio of the shaded area to the sunlit changes depending on the depth of placement of the window in the wall for the window oriented towards the south. This ratio varies most in hours, in which the position of the sun in relation to the wall deviates from an angle of 90 ° relative to perpendicular surface. These results easily illustrate how the heat stream changes, including direct radiation into the room, which is directly proportional to the size of insolation. For 0.3 m size frame, area which is absorbing solar radiation for noon decreased by nearly 35% while for hour 16 solar time this value has decreased by 70%.

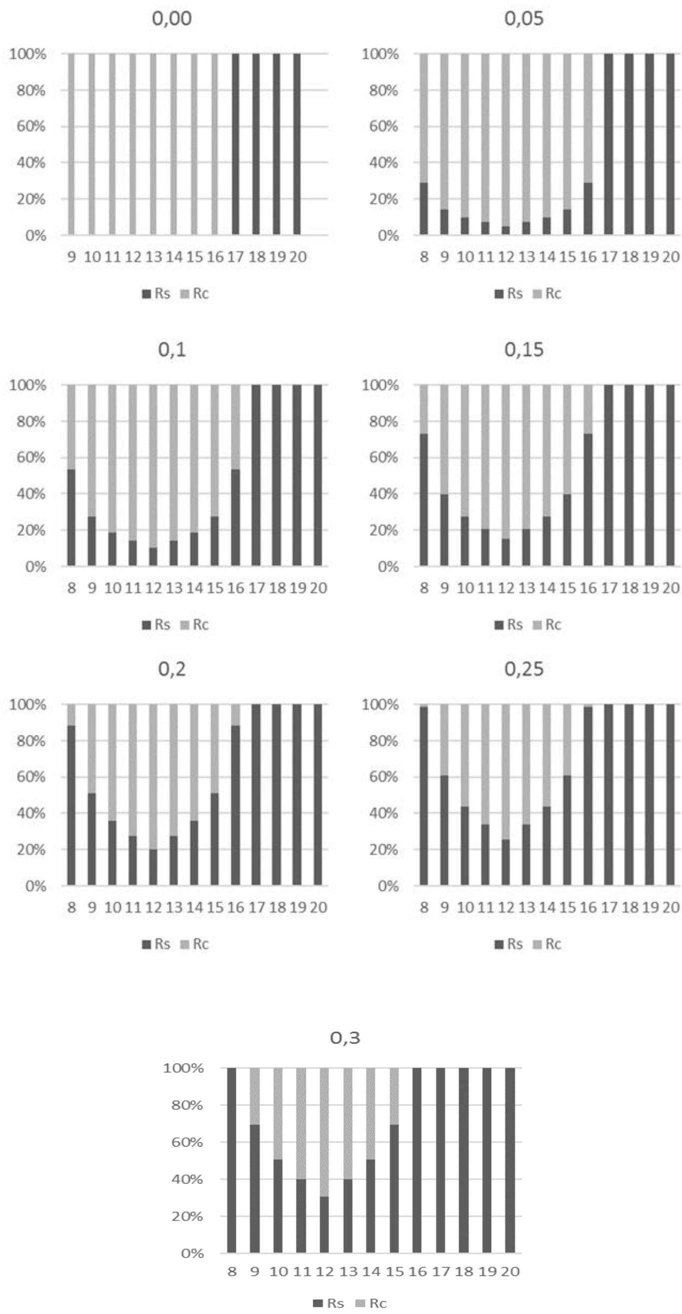

Fig. 5. Charts of changes relation of area exposed on solar radiation to shaded area, where *Rs* - is area exposed on solar radiation and *Rc* - shaded surface

Three-dimensional graph of sensible heat gains (Fig. 6) balanced for all rooms, shows how the value of sensible heat gains for the same parameters of other heat gains during changing the depth of window frame. There is a significant deflection of graph plane with values for solar time between 10-14 hour. This is a result of the arrangement of windows and the change of solar radiation intensity in time.

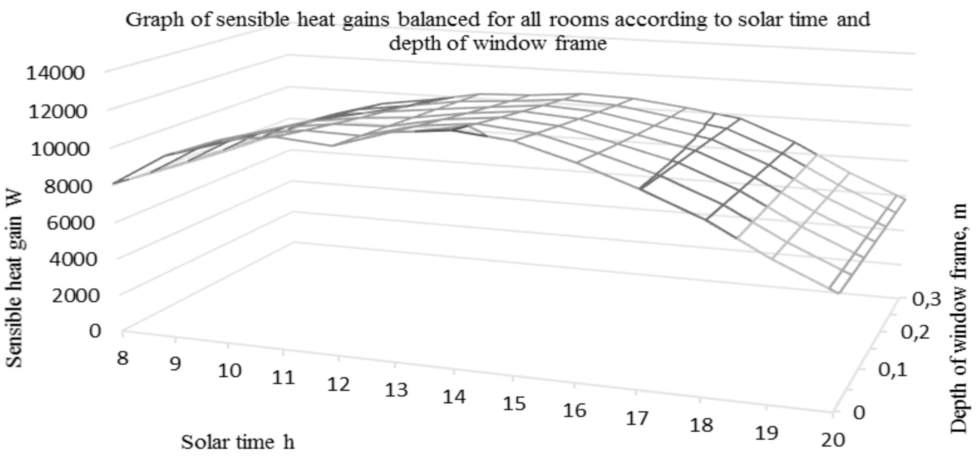

Fig. 6. Chart of the total heat gains

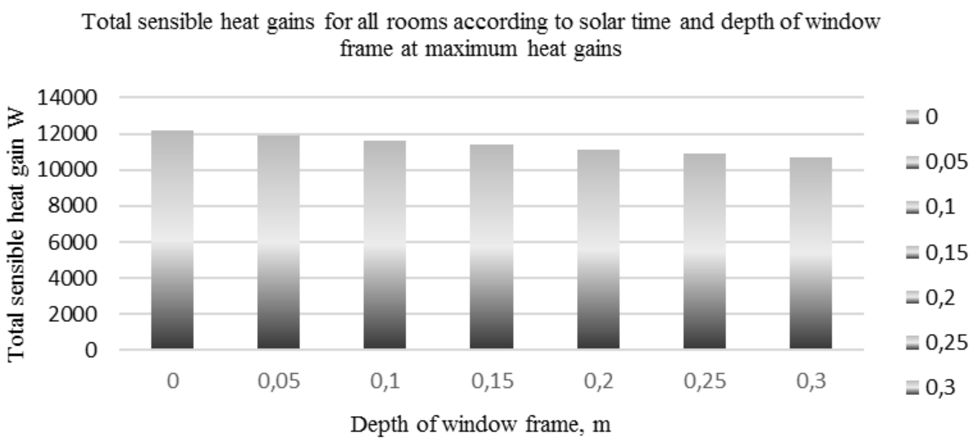

Fig. 7. Chart of the heat balance of rooms for different depths of frame

Fig. 7 shows the thermal balance of the room for different depths of frames at maximum heat gains for all rooms. Chart placed on Fig. 8 shows the change in the total heat gain from all windows for each frame depth depending on solar radiation exposition. The largest differences can be seen between the hours of 10-14 where heat gains make the biggest differences.

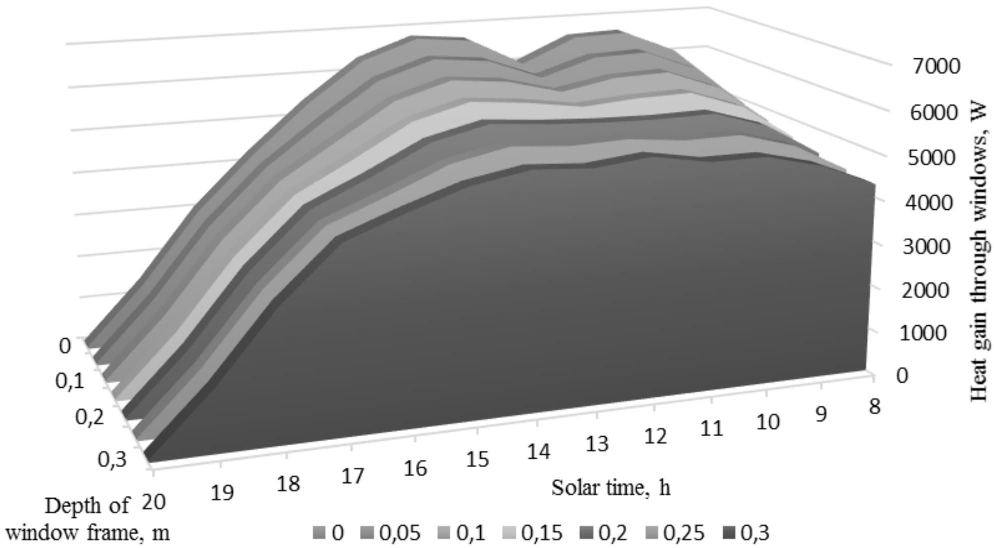

Fig. 8. Diagram of the heat balance of rooms for different depths of frame

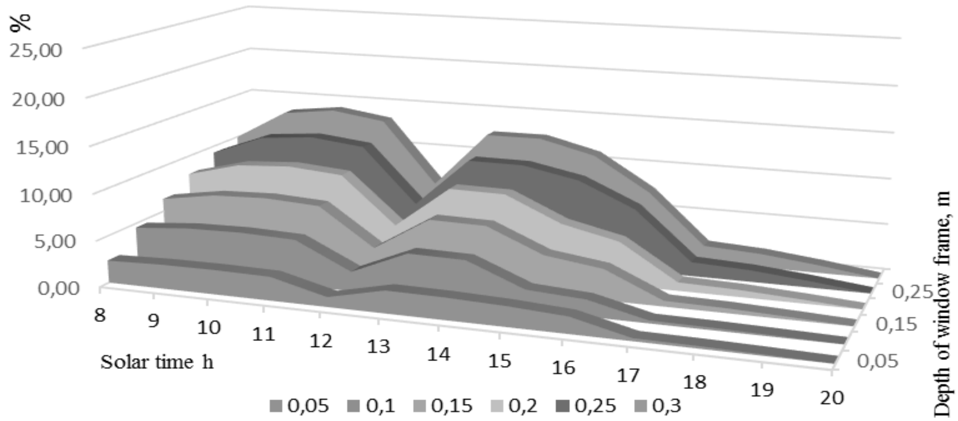

Fig. 9. Graph of the percentage change in size of the heat gains for different sizes of the frame in relation to 0.0 m the depth of frame

Fig. 9 and 10 show the percentage change in size of the heat gains for different sizes of the frame in relation to 0.0 m the depth of frame. Changes were considered in relation to the total profits of sensible heat and in relation to changes in sensible heat gains derived only from solar radiation. Changes in the first case reach more than 14%, what indicates a significant share of solar heat gain. However, in the second case, the changes apply only to changes in solar radiation, at the highest point changes reached almost 24%.

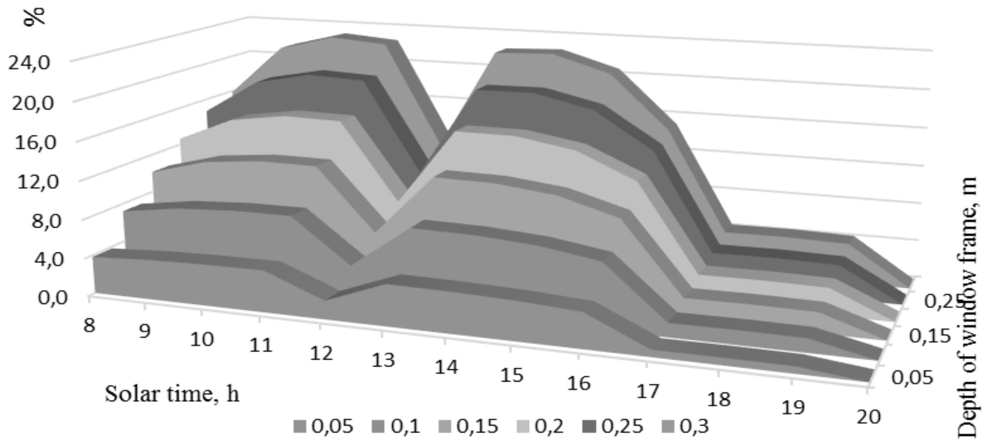

Fig. 10. Graph of the percentage change in size of the solar heat gains for different sizes of the frame in relation to 0.0 m the depth of frame

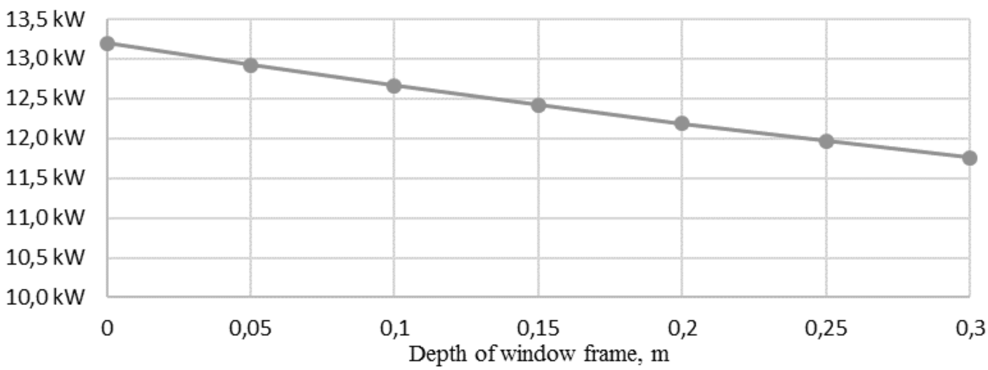

Fig. 11. Diagram of theoretical cooling power

Fig. 11 and 12 show the theoretical cooling power demand for the parameters of supply air at 17 °C, and heat recovery in cross-plate exchanger with 70% theoretical efficiency. The change that was caused by direct solar radiation reached almost 11%

and created a linear relationship. This difference for buildings with much larger areas of glazing and more spaces could cause significant discrepancies that will contribute to the cost of the investment.

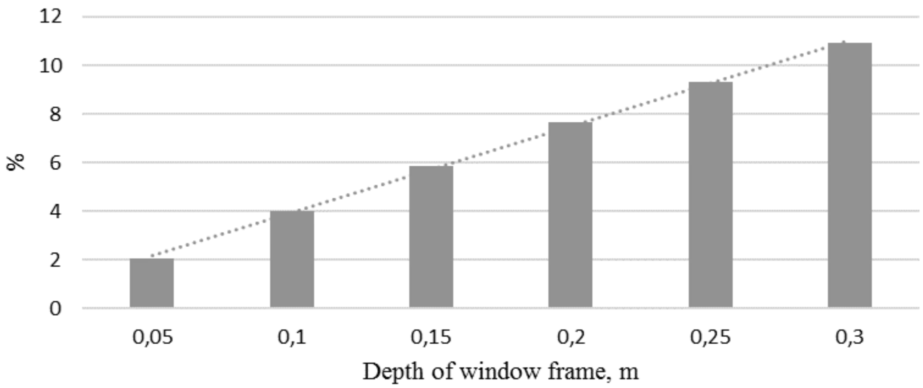

Fig. 12. Diagram of the percentage change in theoretical cooling capacity

3. CONCLUSIONS

From the reviewed data it clearly shows that with the increase in the depth of the location of the window jambs the size of the solar radiation that passes for air-conditioned buildings changes. This reduces the heat balance in the room. Increasing the depth dimension of the frames of 0.0 m to 0.3 m results in a 22.9% change in the amount of radiation that enters into all the rooms. A change of this value, compared to the total heat gain in its maximum point during the day is 14%, which also gives us a significant difference (it should also be noted that the size of glazing of the exterior walls is 18%). The theoretical cooling power demand for each frame size changes from 11.7 to 13.2 kW. This change cause of the difference of 11% for maximum depth of jambs. This changes have linear characteristics. These figures may seem negligible, but on example of a small family house, you can easily tell the difference, which for large volume buildings with a substantial degree of glazing can cause a significant difference. During the design stage, arrangement of windows with shading elements could be designed to restrict to as little as possible access to sunlight in the summer. While in the winter, it should allow solar radiation to reach rooms for the longest possible time.

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