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The Choice of Energy Efficient Thermal Protection of Office Buildings with Different Internal Heat Intake

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Abstract. The annual energy consumption of the building is greatly influenced by the internal heat intake to the premises. Under heating the incoming heat plays a positive role. During the working day, it compensates the heat losses partly or in full. As far as the cooling is concerned, the thermal emissions in the building play a negative role and the specific need for cold increases with the increase in the specific heat emissions. The aim of the study was to identify the dependence of the annual thermal consumption for heating, as well as the needs in cold for natural and artificial cooling of the building, from various factors, such as the shape of the building and its thermal protection. In annual terms, the load on natural and artificial cooling systems is less in the buildings with the lowest thermal protection and with smaller heat access into the room. It is also interesting, that the cooling load is less when the facade is more glazed, since the heat protection of the building is reducing, which only confirms the previous thesis (the heat access from the solar radiation is usually minimal, since the windows in the buildings with cooling are shaded). The smaller the building in volume is, the higher the heat the lowest energy consumption during the year is achieved with the greatest heat insulation. The ratio between the consumption of heat and cold during the year is also an important information, as the cooling of the building requires 3 to 4 times more primary fuel than heating.

1. Introduction.

The appropriate thermal protection of the buildings is important for different countries of the world and should be solved in different ways not only depending on the climate of the construction area, but also both on the mode of operation and the indoor heat access into the premises [1-14]. This article discusses Moscow office and administrative buildings. They differ in heat excesses, which cause the need for cooling of the premises even during the heating period [15]. The greater the thermal protection in the cold season is, the smaller the load on the heating system is. When the building is cooled for a long period of time at an outside air temperature below the room temperature, the energy consumption increases [16].

The aim of the study was to identify the dependence of the annual thermal energy consumption for heating, as well as the electric one for natural and artificial cooling of the office buildings of various size and different portions of the façade glazing, on the thermal protection of the buildings with their different indoor heat accesses. As a result of such a study, the areas of the energy-efficient level of the thermal protection have been provided by determination of the combination of the building size, its façade glazing and specific indoor heat excesses. An energy-efficient thermal protection corresponds to the minimum of the annual energy consumption for maintaining the given microclimate in the office rooms.

2. The method of selection of the energetically feasible thermal protection

The buildings with the same width equal to 20.2 m in external measurement have been subject to consideration. The length of the buildings varied from 13.6 m to 115.6 m. All end walls of the buildings were blind (without windows). The number of storeys made from 1 to 40 storeys. The glazing portion of the longitudinal walls has been presented in two versions: 0.25; 0.55. The windows were dense enough to ignore infiltration. Individual characteristics of some buildings are given in the Table 1.

Table 1. Main geometrical characteristics of the building.

Denomination of the value	The building option					
	1	2	3	4	5	6
Building length, m	13.6	20.4	61.2	88.4	115.6	115.6
Number of floors	2	1	15	24	22	40
Building total area, m^2	549	412	18 544	42 856	51 373	93 405
Area of exterior enclosing structures, m^2	802	729	10 760	22 116	25 638	44 705
Building volume, m^3	2 143	1 607	72 320	167 140	200 353	364 279
Building compactness coefficient	0.567	0.710	0.166	0.143	0.140	0.129

The buildings include four types of the office rooms of the equal size 6.8x10.1x3.9 (h) m: ordinary rooms on the intermediate floors, ordinary rooms on the top floor, corner rooms on the intermediate floors, corner rooms on the top floor. The rooms are of a big depth (10.1 m), which leads to a significant dispersion of heat emissions per unit of the enclosing structures area. For example, in the ordinary rooms of a middle floor the outer enclosing structures have a total area of 26.5 m^2, the corner ones on the top floor – 134.6 m^2.

Three options of the thermal protection of the building have been considered. They differ from each other by the heat transfer resistance of the external walls and coatings. For the variant 1 the thermal resistance of the exterior walls and coverings are approaching to those stated by the formula (5.4) of the Rules SP 50.13330.2012 "Thermal protection of the buildings", as per sanitary and hygienic requirements. The variant 3 of the thermal protection meets the basic standard requirements stating the energy saving items as per the Table. 3 of the above mentioned Rules. For the variant 2, the heat transfer resistance of the outer walls and coverings has been calculated by the formula (5.1) of the above Rules with a 0.63 lowering coefficient for the walls and 0.8 for the coating with respect to the variant 3. For the outdoor enclosing structures the heat transfer resistance values, $m^{2.o}C$/ W, which correspond to the options 1, 2 and 3, are as follows: for the walls: 1.347; 1.704; 2.629; for the coatings: 1.490; 2.871; 3.621. The heat transfer resistance of the windows in all variants is equal to 0.54 $m^{2.o}C$/ W.

The specific heat access to the office rooms has been accounted from 9 a.m. to 6 p.m. and selected at 6 levels: 0 W/m^2, 15 W/m^2, 30 W/m^2, 50 W/m^2, 70 W/m^2 and 80 W/m^2. These values include the solar radiation penetrating through the windows as well.

The attention is drawn to the fact, that in annual energy consumption only the need of buildings for heat and cold to maintain a given thermal microclimate of premises has been investigated. No losses due to an inefficient operation and additional energy consumption for the preparation of the required heat transfer agents of heating and cooling systems were considered. The calculations have assumed that the natural cooling is used at an outdoor air temperature not higher than +5 ° C.

To determine the energy consumption for maintenance of the design indoor climate of the rooms with different enclosing structure thermal resistances provision has been made of the direct calculation of an unsteady thermal regime of the office rooms at various values of the outdoor air temperature. Since the offices do not function all the day round, hence, there are no 24-hour heat emissions, and this explains the unsteadiness of the thermal process. A program for calculation of the non-stationary thermal regime of the room has been adopted as a research tool. It is based on the analysis of the finite differences with the construction of an implicit difference scheme by the heat balance method. The method makes it possible to solve the problem in the most complete formulation in case when the coefficients of the radiant and convective heat transfer change on the surfaces of the enclosing structures without binding the magnitude of the steps in time to these ones in the coordinate and a sufficient accuracy of the got results is provided herewith [17].

The calculations have been performed at 7 different outdoor air temperature values during the year: from the design one for heating to the design one for air conditioning in the warm period of the year. The whole year was divided into 7 intervals, where the selected temperatures were their average ones. The duration of the temperature observation has been determined by [18] and is shown in the Table 2.

Table 2. The number of the outdoor temperature observation days per year

Interval of the outdoor air temperatures, ^{o}C	Average temperature of the interval, ^{o}C	Duration, 24-h days
+21.75≤*t*	+28.5	18
+10≤*t*<+21.75	+15	114
+2.5≤*t*<+10	+5	74
-1.55≤*t*<+2.5	0	8
-6.25≤*t*<-1.55	-3,1	87
-19.2≤*t*<-6.25	-10.4	54
t≤-19.2	-28	9

It is necessary to choose the same heating mode in the building for all rooms with different heat losses. It was accepted that the object should be heated by the Central water heating system in the cold season having local heating devices with temperature control valves, which were set to maintain the maximum permissible temperature in the rooms. To decrease the room temperature to the minimum admissible level by the beginning of the working day, a lowered temperature of the heat transfer agent has been maintained in the heating system at the thermal input to the building in non-working hours. At any temperature of the outdoor air, the heating capacity is subject to two restrictions. First, the heating power should not be greater than the power that supports 20 ^{o}C all the day round in the room. Secondly, there are limits, i.e. the room temperature should not be below 18° C by the beginning of the working day in the heating period and 24 ^{o}C by the end of the working hours. Since the angular room on the top floor is the most cooling down one, the ratio between the required night heat supply and the design power of the heating system at each considered outdoor air temperature should be selected according to this room and be decisive for all premises of the building.

It is clear that the rest of the room does not cool down up to a minimum temperature. As all rooms have individual regulation of the thermal flow. It has been selected individually for each room within the working day in such a way, that by the end of the working hours the temperature could get its maximum. The cooling flows have been selected for each individual calculation option as well.

3. Investigation results

The results of the calculation of the daily heat and cold consumption by the heating and cooling systems showed, that in order to maintain the adopted temperature mode within the same day in the rooms and throughout the building, provision shall be made both of heating and cooling. This thesis is taken into account in the data on the annual amounts of heat and cold needs of the buildings.

The calculations have also showed that a greater thermal protection of the buildings under investigation entailed the increase of the annual cold consumption from the variant 1 of insulation (sanitary-hygienic norm) to the variant 3 (basic rate) 8: 33.9%, and the heat consumption has fallen on 27-86.4% in the considered buildings. The increase in the heat supply to the room from 0 W/m^2 to 80 W/m^2 in the daytime reduces the need for heat by 60-76% in the variant of the thermal protection 1 and 83.9-92% in the variant of the thermal protection 3. The increase in the artificial cold with the

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above specified increase in heat supply makes about 92% in any variant (regardless of the thermal protection).

To summarize the results of the calculations, the total heat transfer coefficient of the building, W/(m^2·^{o}C), has been adopted as the main parameter in accordance with the Rules SP 50.13330.2012 and has been determined by the formula:

$$K_m = \frac{1}{A_e^{sum}} \sum_i \frac{A_i}{R_{o.i}^r}, \tag{1}$$

where A_e^{sum} – the sum of areas of all the exterior enclosing structures of the building thermal protection enclosure, m^2;

A_i- the area of the *i*- portion of the building thermal protection enclosure, m^2;

$R^r_{o,i}$– the reduced resistance to heat transfer of the *i*- portion of the building thermal protection enclosure, (m^2·^{o}C)/W.

This coefficient contains the information about the thermal protection of the building and the size of all external enclosing structures, as shown in Figure 1.

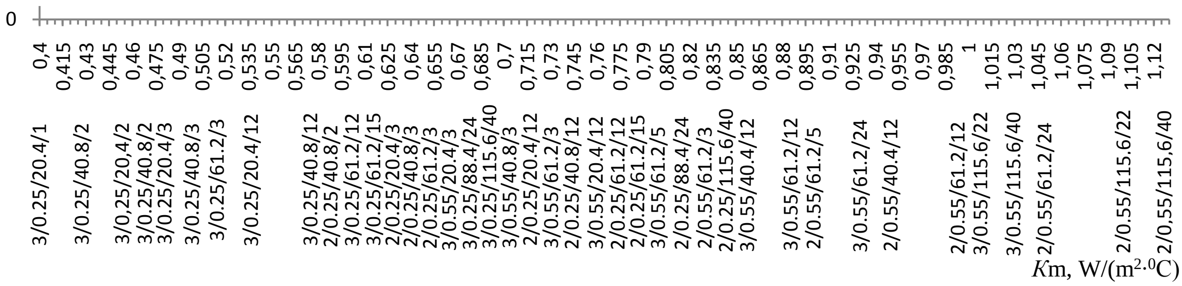

Figure 1. Correspondence of the values of the total heat transfer coefficient, K_m, W/(m^2·^{o}C), to the variants of the buildings under consideration. Consistently specified: option of the building thermal protection, the portion of the façade glazing, the length of the building, m, the number of floors.

It should be noted, that the total heat transfer coefficient K_m increases with a bigger number of storeys of the building due to the fact, that the coating with the highest reduced heat transfer resistance occupies a smaller part of the area of the A_e^{sum} -total area of the thermal protective enclosure of the building. In addition, the K_m decreases with the length of the building, as even in a twelve-storey building the area of the exterior walls and windows increases less than the coverage area. At the same time, it turned out that the facade glazing portion makes it significant independent impact on the level of the appropriate thermal protection, despite the fact that the window size is taken into account in the value of the K_m coefficient. For example, at the same values of K_m coefficients, the value of the specific energy consumption at the 0.55 facade glazing is 1.5 times more than at 0.25 glazing. The less the heat protection is (the bigger the total heat transfer coefficient is), the greater the heat consumption for heating of the building is. So, the thermal protection according to the sanitary and hygienic requirements (variant 1 of the thermal protection 1) leads to 2.5-7 times greater annual thermal needs of the building, than at the basic thermal protection (variant 3 of the thermal protection) at specific heat emissions of 50 W/m^2.

The energy consumption of the building is greatly influenced by its heat emissions. During the heating the heat inflows play a positive role. They compensate a part or all of the heat losses during the working day. Therefore, with specific heat supply of 80 W/m^2, the annual heating consumption is less than this in case of specific heat inputs of 70 W/m^2 and lower. As for cooling, the heat emissions in the building play a negative role and the need for cold increases with greater specific heat emissions.

Looking through the year, the load on natural and artificial cooling systems is less in the buildings with the smaller thermal protection (the variant 1 of the thermal protection), as well as with less heat access to the room. It is also interesting, that the cooling load is less, when the facade is more glazed, since the thermal protection of the building is reduced. It confirms the previous thesis once again. The biggest cooling seasonal loads have been got in the variants of the normative thermal protection (the variant 3 of the thermal protection) at 0.25 façade glazing. Yu. A.Tabunshchikov in [19] writes about the load increase on the cooling systems at a greater thermal protection. We managed to supplement the thesis with a quantitative assessment of this increase depending on the overall heat transfer coefficient of the building [16].

The identification of the energy-efficient thermal protection of the considered variants of the buildings was carried out on the basis of a comparison of the required annual amount of primary fuel. The annual heat consumption of a heating system was calculated in connection with the amount of the primary fuel in 1:1 ratio. For natural and artificial cooling systems, the efficiency of a condensing power plant (on average 0.33) was first taken into account in determining the amount of primary thermal energy, and then the reduction of the power consumption compared to cold consumption due to the conversion factor (COP) was taken into account. Moreover, for natural cooling, the average COP coefficient is taken to be 6.95, and for artificial cooling 3.31[20, 21].

On the basis of the data obtained, provision has been made of a graphical presentation of the areas of the energy-efficient options for the building thermal protection depending on the total heat transfer coefficient of the building K_m, W/(m$^{2.0}$C), and the value of the specific internal heat access. The results of this plotting are presented on Figure 2.

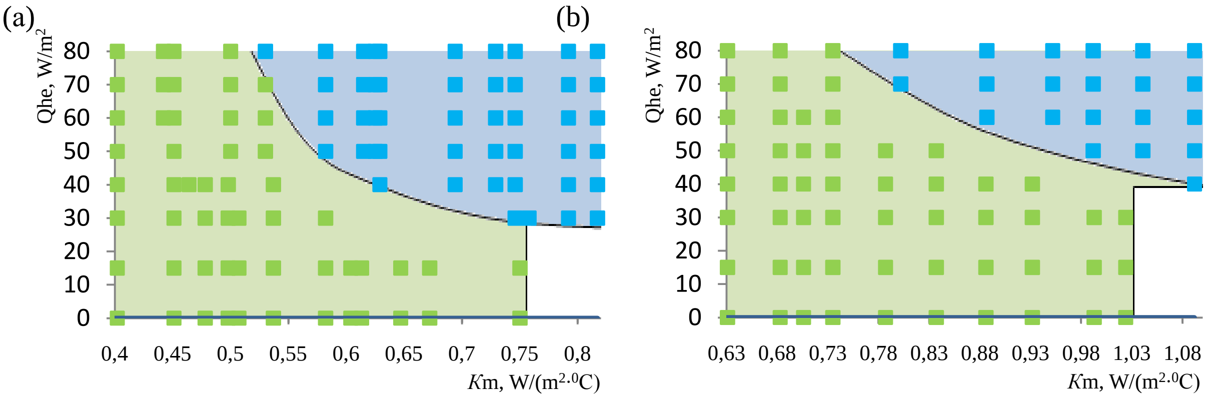

Figure 2. Energetically favorable options of the building thermal protection (a) if the portion of the façade glazing makes 0.25, (b) is the portion of the façade glazing makes 0.55. Legend: blue area-thermal protection with reduced coefficients in relation to the basic thermal protection (variant 2); green area – the basic thermal protection (variant 3).

Uncolored areas in the figure 1 refer to the buildings higher than 40 storeys with sizes in the plan of more 115.6x20.2 m, which have not been subject to the investigation.

4. Conclusions

1. The analysis of the daily and annual energy consumption to maintain the design thermal regime of the office rooms showed, that the buildings with significant internal heat emissions may require cooling in the same day during the working hours, and heating in non-working hours.
2. The supplied heat plays a positive role for heating. During the working day, they compensate for part or all of the heat losses. As for cooling, the heat emissions in the building play a negative role, and the specific need for cold increases with greater specific heat emissions.
3. In the annual context, in the climatic conditions of Moscow, the load on natural and artificial cooling systems is less in the buildings with the least thermal protection. The cooling load becomes less with a greater portion of the facade glazing, as the thermal protection of the building is reduced. The largest seasonal cooling loads have been stated in the variants of the normative thermal protection (variant 3 of the thermal protection), when the portion of the façade glazing is 0.25.

4. The need in the cold consumption by the buildings at the temperature of the outdoor air below the room temperature, is as bigger as bigger the specific heat emissions and the building volume are. Therefore, at high specific heat emissions in the buildings of a large volume, it is energetically advisable to reduce the thermal protection by comparison to the basic one. For small volume buildings provision shall be made of a thermal protection with the basic values of the heat transfer resistances at any portion of the façade glazing. The option of the thermal protection according to the sanitary requirements (the variant 1) is not energetically beneficial for the buildings under investigation.

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