Calculating the load on the room cooling ceiling panel at solar heat gains

E G Malyavina\(^1\) and A G Lomakin\(^1\)

\(^1\)Moscow State University of Civil Engineering, 26, Yaroslavskoe shosse, 129337, Moscow, Russia

E-mail: emal@list.ru

Abstract. It is known from the theory of heat exchange that for the assimilation of the room heat gains that are not constant in time, a cold flow of the same nature that assimilates them must be equal to them in magnitude. This is obvious with respect to convective heat gains that introduce directly into the air. The case is more difficult with the radiant heat gains, since the incoming radiant flow can be directed to one surface, and the assimilating one comes from another. The article aims to check to what extent this provision plays a role in the realities of maintaining a given room microclimate. However, in engineering practice, there are no purely radiant heat assimilating systems. Therefore, as a room cooling system, a ceiling cooling panel has been used, the heat flow from which is of a radiant-convective nature. The radiant load of the room occurred from the solar radiation, penetrating through the windows of various orientations on the cardinal directions. Determination of the load on the cooling system was performed by calculation. Based on the results of the calculation, it was found that the load on the ceiling panel significantly depends on the internal heat stability of the room.

1. Introduction
The role of the thermal stability in forming the load on systems for maintaining a given microclimate of premises for various purposes in the design practice is greatly underestimated [1-7]. Moreover, in Russia, scientists have long established that non-constant in time heat gains of different nature - radiant or convective ones - provide a different maximum load on the room cooling systems [8]. In addition, in premises that are not operated around the clock, the required cold supply for a working day does not coincide in value with the amount of heat gains for the same time [1]. The purpose of this article is to estimate the dependence of the cooling load on the incoming radiant heat from the internal thermal stability of the room. The ceiling panel acts as a room cooling system. The source of radiant heat gains was the solar radiation heat coming through the room windows, which are differently oriented to the cardinal directions, in the climatic conditions of Moscow. This is of interest to find the required maximum capacity of the cooling system and the required flow of cold during the working hours from 9 a.m. to 6 p.m. to maintain a constant resulting room temperature of 24 °C.

Provision has been made of three row rooms on intermediate floors of the building of the same geometry: 4.5 m x 4.5 m in plan and 3.5 m in height with a window 2.0 m x 2.0 m in one outer wall. The rooms had different internal heat resistance mainly due to different interior room finishes:

- with high thermal stability-walls and partitions made of reinforced concrete, ceiling- a reinforced concrete slab, floor-a gypsum slab on a reinforced concrete slab;
with average heat resistance – cement-sand plaster is taken into account on the wall and partitions, the ceiling – a reinforced concrete slab, the floor- the linoleum on a reinforced concrete slab;

- with low thermal stability- the perlite plaster is taken into account on the wall and partitions, the ceiling is a reinforced concrete slab, the floor is a carpet on a reinforced concrete slab.

The room has only one exterior wall with a window. All other enclosing structures are as considered internal ones, that is, they separate the room under design from the other premises with the same temperature conditions. The absence of heat flow is set on the thermal axis of each internal enclosing structure.

To minimize the influence of the heat transfer through the outer wall and the window from the outside environment, the outdoor air temperature has been assumed to be constant during the day and equal to 24 °C. In this case, the sun heating of the outer wall surface was not taken into account, as well as the window filling.

In the ceiling, the cold water circulates all the day round. The temperature of the coolant circulating in the ceiling panel is selected so that the resulting room temperature (the average between the air temperature and the room radiation temperature) does not deviate from 24 °C by more than 0.4 °C in any direction within 24 hours.

The internal surfaces of all the structures enclosing the room are heated by solar heat that penetrates through the window. And initially all the solar heat falls on the floor, and only after heating it, due to radiant and convective heat transfer, the solar heat heats the air and the floor surrounding surfaces.

2. Methods

The influence of the room internal thermal stability on the formation of the cooling load has been estimated by calculation. Many authors resort to calculating the non – stationary thermal mode of a room [9-12]. The calculation of the non-stationary heat transfer through all external and internal enclosing structures has been performed by the method of finite differences in Cartesian coordinates using an implicit scheme when modeling the daily non-stationary thermal regime of the room. A complete system of equations has been solved for the radiant heat exchange between all surfaces facing the room and the convective heat exchange of each surface with the room air [13-20]. When considering the radiant heat transfer, the irradiance coefficients of the surrounding surfaces were calculated for each one, and the sum of these coefficients for each surface was strictly equal to 1.000.

Since the numerical method of finite differences does not enable generalization of the room thermal characteristics to assess their internal thermal stability, the paper uses a characteristic adopted in the theory of thermal stability [8], i.e. the room heat absorption index. The use of this indicator as the main characteristic of the room's thermal stability is all the more legitimate, since a periodic problem is to be solved.

The indicators of the room heat absorption take the following values: with high thermal stability $Y_r=1727$ W/°C, with average thermal stability $Y_r=1099$ W/°C, with low thermal stability $Y_r=430$ W/°C.

3. Results and discussion

The daily heat regime of each room was considered when oriented to three different cardinal directions: East, South and West. The ceiling cools the room due to both the radiant and the convective heat. Figure 1 shows the changes during the day in the incoming solar radiation heat through the windows of different orientation, as well as the convective and the radiant heat flows from the ceiling. Figure 2 shows the changes in the ceiling, air and radiation temperatures of the rooms oriented to the East, South and West, respectively. Jumps in the temperature and heat flow charts are explained by changes in the temperature of cold water in the panel.
Figure 1. Changes in heat flows within 24 hours in a room of average thermal stability, oriented a - to the East, b - to the West: 1 - the intensity of solar radiation, 2- the convective flow from the cooling ceiling, 3- the radiant flow from the cooling ceiling, 4- the total flow from the cooling.

Figure 2. Changes in the temperature 1- radiant, 2- the room air, 3- the cooling ceiling in a room of average thermal stability, oriented a-to the East, b-to the West.
Figure 3. Comparison of a-total heat flows from the cooling ceiling and b- the air temperature of the room oriented to the East at 1-low, 2 – medium and 3 – high thermal stability.

It follows from the figures that during the time when the ceiling temperature is below the air temperature, the air temperature is lower than the room radiation temperature by about 0.15 °C. Herewith, the room receives a cold (negative) heat flow from the ceiling. When the ceiling temperature is higher than the air temperature, the air temperature is lower than the radiation temperature of the room. At this time there is a convective heat influx from the ceiling in the room. The air temperature at this time is higher than the radiation temperature.

To select the power of the cooling system, it is of importance that the maximum heat gains to the East oriented room are observed before the working day, and to the South and West oriented one – during the working hours. Table 1 shows that with the Eastern orientation of the room, the load on the room ceiling cooling system increases with a decrease in its internal thermal stability. The increase in the maximum load on the ceiling panel in the East oriented room in comparison with the maximum heat gains is due to the room overheating before the beginning of the working day. The same tendency to increase the maximum load on the ceiling cooling panel with a decrease in thermal stability persists when the room is oriented to the South and West. However, in these cases, the load is less than the room maximum heat gains.

Table 1. Maximum heat flows into the room and the time of their observation (a).

| Thermal stability of the room | Room orientation to the cardinal directions | Heat gains (W) | Time of maxim al heat gains (h) | Heat gains in working hours (W) | Time of maxim al heat gains (h) | Cooling load (W) | Radiant part of the load (W) | Conve ctive part of the load (W) | Time of maxim al load (W) |
|------------------------------|---------------------------------------------|----------------|-------------------------------|--------------------------------|-------------------------------|-----------------|-----------------------------|-------------------------------|-------------------------|
| Light East                   | 744.5                                       | 7-30           | 623.3                         | 9-00                           | 1100.3                        | 576.6           | 523.7                       | 9-00                           |                         |
From the data in Table 2, it follows that the room is cooled with a slight preponderance of the radiant part of the load. It should be borne in mind that the ceiling cools the room even after the cooling load on the panel stops, since the panel has a heat resistance, as shown in figure 1. In addition, in this case, the load on the cooling ceiling panel falls. Moreover, the maximum load is less than the maximum heat gains.

It is interesting that the maximum cooling load in the East oriented room falls at the very beginning of the working day, since by this time the room is overheated. The greater the thermal stability of the room, the greater the time lag between the maximum load on the cooling ceiling panel and the maximum heat gains. In addition, in this case, the load on the cooling ceiling panel falls. Moreover, the maximum load is less than the maximum heat gains.

When comparing the data in Table 2 – the heat gains per day with the cold gains from the cooling for the same time - it is seen that these flows of heat and cold are almost equal, which means that the calculations are correct. It should be borne in mind that the ceiling cools the room even after the circulation of the coolant on the panel stops, since the panel has a heat resistance, as shown in figure 1. From the data in Table 2, it follows that the room is cooled with a slight preponderance of the radiant component over the convective one.

**Table 2.** Heat gains from the solar radiation coming through the window and cold gains from the cooling ceiling.
As for the difference between the amount of heat gains received during the working hours and the amount of heat received within 24 hours as a whole, despite the fact that the heat gains of the working hours are significantly less than these of 24 hours, the load on the cooling panel modularly approaches the sum of heat availability per day. This result has been got, despite the fact that the set room temperature is maintained only for 9 hours a day. However, it should be borne in mind that the outdoor temperature is assumed to be equal to the temperature that is maintained in the room during the working hours.

Table 2 shows that radiant assimilating flows, rather than convective ones, make up a large proportion of the ceiling panel load. Despite this, the share of convective cooling heat flows in the total cold flow is at least 40%. It is known that when the radiant heat gains are assimilated by convective heat flows, the value of the assimilating flows is less, the higher the room thermal stability. This conclusion is confirmed by the data of the Table 1.

The Table 1 shows that the maximum load values fall on the cooling ceiling panel in the rooms of the southern and western orientations, that is, in the case of overheating of the room before the beginning of its cooling is not great. The overheating heat flow accumulated by the enclosing structures begins to play a dominant role in case of the Eastern orientation of the room.

4. Conclusions
1. The load on the ceiling panel depends significantly on the internal thermal stability of the room.
2. A large role in the load is played by the presence or absence of overheating of the room before it begins to cool.
3. When the heat gains are due only to the radiant energy of the sun, which enters the room through the windows, almost all the heat entering the room during the entire time of its influx is assimilated by the cooling system.

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