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THE INVESTIGATION OF PECULIARITIES OF HEAT AND MASS TRANSFER ON THE ROOF OF THE INDUSTRIAL BUILDINGS AND STRUCTURES

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The main processes of heat and mass transfer are considered during melting snow at the moment when it falls on the glass surface lanterns of the roof in order to maintain natural light and create a minimum snow load on the roof of the structure.

Key words: microclimate, temperature regime, melting snow, translucence, heat flow, heating, thermal calculation, heat- and mass transfer.

Introduction. The creating of the suitable microclimate in industrial buildings and structures in accordance with regulatory requirements is one of the tasks for the increasing the efficiency of workers, reducing the incidence. The appropriate temperature and humidity regime, air exchange and lighting must be provided premises with permanent location of workers. The providing light penetration through fencing is one of the decisive factors for the creating favorable conditions for work. The natural light in combined with artificial lighting can provide some energy savings for artificial lighting. The analyses of literary sources [1-3] shows that the question of melting snow is solved, mainly without deep theoretical research in other areas of the technology. The calculation of the power required for the thermal removal of snow is based on the value of the snow cover height, depending on the apparent density of snow from the temperature of the outside air, the cost of heat for melting snow from an area of 1 m^2 in thickness of 1 cm. This approach is considered the process of snow melting on the surface, which is heated, after some accumulation of snow mass, and in this case this calculation can not be applied because of snow accumulation on the glass surface is unacceptable, that snow melting should occur at the time of loss.

The problem. Of course, with the accumulation of a large amount of snow on the roof may be its destruction. Creation in the construction of high internal temperatures in comparison with the temperature of external air in winter, as well as maintaining the relative humidity of the air depends on the heat engineering solution of the building: heating systems, coolant, the presence of heat from operating equipment, climatic conditions of the construction area and some other factors. Heat flows in the room create positive temperatures on the surface when they accumulate in the upper zone, and the snow melts when it falls on a warm surface of the coating. The observations show that on the glass roof lamps of the normally heated room, the snow melts in the case of fairly intense snowfall. It is known that the lanterns are clean if the room is exploited, and at the same time there is a layer of snow in the non-exploited buildings. The formulas which are proposed now for calculating the amount of heat to remove snow from the coating does not describe the physics of the phenomenon: do not include consumption of heat for heating the melt water, snow water content in a liquid phase. Also, an empirical formula that is used to determine the heat flow from the surface by radiation and convection in the environment does not cover the physical picture of processes.

The purpose of research. The purpose of these studies was the investigation the temperature in industrial buildings and structures and the using of warm air from the upper zone of the room to blowing skylights on the roof. Thus it was expected cleaning of snow and frost cover glass by heating warm air, which will use natural lighting without further purification roof and maximize transparency during snowfall. In addition, the snow load decreases on the roof. The objective is to determine the main objectives of the study: - the studying of the processes of heat- and mass transfer in the melting of snow at the time of falling to the surface of the lanterns; - the construction of an engineering method of heat engineering calculation of a building (structure) under conditions of melting of snow at the time when its fall on a glass surface; - the development of recommendations for the application of some engineering measures that contribute to snow melting on the lanterns.

The results of the research. The basis of the research was the study of temperature regimes on the surface of the roof, at which a film of melt water was formed on this surface with a temperature which is greater than the melting point of snow, i.e. $\tau_m > 0°C$. It was determined that the thickness of the melt water film increases with the increase in the intensity of snowfall under other equal conditions in analyzing the results of calculations. This leads to the decrease of the temperature on the surface, increasing the likelihood of ice formation. The temperature on the surface of the film from melt water may differ from the surface temperature by 0.1 ... 0.15°C, when the temperature of the surface of the lantern glass reaches 1°C. It is necessary the influence of wind to take into account: the increasing of the wind speed in conjunction with the lower temperatures causes the decrease in the thickness of the water film due to more intense evaporation of water. The results of the calculations show that the temperature on the glass surface $\tau_C = 0{,}5°C$ is most favorable for practical calculations of heat consumption to ensure melting of the snow on the heated surface, because only in this case the film of water does not form ice [4]. Calculation of the amount of heat q_1 for temperature $\tau_C = 0{,}5°C$ was carried out with the help of mathematical statistics methods (it was used the method of least squares). Correlation was carried out consistently according to different parameters: P – the intensity of snowfall, kg / (m^2 • h); v – the speed of the wind, m/s; t_o – the temperature of external air, °C. A formula was obtained which allowed the accuracy of calculating the heat consumption q_1 required in the practical calculations to allow for the melting of snow, depending on the intensity of snowfall P and the conditions of its loss (v and t_o) [1]:

$$q_1 = 39{,}2 - 5{,}87t_o + (81{,}3 - 0{,}6t_o)P + (13{,}9 - 3{,}09t_o)v, \quad (1)$$

It is determined that the results obtained under this formula have a relative error of 1.37% with a significance level of 5% in comparison with the standard calculation by a system of equations. The thermal processes were considered in the film of melt water and on its surface to ensure the supply of heat for melting snow intensity P at the time of its fall on the glass surface of the lantern. Figure 1 shows the scheme of heat flows.

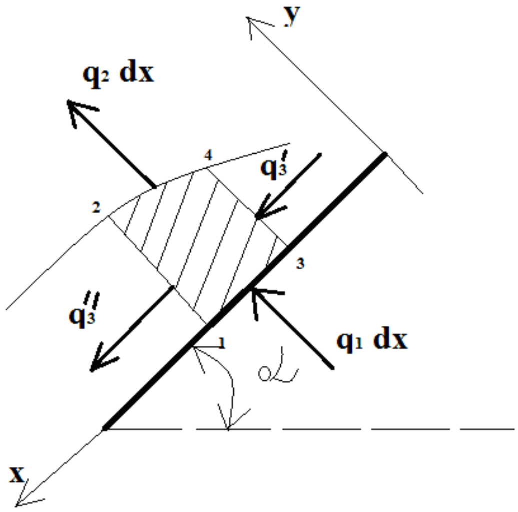

Fig. 1. Calculation scheme of heat flows in the elementary volume of melt water flowing from the slope: q_1 – the amount of heat that enters to the elementary volume through the plane 1-3; $q_3^{/}$ - the amount of heat that flows through the plane 3-4; $q_3^{//}$ - the amount of heat that goes away from the bulk element through the plane 1-2.

The size of the value q_1 depends on the power of the heat source and is not related to the specifics of melting snow. In this case, the steady state is considered, therefore the value q_1 is assumed to be constant over time and along the entire surface of the slope: q_1 = const. Determine the change in the heat capacity of the flow in the elementary volume by the formula:

$$q_3 = q_3^{//} - q_3^{/} , \qquad (2)$$

The planes that limit the selected area are parallel to the plane of the drawing. They are from one another at a distance unit. Heat balance equation of the elementary volume from the film of melt water is as follows:

$$q_1 \cdot dx + q_2 \cdot dx + q_3 = 0 , \qquad (3)$$

We calculate the value q_3 by the formula according to the theory of the boundary layer [6] and using the methods of integral relations:

$$q_3 = 3600\gamma \cdot c \cdot dx \cdot \frac{d}{dx}\int_0^{\sigma_X} t \cdot W_x \cdot dy , \qquad (4)$$

where γ - the weight volume of air at a temperature t_H, kg / m^3; Wx - fluid flow velocity in the cross section x;

$$W_X = -\frac{\gamma \cdot \sin\alpha}{2\mu} y^2 + \frac{\gamma \cdot \sin\alpha \cdot \delta_X}{\mu} y , \qquad (5)$$

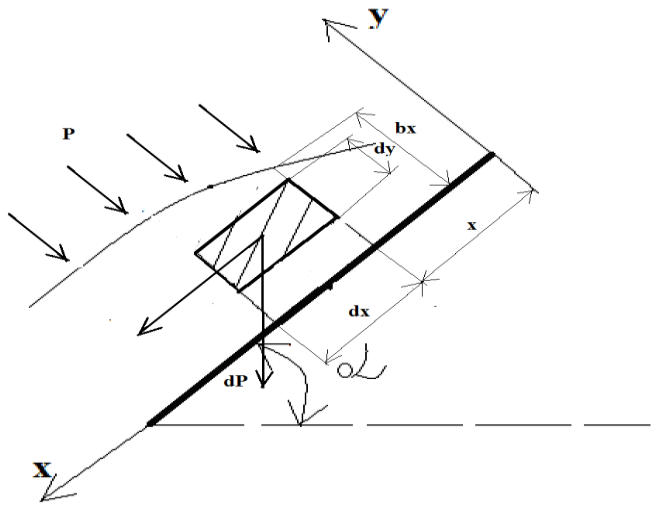

Fig. 2. The interaction scheme of the forces in the elementary volume of melt water flowing from the slope.

The snowfall intensity affects the increase in the amount of fluid flowing through the cross section. The increasing amount of fluid that moves along the slope due to the snow that melts. Also evaporation from the surface increases. Some snow falls $P \cdot d_X \cdot 1$ on the surface $d_X \cdot 1$ and evaporates from the same site $G_{ev} \cdot d_X \cdot 1$. Thus, the change in the amount of water flowing through the cross section $x+dx$ can be expressed as a dependence:

$$dG = (P - G_{ev}) \cdot d_X \, , \tag{6}$$

Let's express the coefficient of evaporation through the wind speed empirical dependence:

$$\beta = 22{,}9 + 17{,}4v \, , \tag{7}$$

Then the mass transfer equation can be written in the form:

$$\frac{d\sigma_X}{dx} = \frac{\left[P - (22{,}9 + 17{,}4v)\left(l_m^o - l_o^o \cdot \varphi_H\right)\frac{760}{P_\delta \cdot 10^3}\right]\mu}{\gamma^2 \cdot \delta_X^2 \cdot \sin\alpha} \, , \tag{8}$$

The equation (8) relates not only the change in the thickness of the melt water film along the length of the rock with the physical parameters of the liquid (γ, μ), the geometric characteristics of the heated surface, but also the meteorological conditions that are associated with snowfall (wind speed v, relative humidity air φ_H and the temperature of the outside air due to the values of the corresponding partial pressures). Proceeding from the calculation that the layer of liquid directly on the surface of the slab under the influence of frictional force is practically not moving, then the thermal flow from the glass to the water film is determined by the equation of heat conductivity:

$$q_1 = -\lambda\left(\frac{dt}{dy}\right)\Big|_{y=0}, \tag{9}$$

The heat flow q_2 characterizes the total amount of heat that goes from the surface of the film of water:

$$q_2 \cdot dx = (q_{ef} + q_C + q_{ev} + q_{hs} + q_m + q_{hw}) \cdot dx \, , \tag{10}$$

where q_{ef} – effective radiation from the surface of the water film in the environment; q_C – amount of heat, which is transmitted from the surface of the film with forced convection; q_{ev} – amount of heat consumption for evaporation; q_{hs} – amount of heat needed to heat the snow; q_m – amount of heat for melting ice; q_{hw} – amount of heat that is used to heat the water flowing down the slope.

The film thickness of melt water close to the ridge of the roof can consider equal to zero. This is the limiting condition for the equation of thermal balance for this section. Increasing the wind speed at lower temperatures of the outside air contributes to reducing the thickness of the water film due to more intense evaporation and reducing the difference between the temperatures τ_{rs} (temperature of the roof slope) and τ_{wf} (the temperature of the outer surface of the water film). The lowest values for v_{min} and P_{max}. Dependences of the values τ_{wf} from P, v, t_o and t_s are presented in Table 1.

Table 1. **The value of t_{wf} in depending of P, v, t_o and t_s**

τ, ºC	v, m/s	t_o = 0ºC				t_o = -10ºC				t_o = -20ºC				t_o = -30ºC			
		P, kg / (m^2 • h)															
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0,5	1	0,46	0,42	0,39	0,37	0,46	0,43	0,40	0,37	0,46	0,43	0,40	0,38	0,46	0,43	0,40	0,37
	5	0,48	0,46	0,44	0,43	0,48	0,46	0,45	0,43	0,49	0,47	0,45	0,44	0,49	0,47	0,45	0,44
	9	0,49	0,47	0,46	0,45	0,48	0,48	0,46	0,44	0,49	0,48	0,47	0,46	0,49	0,48	0,47	0,46
1	1	0,86	0,84	0,82	0,74	0,92	0,85	0,80	0,75	0,92	0,86	0,80	0,76	0,93	0,86	0,80	0,46
	5	0,96	0,92	0,88	0,85	0,96	0,93	0,90	0,87	0,97	0,94	0,90	0,86	0,97	0,94	0,91	0,86
	9	0,97	0,94	0,98	0,90	0,98	0,96	0,93	0,91	0,99	0,96	0,94	0,91	0,99	0,96	0,94	0,92
3	1	2,74	2,53	2,37	2,24	2,77	2,67	2,41	2,40	2,78	2,58	2,42	2,29	2,79	2,59	2,43	2,29
	5	2,90	2,77	2,67	2,58	2,98	2,81	2,72	2,63	2,93	2,83	2,73	2,64	2,34	2,85	2,74	2,65
	9	2,93	2,85	2,77	2,71	2,96	2,89	2,82	2,75	2,98	2,90	2,63	2,77	2,98	2,91	2,84	2,78

The surface temperature of the glass τ_c = 0,5ºC is most favorable for ensuring melting of the snow on the heated surface. In this case, the drop in the temperature of the water film does not provide the creation of ice with the increase in snow intensity in the calculated limits. This is also confirmed in foreign literary sources [4, 5], which states that when designing systems for melting snow for the heating of sidewalks, and other it is necessary to take the temperature on the surface, which is equal to 33ºF, which corresponds to ≈ 0.55ºC. The analysis of physical processes that accompany the melting of snow falling on the slope of the roof allowed to establish a connection between the amount of heat flowing to the slope from the inside, the snowfall intensity, the temperature and humidity of the outside air, the speed of the wind, the thickness of the melt water film and the temperature of its surface.. All these dependences are described by a system of differential equations. Analysis of the results of calculations allowed setting the lower temperature limit of the outer surface of the slope, which provides melting snow at the time of its fall. The expected result of the calculations involves the determination of the amount of heat released in the building, for use as a heat-carrier for the distribution of heated air to the inside of the lanterns of the roof. A well-known formula is used for heat engineering calculation of a building:

$$Q = K_0 \cdot F_w \cdot (t_{in} - t_o), \tag{11}$$

Formula (11) was used in the heat engineering calculation of any construction with the change only in the value of the coefficient of heat transfer K_0. The formation of this coefficient is influenced by external factors such as external temperature, wind speed, solar radiation, humidity of external air, precipitation, and internal factors that characterize the internal climate of the structure and the state of structures of external fences. In general, according to [7], the structure is considered as an energy whole. The calculation scheme of the heat and mass exchange of the heated building is shown in Fig. 3. The system of equations corresponds to the calculation scheme (Fig. 3): - heat balance equation for the whole building:

$$Q_{\mathrm{t}} + Q_{r2} + Q_{c2} + Q_{\mathrm{hs}} + Q_{\mathrm{eq}} + Q_{in} = 0, \qquad (12)$$

- balance equation for moisture in the volume of the building:

$$G_{\mathrm{ad}} = 0, \qquad (13)$$

- equation of constant amount of air by mass:

$$L_{tid} + L_{\mathrm{rem}} = 0, \qquad (14)$$

where L_{tid} – amount of inflow air, m^3/h; L_{rem} – amount of air that is removed, m^3/h.
Flows of heat and mass, which are taken into account by the system of equations (12-14), depend on the engineering solution of heating. According to the technological requirements, solving these systems of equations can determine how much heat is required to provide the appropriate temperature of air in the working area, determine the need for additional humidification or dehumidification of air to maintain the required moisture, determine the temperature of the surfaces of the enclosing structures. These calculations will ensure the creation of the most effective ways to manage the microclimate in the building.

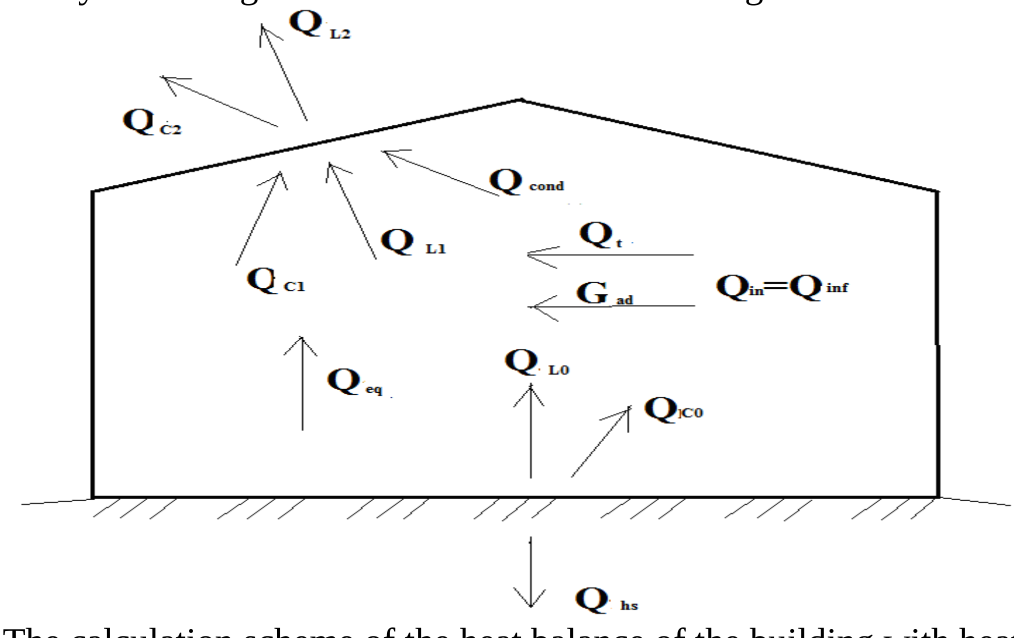

Fig. 3. The calculation scheme of the heat balance of the building with heating.
Q_{R0}, Q_{R1}, Q_{R2} – radiant heat flux according from the ground, to the roof, from the roof, J/h; Q_{C0}, Q_{C1}, Q_{C2} – heat transfer by convection from the ground, to the roof, from the roof, J/h; Q_{cond} – heat release when condensing steam on the roof, J/h; Q_{eq} – allocation of heat from equipment, J/h; Q_t – heat flow from the system of tent heating of the building, J/h; Q_{hs} – losses of heat through the soil, J/h; G_{ad} – additional humidification of internal air, kg/h.
Based on the above calculations, the use of heated air, which rises under the grasshopper roof, for the blow-out of lanterns is proposed. Thus, it will be possible

to reduce the snow load on the roof and lights, to simplify their cleaning, to ensure the natural lighting of the premises. That is why may be formed a comfortable microclimate in the room at relatively small capital costs.

Conclusions. It is estimated that the cost of forced thermal removal of snow from the roof is about 10% of the cost of mechanical removal, and this does not include depreciation of equipment. The need for such a method of removing snow exists because: 1) snow should not be on the glass surface of the lanterns; 2) a large area of glazing excludes the mechanical cleaning of glass from snow, because it can cause its destruction; 3) adoption of a minimum snow load will improve the economic performance of the building.

It is estimated that steel savings from reducing the snow load of 1 kg/m^2 of the roof is about 0.14 kg/m^2. Removal of the snow load by only 10 kg / m2 gives a saving in metal by almost 10%.

REFERENCES

1. Abstract of the dis. Cand.Tech.Sci. Agharkova A.M. - Eagle, 1971. - 36 p.

2. Maximov G. A. The movement of the air during operation of ventilation and heating systems / G. A. Maximov, V. V. Derugin. - L.: Buildpublishing house, 1972. – 99 p.

3. Sukach S. V. System approach to the mathematical modeling of the ventilation systems / S. V. Sukach // Weapons systems and military equipment. — 2016. — № 3. — P. 137-143.

4. ASHRAE **(**American Society of Heating, Refrigerating, and Air-Conditioning Engineers**)**, Guide and Date Book, 1962. Applications for heating, refrigeration, ventilation and conditioning, ch. 76. Melting.

5. Chapman W. P. Heat requirements of snow melting systems / W. P. Chapman and S. Katunich. // ASHRAE, Transactions. - Vol. 62. - 1956. - P. 359.

6. Eckert, E. R. Introduction to the theory of heat and mass transfer. / E. R. Eckert, R. M. Drake. - M.-L. : State Energy Publishing, 1961. - 680 p.

7. Bogoslovsky, Victor Nikolaevich Construction thermophysics (thermophysical basis of heating, ventilation and air conditioning) : a textbook for universities / V. N. Bogoslovsky. – 3-rd ed. - S.-Pb. : ABOK North-West, 2006. - 400 p. - (Engineering systems of buildings). – ISBN 5902146100.

ИССЛЕДОВАНИЕ ОСОБЕННОСТЕЙ ТЕПЛО- И МАССООБМЕНА НА ПОКРЫТИЯХ ПРОМЫШЛЕННЫХ ЗДАНИЙ И СООРУЖЕНИЙ

Мартынова Е.Б.

Ключевые слова: микроклимат, температурный режим, таяние снега, светопрозрачность, тепловой поток, обогрев, теплофизический расчёт, тепло- и массообмен.

Резюме

Рассмотрены основные процессы тепло- и массообмена при таянии снега в момент выпадения на стеклянную поверхность фонарей кровли для поддержания естественного освещения и создания минимальной снеговой загрузки на кровлю сооружения.

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Summary

The main processes of heat and mass transfer are considered during melting snow at the moment when it falls on the glass surface lanterns of the roof in order to maintain natural light and create a minimum snow load on the roof of the structure.