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COMPARATIVE ANALYSIS OF TEMPERATURE CONDITIONS OF ROOMS IN THE PRESENCE AND ABSENCE OF SOLAR RADIATION

Summary. *The article presents the results of a comparative analysis of the temperature conditions of office premises that meet the solution of heat transfer problems in the presence and absence of solar radiation, and establishes the effects of its influence on the heat state of the premises. It is shown that in the presence of solar radiation the air picture and the nature of the temperature fields in the room change noticeably. In particular, under these conditions, the increase in the average temperature of the room for the studied period is 2.5 ºC. It is noted that there is a possibility of some reduction in the load on the heating system in the presence of solar radiation.*

Key words: *heat state of the room; mathematical modeling, solar radiation, energy saving.*

Introduction. Much attention is paid to the study of the heatl state of premises using different energy sources [1-15]. The inexhaustibility and environmental cleanliness of renewable energy sources make them promising for wide implementation in various applications (see, for example, [1]). Among renewable energy sources, solar energy deserves special attention, the use of which is rapidly developing [1; 2; 10].

Important areas of solar energy use include space heating and hot water supply. The results of relevant studies are covered in a large number of works. However, most of them were performed using simplified mathematical models that provide only an approximate idea of the formation of the microclimate in premises under the influence of solar radiation.

The performed analysis of literary sources shows that studies of the influence of solar radiation on the air-temperature regime of premises using modern refined models of flow and radiative-convective heat transfer are relevant.

At the same time, studies of the effects of solar radiation on the formation of the microclimate in premises in the winter period of the year with an increased load of heating systems are of particular interest.

Research results. In order to study the influence of solar radiation on the formation of the premise microclimate, the authors performed computational studies of the air-thermal state in the absence and presence of solar radiation. As an example, we consider the air-temperature regime of a room with two windows and two radiators installed under the windows. The height of the room is 3 m; length 5.6 m; width 6.3 m. The thickness of the external concrete wall is 0.24 m. The internal walls, floor and ceiling are also made of concrete. The thickness of the internal walls is 0.12 m. The windows in the room are single-chamber. The glass thickness is 3 mm. The distance between the glass sheets is 60 mm. The area of the panel radiators is 0.5 m^2. The width of each panel is 10 mm. The distance between the panels is 100 mm. We consider the case when the temperature of the radiator panels is t_r = 40 °C. The outside air temperature is t_{en} = 10 °C. On the side of the external air environment, the heat transfer coefficient value α_{en}=23 W/(m^2 K) is set according to the recommendations in [16]. In the absence of solar radiation, the temperature regime of such a room was studied in [17]. In the presence of solar radiation, it is considered that it enters the room through the window and hits the section of the wall and part of the floor opposite the window. The air-thermal state of the room is described by a system of equations including the Navier-Stokes, continuity and energy equations. To close the system of turbulent transfer equations, the k-ε turbulence model was used. When solving the problem under consideration, the following boundary conditions and conjugation conditions were set.

The following boundary conditions were assumed on the surfaces of the walls of the room

$$u_x = 0; u_y = 0; u_z = 0; k = 0.$$

The condition k=0 on a solid surface is accepted, taking into account that the kinetic energy of turbulence is specified as a half-sum of the squares of the turbulent velocity pulsations. In the nodes closest to the surface, the energy dissipation is determined from the expression $\varepsilon = C_D \frac{k^{3/2}}{\kappa \cdot \Delta n}$, where $C_D \approx 0{,}08/C_{\mu}'$, Δn is the distance from the grid node closest to the surface to the surface itself; $\kappa \approx 0.4$ is the Karman constant.

On the surface of the outer wall and window from the side of the environment, boundary conditions of the third kind are specified:

$$-\lambda_c \frac{\partial T}{\partial n} = \alpha_{en}(T_c - T_\infty),$$

where n is the external normal to the surface.

At the boundary between the window glass and the air gap, the conjugation conditions are set, that is, the boundary conditions of the fourth kind, taking into account the radiant heat exchange between the glass surfaces:

$$-\lambda_{gl} \frac{\partial T}{\partial n} = -\lambda_{air} \frac{\partial T}{\partial n} + q_n.$$

The density of the radiant heat flux q_{sur}, transferred from a surface with temperature T_{w1} to a surface with temperature T_{w1}, is calculated according to the Stefan-Boltzmann law:

$$q_{sur} = \frac{C_0}{\frac{1}{\varepsilon_{w1}} + \frac{1}{\varepsilon_{w2}} - 1} \int \left[\left(\frac{T_{w1}}{100} \right)^4 - \left(\frac{T_{w2}}{100} \right)^4 \right] \frac{cos(\psi_{w1-n_w}) \cdot cos(\psi_{w2-n_r})}{\pi r^2} dF.$$

On the internal surfaces of the window and internal surfaces of the walls, conditions of the fourth kind are also set taking into account the radiant component of the heat flow.

q_{rad}:

$$-\lambda_{wl} \frac{\partial T}{\partial n} = -\lambda_{air} \frac{\partial T}{\partial n} + q_n$$

.

$$-\lambda_{wl} \frac{\partial T}{\partial n} = -\lambda_{air} \frac{\partial T}{\partial n} - \frac{C_0}{\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_{rd}} - 1} \int \left[\left(\frac{T_{rd}}{100} \right)^4 - \left(\frac{T_w}{100} \right)^4 \right] \frac{cos(\psi_{w-n_w}) \cdot cos(\psi_{rd-n_r})}{\pi r^2} dF_{rd}.$$

The surface temperature of the radiator $T = T_r$ is assumed to be given and constant.

The calculation domain includes the internal volume of the room, limited by the walls. Only half of the side walls, ceiling and floor belong to the calculation domain. The second halves of the side walls are considered to belong to adjacent rooms. It is assumed that the temperature regime in adjacent rooms is the same as in the room under consideration. Taking this into account, the conditions of thermal symmetry, i.e. adiabatic $\frac{\partial T}{\partial n} = 0$, are set on the outer boundaries of the internal walls (as well as floors and ceilings). The control volume method was used to solve the problem under consideration.

Solar radiation passing through the window enters the lower section of the wall opposite the window and the floor adjacent to this wall. Accordingly, the boundary conditions on these sections of the wall and floor are set taking into account the density of the heat flux from solar radiation. q_{sol}

$$-\lambda_{wl}\frac{\partial T}{\partial n} = -\lambda_{air}\frac{\partial T}{\partial n} - \frac{C_0}{\frac{1}{\varepsilon_w}+\frac{1}{\varepsilon_{rd}}-1}\int\left[\left(\frac{T_{rd}}{100}\right)^4 - \left(\frac{T_w}{100}\right)^4\right]\frac{cos(\psi_{w-n_w})\cdot cos(\psi_{rd-n_r})}{\pi r^2}dF_{rd} - q_{sol}.$$

The results of calculating the velocity and temperature fields in the room in the absence of solar radiation are presented in Fig. 1. The data are given for the vertical section C-C, parallel to the outer wall of the room, located at a distance of 1.6 m from the inner surface of the outer wall.

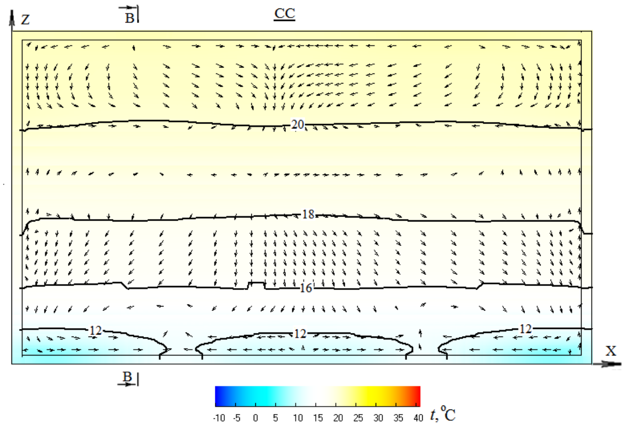

Fig. 1. Fields of air velocity vectors and temperature in vertical section C-C for t_{rd} = 40 °C; t_{en} = -10 °C in the absence of solar radiation

The results of the calculation studies obtained in the presence of solar radiation are shown in Fig. 2. These data refer to cloudless weather conditions on December 22 in Kyiv. The angle of the Sun's altitude, i.e. the angle between the horizon and the beam to the Sun, is at 12:00 in Kyiv γ = 0.28 radians, and the maximum density of solar radiation q_{sol} = 393 W/m^2 (in the complete absence of clouds and dust in the atmosphere). The direction of this flow coincides with the direction from the window cut to the Sun, i.e. is parallel to the beam, which forms an angle of q_{sol} = 0.28 radians with the Earth's surface.

Over time, the angle γ changes, and the density of solar energy flows falling on the wall and floor changes accordingly. In addition, the sky may be partially covered with clouds. Taking this into account, to calculate the effect of solar radiation on the temperature state of the room, it is assumed that in the interval from 11-00 to 13-00 the average time density of the heat flow from the Sun is somewhat less than the value given above. According to estimates, it is q_{sol} ~300 Вт/м^2. The density of the heat flow falling on the floor is $q_{sol,z}$= q_{sol} ×sin(γ), and on the wall opposite the window – $q_{sol,y}$= q_{sol} ×cos(γ). The results of calculating the velocity and temperature fields in the room under the condition of exposure to solar radiation are presented in Fig. 2.

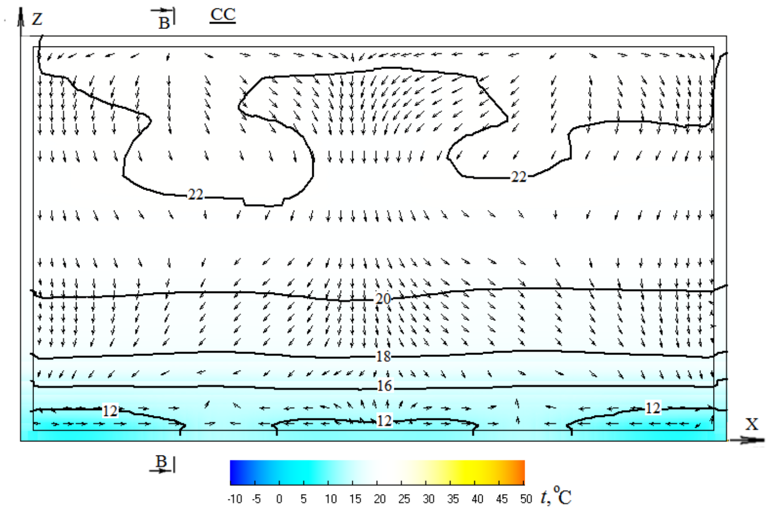

Fig. 2. Fields of air velocity vectors and temperature in vertical section C-C for t_{rd} = 40 °C; t_{en} = –10 °C in the presence of heat input from solar radiation

Comparison of air temperature distribution in Fig. 1, 2 shows that under these conditions solar radiation leads to an increase in air temperature by approximately 2.0 °C. Consequently, in the presence of solar radiation, it is possible to slightly reduce the temperature of the coolant in the heating device while maintaining the microclimate conditions in the room.

Conclusion. Based on the results of a comparative analysis of the air-thermal states of premises that meet the solution of transfer problems in the presence and absence of solar radiation, the effects of its influence on the air flow structure and the temperature regime of the premises were established. It was shown that in the presence of solar radiation, the air flow pattern changes noticeably; this primarily concerns the zone adjacent to the inner wall of the room opposite the window,

Legend

a – coefficient of thermal diffusivity of air; *F* – area; *g* – acceleration of gravity; *k* – kinetic energy of turbulence; *n* – external normal to the surface; *p* – pressure; *r* – distance between a point on the wall surface and a point on the radiator surface; *q* – heat flux density; *T* – temperature, K; *t* – temperature, °C; u_x; u_y; u_z – projections of the velocity vector on the coordinate axes.

Greek symbols

α – heat transfer coefficient; ε – rate of dissipation of kinetic energy of turbulence; ε_w; ε_p – emissivity of surfaces, the values of which are taken equal to 0.8; λ – coefficient of thermal conductivity; ν – kinetic coefficient of molecular viscosity; ρ – density of outside air; τ – time; $\psi_{w\text{-}n_w}$ – angle between the radius vector drawn from a point on the wall surface to a point on the radiator surface and the normal to the wall surface; $\psi_{p\text{-}n_r}$ – angle between the radius vector drawn from a point on the radiator surface to a point on the wall surface and the normal to the radiator surface

Subscripts

t – turbulent, *en* – external environment; *ef*- effective, *rad* - radiant; *air* – air; *rd* – radiator; *wl* – wall; *gl* – glass; *sol* – solar; ∞ – environment;

References

1. Kudia S.O. Non-traditional and renewable energy sources. Kyiv: NTUU "KPI". 2012. 492 p.

2. Basok B.I., Veremiychuk Yu.A. Assessment of the resource potential of solar power generation in the Odesa region. Kyiv: Vydavnychyy dim «Kalita». 2018. 250 p.

3. Fialko N.M., Chernykh L.F. Thermal state of three-layer external walls of a room with floor electric heat-accumulation heating. *Industrial heat engineering*. 2004. 26(5). P. 48-56.

4. Fialko N.M., Chernykh L.F., Postolenko A.M. Influence of the internal frame of the building on its thermal regime. *Window technologies*. 2005. 20-21. P. 44-47.

5. Fialko N.M., Chernykh L.F. Energy-efficient electric heat-accumulating floor heating of residential and public buildings. *Window technologies*. 2005. 22. P. 50–56.

6. Fialko N.M., Chernykh L.F. Theoretical studies of the thermal state of residential and public buildings heated by electric heat-accumulating floor heating. *Window technologies*. 2006. 23. P. 40-49.

7. Fialko N.M., Chernykh L.F. Control experimental studies of the thermal regime of residential and public buildings with a floor electric cable heating system of heat accumulation action. *Window technologies*. 2006. 24. P. 33-40.

8. Chernykh L.F., Fialko N.M., Rozinsky D.I., Savenko V.I. Thermal conditions of premises with environmentally friendly heat-accumulating floor electric heating. Kyiv: Sofia-A, 2014. 404 p.

10. Deshko V.I., Bilous I.Yu., Golubenko O.O., Serdechnyi P.Yu., Yarkova N.A. Evaluation of the school's energy efficiency, taking into account local

renewable energy sources. Integrated technologies and energy saving. 2024. № 1. P. 83-98. https://doi.org/10.20998/2078-5364.2024.1.08.

11. Misiura T.A., Fialko N.M. Calculation Analysis of a Heat Pump Split System Efficiency with Cold Exhaust Air Utilisation. *International scientific journal "Internauka".* 2024. № 5 (160). P. 102-106. https://doi.org/10.25313/2520-2057-2024-7-10154.

12. Scientific and technical foundations of energy-efficient environmentally friendly electric heating of premises, energy saving and energy management. 2nd ed. Revised and supplemented: [monograph] / Under the general editorship of Fialko N.M., Savenko V.I. Kyiv: Center for educational literature, 2018. 472 p.

13. Scientific methods of energy saving, energy management, corrosion control, and efficient process management: monograph / Edited by Fialko N.M., Savenko V.I., Vysotskaya L.N. Kyiv: Center for Educational Literature, 2019. 200 p.

14. Energy-saving environmentally friendly technologies for heating premises and combating corrosion, process control and energy management: monograph / Under the general editorship of Fialko N.M., Savenko V.I., Vysotskaya L.N. Kyiv: Center for educational literature, 2019. 192 p.

15. Misiura T.A., Fialko N.M. Thermodynamic analysis of the efficiency of a heat pump split system with utilization of exhaust air cold. *International scientific journal "Internauka".* 2024. № 5 (160). P. 72-75. https://doi.org/10.25313/2520-2057-2024-5-9950.

16. SBN V.2.6-31:2006. Constructions of buildings and structures. Thermal insulation of buildings. Minbud Ukrainy. Kyiv, 2006. 70 p.

17. Basok B.I., Davydenko B.V., Timoschenko A.V., Goncharuk S.M. Temperature conditions of a room heated by two double-panel radiators. *Energy: economics, technology, ecology.* 2018. № 4. P. 20-26.