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DETERMINATION OF THE HEAT RETURN COEFFICIENT OF THE ICE SURFACE FOR THE MIXED AIR DISTRIBUTION SCHEME

Statement of the problem. Existing dependencies by the determination of the heat return coefficient at convective heat exchange of the ice field surface with the surrounding air does not take into account the characteristics of the movement mode of the ventilation flow for the mixed scheme of air distribution. In this regard, the main interest is the need to offer new or correct existing dependences for determination the heat return coefficient taking into account features of the mixed scheme of air distribution of the systems of air conditioning and ventilation of ice arenas.

Results and conclusions. Based on the similarity criteria equations the dependence by determination of the coefficient of heat return in the convective heat exchange, which takes into account the characteristic regime of the flow of the ventilation stream for mixed diagrams of air distribution is offered. For the accounting of the heat stream connected with loss of condensate on a surface of ice the correction coefficient of moisture loss is entered in received expression. The proposed dependence allows to achieve increase accuracy of calculation of convective heat gain. As a result the energy savings in the engineering systems will be about eight, ten percent.

Keywords: convective heat exchange, the similarity equation, air conditioning, ice arena, the heat return coefficient, the similarity criteria, ventilation.

Introduction

The tightening of architectural, sanitary-hygienic and energy-saving requirements in relation to the newly built or reconstructed facilities of public use leads to the necessity of making accurate the existing and development of new methods and algorithms for the design of engineering systems. In [1, 2] it was specified that covered multipurpose ice arenas belong to the most complex objects of this kind (from the point of view of design and operation).

The greatest difficulties at design of engineering systems of these objects appear in the calculation of the required capacities of refrigeration systems and the air conditioning of the ice field. For example, at a lack of power of the cooling system of the ice field, ice deterioration and misting over its surface are possible. In this regard, the exact calculation of the heat regime of the ice arena, which depends on the heat inflows, caused mainly by negative temperature of the ice surface gets the important role [3].

At steady-state operation the refrigerating appliances of ice field have to compensate heat inflows to the ice surface (Fig. 1), the total number of which is determined by the formula [3]:

$$Q = Q_1 + Q_2 + Q_3 + Q_4, \tag{1}$$

where Q_1 — convective inflow of heat from the air to the surface of the ice, Wt; Q_2 — a inflow of the radiant heat from the ceiling to the ice surface, Wt; Q_3 — heat inflows to the surface of the ice from illuminators, W; $Q_{t.l}$ — heat inflows from people ,Wt.

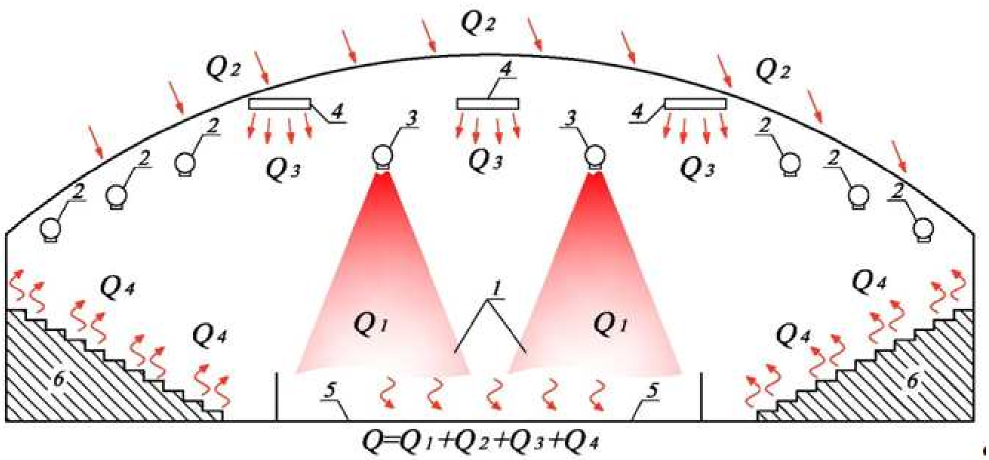

Fig. 1. Schematic diagram of impact of the perceived heat inflows on the surface of ice:
1 — flow of fresh air, 2 — exhaust air ducts of conditioning of spectator stands,
3 — supply air conditioning ducts of the ice field, 4-illuminators, 5 — ice field,
6 — auxiliary facilities of the Ice Arena

Determination of heat inflows from people, ceiling and illuminators has been considered in details in the work [3], the greatest interest in the solution of equation (1) is the determination of the convective component of the total number of inflows of heat to the surface of the ice.

1. Determination of heat inflows at convective heat exchange

After analysis of literary sources about convective heat exchange in is possible to draw a conclusion that in general, the heat stream transmitted to the unit surface of the area dF for elementary time interval $d\tau$ at convective heat exchange [4-10] is determined by the Newton-Richman formula:

$$d^2Q_\tau = \alpha(t_l - t_w)dFd\tau, \qquad (2)$$

where α — heat return coefficient, Wt/(m^2°C); t_l — the temperature of the liquid (gas), °C; t_w — the temperature of the wall (surface), °C.

For the considered problem, at constant values of α, t_l, t_w, the formula (2) becomes:

$$Q_{t.k} = F_i\alpha_{kon}(t_{l1} - t_w) = F_i\alpha_{kon}\Delta t, \qquad (3)$$

where F_i — the area of the ice rink, m^2; α_{kon} — the coefficient of heat return to the ice surface, W/(m^2°C); t_{l1} — the air temperature in the zone of the ice field, °C; t_{w1} — the temperature of the ice surface, °C

The intensity of the convective heat exchange is characterized by a heat-return coefficient, which is generally a function of the following parameters (see [5]):

$$\alpha = f(F, l, w, \lambda, c, v, \rho, t_w, t_l), \qquad (4)$$

where F — a characteristic geometric shape of a surface of the heat exchange; l — the characteristic size of a surface of the heat exchange; w — velocity of movement of liquid or gas; λ — heat conductivity coefficient; c — heat capacity; v — kinematic viscosity; ρ — density.

In the modern domestic and foreign techniques [3, 11, 12], the coefficient of heat return is recommended to determine by empirical formulas:

$$\alpha_{kon} = 1,31\sqrt[4]{t_{l1} - t_{w1}}, \qquad (5)$$

$$\alpha_{kon} = 3,41 + 3,55 v_{w1}, \qquad (6)$$

where v_{w1} — air speed at an ice field, m/s, which is recommended to take equal 0.25 m/s [3, 12].

Equations (5) and (6) have obvious drawbacks. Thus, in (5) rate α_{kon} is determined by average sizes and has empirical character. In the formula (6) the coefficient of heat return is represented as a constant because it is recommended the speed of air above the ice field to take constant and the difference of temperatures between the surface of the ice and indoor air is supposed to neglect. It is not permissible when activities (such as hockey games and high-speed skating competitions), requiring different characteristics of the ice are held.

In work [11] it is pointed out that the given formulas are characteristic for natural convection. For forced convection (the design of outdoor rinks), heat return coefficient is determined by the formula [11]:

$$\alpha_{кон} = 0{,}037\left(\lambda_в / v_в^{0,8}\right) w_в^{0,8} l^{-0,2} \qquad (7)$$

where λ_a — the coefficient of heat conductivity of air, Wt/(m·ºC); v_a — kinematic coefficient of viscosity of air, m^2/s; w_a — the average monthly wind speed in the current period, m/s; l — linear size of a field in the direction of a wind, m.

Fig. 2 shows the dependence of the heat return coefficient on the difference in temperatures between the surface of the field and the air above it. Fig. 2 shows that the values of α_{kon} calculated by formulas (5), (6) and (7) are different, the difference can be more than a hundred percent. At the design of systems of ventilation and air conditioning of ice rink, the most widely spread is the way of mixing ventilation, organized on scheme «top-up» and «top-down».

According to work [13] the most appropriate, in terms of energy efficiency, air distribution scheme is the second scheme, however, in applying this scheme during the cold period of year there can be a need in the additional installation of section of irrigation, the lack of which will cause the gradual drying of indoor air up to not admissible values.

It is offered to avoid it by means of two-stage mixing of recirculated air flows with different parameters using a mixed scheme of air distribution. Supply of inflow air in the mixed scheme is carried out from the upper zone through the air diffusers arranged at an angle along the long sides of the ice field [13].

Removal of air is made from upper and lower zones with the help of air intake located respectively above the ice surface and in close proximity to it (Fig. 3).

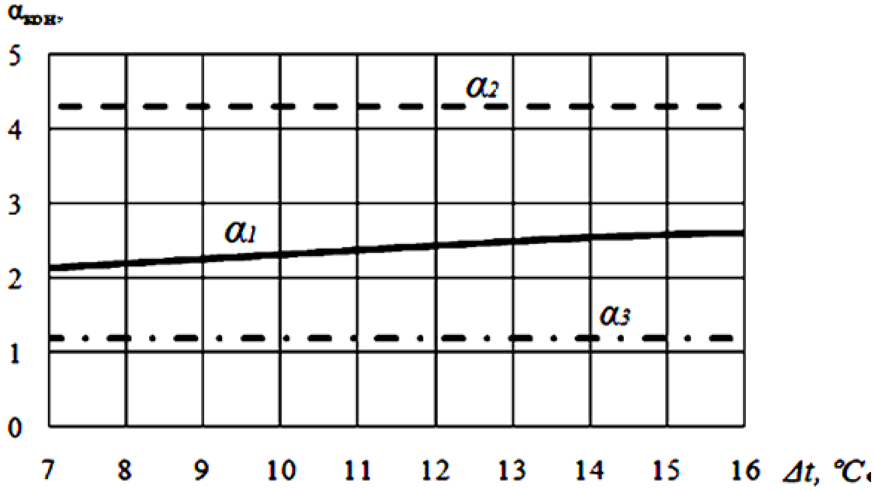

Fig. 2. The dependence of the heat return coefficient at convective heat exchange on the difference in temperatures *Δt*: α_1, α_2 and α_3 — heat return coefficients are calculated according to formulas (5), (6) and (7), respectively

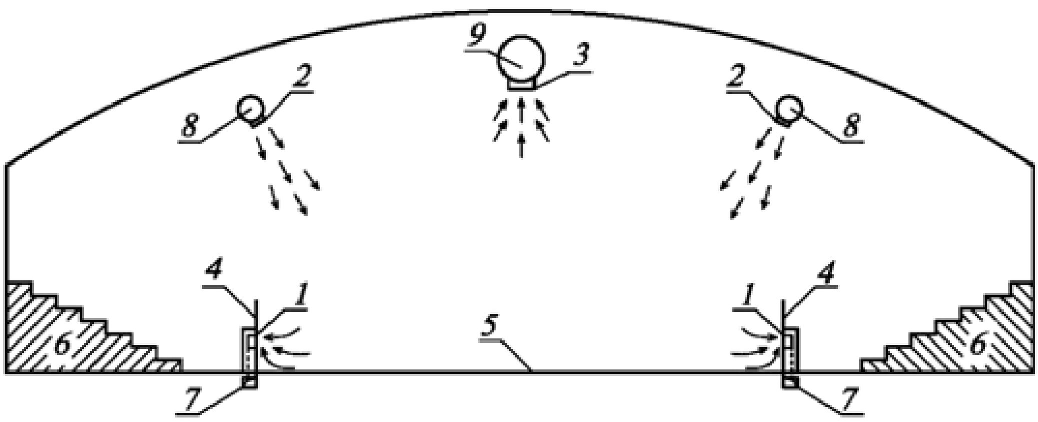

Fig. 3. Organization of distribution of air according to the mixed scheme:
1 –air intakes ice embedded in protecting beads; 2 — supply air diffusers; 3 — exhaust device located above the ice surface; 4 — protecting bead; 5 — ice field; 6 — subtribune room; 7 — exhaust air ducts located in underground channels, 8 — air supply ducts, 9 — exhaust air ducts located over the ice surface

Change of the air distribution scheme in the area of the ice field affects directly the mode of air flow, which in turn affects the intensity of convective heat exchange [13]. As the aforementioned dependences determining heat return coefficient do not consider feature of interaction of ventilated streams with ice at the air exchange organization according to a mixed scheme, there is a need to clarify the existing equations for calculating the heat return coefficient.

2. Application of the theory of similarity in the solution of problems of convective heat exchange

The engineering solution of problems of convective heat exchange is most often consolidated to determination of heat return coefficient on the basis of the corresponding equation of similarity to this case [5]. Relationship between the numbers of similarity, describing this or that process is established on the basis of experimental or field studies. For convective heat exchange usually criteria of similarity of Nusselt *Nu*, the Reynolds *Re* and Prandtl *Pr* are used [8].

Criterion or Nusselt number characterizes the intensity of process of convective heat exchange [6] and is given by:

$$Nu = \frac{\alpha \cdot l}{\lambda_l}, \tag{8}$$

where α — heat return coefficient, W/(m^2·ºC); l — characteristic geometric dimension of the system; λ_l — coefficient of thermal conductivity of the medium (liquid or gas), W/(m·ºC). In the problems of convective heat exchange Nusselt criterion, as a rule, is an unknown quantity, as it includes a defined coefficient α.

The intensity of the convective heat exchange to a considerable extent depends on regimes of fluid flow (liquid or gas) that are characterized by a Reynolds number, called by dimensionless complex and determining the ratio of inertia forces and viscosity [6].

The Reynolds number is calculated from the formula:

$$Re = \frac{w_0 l}{v_l}, \tag{9}$$

where w_0 — the characteristic velocity of the gas (liquid), m/s; v_l — the kinematic coefficient of viscosity of gas (liquid), m^2/s.

Dimensionless complex Prandtl (10) is entirely made up of physical parameters of gas (liquid) owing to what it is such, its numerical values are given in tables [6].

$$Pr = \frac{v_l}{a}, \tag{10}$$

where a — coefficient of thermal diffusivity, m^2/s.

The coefficient of thermal diffusivity, presented in (10) characterizes the rate of change of temperature of substance in the thermal non-equilibrium processes and is given by:

$$a = \frac{\lambda_l}{c_p \rho}, \tag{11}$$

where c_p — isobaric heat capacity of the gas (liquid), kkal/(kg·ºC); λ_l — the coefficient of thermal conductivity of the medium (liquid or gas), kcal/(m·s·ºC); ρ — density of the medium, kg/m^3. The empirical formula describing the convective heat exchange is usually represented as:

$$Nu = C\,\mathrm{Re}^n\,\mathrm{Pr}^m, \tag{12}$$

where C, n and m are constants.

Criteria of similarity entering into such dependences are often inextricably connected with temperature [8] therefore an unknown coefficient of heat return α is also a function of temperature.

3. Specification of dependence for determining the heat return coefficient at a mixed scheme of air distribution based on the similarity theory

As for the air Prandtl criterion is constant and is about 0.71 the similarity equation becomes:

$$Nu = C\,\mathrm{Re}^n, \tag{13}$$

Connection between the components of criterion equation at convective heat exchange of ventilation flows with a horizontal surface has been established on the basis of experimental studies according to which the criterion equation of heat exchange takes the form:

$$Nu = 0{,}524\,\mathrm{Re}_l^{0{,}65}, \tag{14}$$

From the joint solutions of equations (14), (8) and (9) follows that the heat return coefficient is determined by the formula:

$$\alpha = \frac{0,524\lambda_l \left(\frac{v_0 l}{\upsilon_l}\right)^{0,65}}{l}, \tag{15}$$

4. Determination of heat inflows at the convective heat exchange taking into account the condensation of moisture on the surface of the ice field

Since during the experiment did not take into account the heat flow in the formation of condensation on a horizontal surface, typical for the operation of ice arenas, the formula (15) should be adjusted.

The account of the heat flow associated with condensation on the surface of the ice can be made by means of the relative heat return coefficient [11], which is determined by the formula:

$$\alpha' = \alpha \cdot \xi, \tag{16}$$

where ξ — the coefficient of moisture loss, taking into account the evolution of heat during condensation of moisture on the heat exchange surface and is determined by the formula:

$$\xi = \frac{\left(\left(i_a - i''_{w1}\right) - \left(d_a - d''_{w1}\right) i_{w1}\right)}{c_{pa}\left(t_a - t_{w1}\right)}, \tag{17}$$

where i_a, i''_{w1}, i_{w1} — respectively, the enthalpy of the air above the ice rink, the enthalpy of saturated air at the temperature of the ice surface, and the enthalpy of ice; d_a, d''_{w1} — respectively, moisture content in a stream of air over the ice rink and the moisture content at Ice surface temperature at full saturation. Finally, the equation for determining the relative heat return coefficient becomes:

$$\alpha' = \frac{0,524\lambda_l \left(\frac{v_0 l}{\upsilon_l}\right)^{0,65} \left(\left(i_a - i''_{w1}\right) - \left(d_a - d''_{w1}\right) i_{w1}\right)}{l \cdot c_{pa}\left(t_a - t_{w1}\right)}, \tag{18}$$

Thus, the amount of heat accepted by surface of the ice field at the convective heat exchange, taking into account the heat stream associated with the formation of condensate and its freezing point is determined by the formula:

$$Q_1 = \frac{0,524 F_{w1} \cdot \Delta t \lambda_l \left(\frac{v_0 l}{\upsilon_l} \right)^{0,65} \left(\left(i_a - i''_{w1} \right) - \left(d_a - d''_{w1} \right) i_{w1} \right)}{l \cdot c_{pa} \left(t_a - t_{w1} \right)}, \qquad (19)$$

The calculations show that the use of existing dependences for determining the heat return coefficient at convective heat exchange of the ice surface with the air at a mixed scheme of air distribution, overstates the amount of necessary expenses of the cold for systems of air-conditioning and refrigeration of ice field for eight- ten percent. This negatively affects the efficiency of system of ventilation and air-conditioning of the ice arena.

Conclusions

Determination of convective heat inflows to the ice surface at the mixed scheme of distribution of air through the existing formula overstates the amount of necessary expenses of the cold, for system of air conditioning and refrigeration ice field, as dependences of heat return coefficient do not take into account the typical flow scheme of air flow near the ice rink.

This can be avoided by using the refined formulas for determining the heat return coefficient at convective heat exchange, based on the theory of similarity.

The dependence received during experimental studies (18), takes into account the singularity of conditions of flow of air streams near the ice field at the mixed scheme of air distribution, which allows achieving the increasing of accuracy of the calculation of convective heat inflows. As a result, the energy savings in the engineering system will be about eight, ten percent.

References

1. **Mel'kumov, V. N.** Organizatsiya vozdukhoraspredeleniya krytykh mnogofunktsional'nykh ledovykh aren / V. N. Mel'kumov, S. V. Chuykin // Nauchnyy vestnik Voronezhskogo GASU. Stroitel'stvo i arkhitektura. — 2012. — № 3 (27). — S. 29—36.

2. **Mel'kumov, V. N.** Sovremennye sposoby sozdaniya mikroklimata krytykh ledovykh aren i katkov / V. N. Mel'kumov, S. V. Chuykin // Inzhenernye sistemy i sooruzheniya. — 2012. — № 2 (7). — S. 68—73.

3. **Kokorin, O. Ya.** Sovremennye sistemy konditsionirovaniya vozdukha / O. Ya. Kokorin. — M.: Izd-vo fiz.-mat. lit., 2003. — 272 s.

4. **Nashchokin, V. V.** Tekhnicheskaya termodinamika i teploperedacha: ucheb. posobie dlya neenergeticheskikh spetsial'nostey vuzov / V. V. Nashchokin. — M.: Vyssh. shk., 1975. — 496 s.

5. Otsenka akkumuliruyushchey sposobnosti ventiliruemykh ob"emov dlya snizheniya trebuemogo vozdukhoobmena v pomeshcheniyakh / V. N. Mel'kumov [i dr.] // Vestnik Voronezh. gos. tekhn. un-ta. — 2007. — T. 3, № 1. — S. 205—207

6. **Mikheev, M. A.** Osnovy teploperedachi / M. A. Mikheev, I. M. Mikheeva. — 2-e izd., stereotip. — M.: Energiya, 1977. — 344 s.

7. **Inshakov, Yu. Z.** Ekologicheskoe vozdeystvie pozharov na okruzhayushchuyu sredu / Yu. Z. Inshakov, V. N. Mel'kumov, V. S. Turbin // Pozharnaya bezopasnost'. — 2003. — № 1. — S. 62—67.

8. **Mukhachev, G. A.** Termodinamika i teploperedacha: ucheb. dlya aviatsionnykh vuzov / G. A. Mukhachev, V. K. Shchukin. —3-e izd., pererab. —M.: Vyssh. shk., 1991. — 481 s.

11. **Chuykin S.V.** Kharakternye osobennosti organizatsii mikroklimata krytykh ledovykh aren / S.V. Chuykin, O.V. Svishchev, V.S. Sherstobitova, Yu. A. Soya // Inzhenernye sistemy i sooruzheniya. — 2012. — № 4. — S. 59—67.

12. **Mel'kumov V.N.** Sovremennye sposoby sozdaniya mikroklimata krytykh ledovykh aren i katkov // V.N. Mel'kumov, S.V. Chuykin // Inzhenernye sistemy i sooruzheniya. — 2012. — № 2. — S. 68—73.

13. **Chudinov D.M.** Razrabotka algoritma obosnovaniya struktury energokompleksa na baze vozobnovlyaemykh istochnikov energii / D.M. Chudinov, K.N. Sotnikova, M.Yu. Morozov, S.V. Chuykin // Inzhenernye sistemy i sooruzheniya. — 2009. — № 1. — S. 147—154.