HEAT AND GAS SUPPLY, VENTILATION, AIR CONDITIONING, GAS SUPPLY AND ILLUMINATION

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HEATING ENCLOSURES AFTER SWITCHING ON A HEAT SOURCE

Statement of the problem. A research of the dynamics of the non-steady heat transfer in multi-layer enclosures in the presence of heat source indoors is one of the important problems faced in the building heat engineering. Therefore the need for the improvement of the calculation methods arises. The task to design a refined mathematical model of heat transfer and to create a computer program based on this model is stated. To reduce a number of parameters and describe the calculation scheme in the most general form heat exchange equations are presented in generalized variables.

Results. The mathematical model of heat exchange for multilayer enclosures of buildings after switching on a heat source is presented. According to the results of the numerical experiments, relations were identified of changes of enclosure temperatures and showed the effects of the key parameters of transfer process on thermal regime dynamics.

Conclusions. Based on the analysis, the parameters of transfer problem essentially influencing non-stationary heating process of enclosures were defined. The mathematical description of heat exchange processes gives an opportunity for a reasonably easy calculation of steady state of the examined structure.

Keywords: heat source, non-stationary thermal regime, multi-layered enclosures.

Introduction

Studies aimed at developing the methods for calculating non-stationary heat modes of multi-layer enclosures is of particular significance in heat engineering. Considering a non-stationary nature of heat transfer becomes necessary, e.g., when there is a constantly operating heat source in a facility. Heating of enclosures is dealt with in [1, 2], some aspects are looked into in [3—5].

The solutions of a system of differential equations of heat transfer that describe heating of facilities after switching on a heat source depend on a large group of similarity numbers. In order to avoid dealing with too many generalized variables for solving heat transfer tasks, [6] discussed the simplest model of a facility which includes a heat source and thermally thin enclosure. Even though being rather inaccurate, the obtained data has a limited significance, it enables a parameter analysis of a non-stationary heat transfer in a facility as well as the resulting heat mode.

This paper is a logical follow-up of [6] attempting at showing the dynamics of heating multilayer enclosures after switching on a heat source. Heat is supplied to the inside of the enclosure from a convection and radiation source all at the same time and rejected from the outside by means of convection.

1. Mathematical description of heat transfer. Calculation method

The task of radiative and convective heating of enclosures includes a heat transfer equation for certain layers of the structure and corresponding boundary conditions:

$$\frac{\partial \theta_i}{\partial Fo} = A_i \frac{\partial^2 \theta_i}{\partial X^2}; \quad i = 1, 2, ...m; \quad \theta_i = \theta_0; \quad Fo = 0;$$

$$-\frac{\partial \theta_1}{\partial X} = Bi_н (\theta_н - \theta_1); \quad X = 0; \quad \Lambda_i \frac{\partial \theta_i}{\partial X} = \frac{\partial \theta_{i+1}}{\partial X}; \quad \theta_i = \theta_{i+1}; \quad X = X_i;$$

$$\frac{\partial \theta_m}{\partial X} = Bi_{вн} \left[\theta_c(Fo) - \theta_m \right] + Sk \left[\theta_c^4(Fo) - \theta_m^4 \right]; \quad X = 1.$$

As shown in [6], the temperature of a heating medium after switching on a heat source changes in time roughly based on the exponential law

$$\theta_c(Fo) = 1 - (1 - \theta_0) \exp(-Pd \cdot Fo),$$

where Pd is Predvoditelev number that characterizes the intensity of temperature change in time [7].

In the calculation the ratios were used that were obtained based on the method of elementary balances and dispersion of a composition body into homogeneous elements [8].

The calculation point is inside the *i*-th layer:

$$\theta_{n,Fo+\Delta Fo} = \theta_{n,Fo} + \Delta Fo \cdot N^2 (\theta_{n-1,Fo} - 2\theta_{n,Fo} + \theta_{n+1,Fo}).$$

The calculation point is in between the *i*-th and (*i*+1)-th layers ($n = n_i$):

$$\theta_{n_i,Fo+\Delta Fo} = \theta_{n_i,Fo} + \frac{2}{1+K_i} \Delta Fo \cdot N^2 \left[K_i (\theta_{n_{i-1},Fo} - \theta_{n_i,Fo}) - \theta_{n_i,Fo} + \theta_{n_{i+1},Fo} \right].$$

The calculation point is at the interior boundary of the shell ($n = n_m$):

$$\theta_{n_m,Fo+\Delta Fo} = \theta_{n_m,Fo} + 2\Delta Fo \cdot N \sqrt{\frac{a_m}{a_1}} \left\{ Bi_{вн} \left[\theta_c(Fo) - \theta_{n_m,Fo} \right] + Sk \left[\theta_c^4(Fo) - \theta^4_{n_m,Fo} \right] \right\} -$$
$$- 2\Delta Fo \cdot N^2 (\theta_{n_m,Fo} - \theta_{n_{m-1},Fo}).$$

The calculation point is at the outside surface of the system ($n = 0$):

$$\theta_{0,Fo+\Delta Fo} = \theta_{0,Fo} + 2\Delta Fo \cdot N^2 (\theta_{1,Fo} - \theta_{0,Fo}) - 2\Delta Fo \cdot N \cdot Bi_н (\theta_{0,Fo} - \theta_н).$$

Here we have the following designations: $\theta = T / T_*$, T_* is the attribution scope; $X = x / R_m$ is a dimensionless coordinate; R_m is the thickness of a multi-layer wall; $Fo = \frac{a_1 \tau}{R_m^2}$ is the Fourier number; τ is the time; $Bi_{вн} = \frac{\alpha_{вн} R_m}{\lambda_1}$; $Bi_н = \frac{\alpha_н R_m}{\lambda_m}$ is the Biot number; $Sk = \frac{\varepsilon_{пр} \sigma_0 T_*^3 R_m}{\lambda_m}$ is the Stark number; $A_i = \frac{a_i}{a_1}$; $\Lambda_i = \frac{\lambda_i}{\lambda_{i+1}}$; $K_i = \frac{\lambda_i}{\lambda_{i+1}} \cdot \sqrt{\frac{a_{i+1}}{a_i}}$;

$$N = \frac{1}{\Delta X_1}; \ \Delta X_1 = \frac{\Delta x_1}{R_m}; \ \Delta X_i = \Delta X_1 \sqrt{\frac{a_i}{a_1}}; \ n = \sum_{j=1}^{i} \frac{X_j - X_{j-1}}{\Delta X_j}.$$

In order to make the presented equations stable, the condition $\Delta Fo \cdot N^2 \le 0,25$ was met. Based on the difference scheme for the approximation of differential equations of heat transfer and boundary conditions, a computing program was designed.

2. Results of the numerical experiments

A parameter study of the initial transfer task poses a challenge due to a large number of variables and therefore below are some typical cases.

In order to illustrate a two-layer exterior wall that consists of a layer of brick and heat insulation is discussed [9].

The thickness of the brick layer is $\delta_к$ = 0.38 m; thermal and physical characteristics are $\lambda_к$ = 0.7 Watt/(m·K), $a_к = 4.42 \cdot 10^{-7}$ ^{m}m^2/sec; the thickness of the ehat insulation layer is $\delta_у$ = 0.12 м; thermal and physical characteristics are $\lambda_у$ = 0.07 Watt/(m·K), $a_у = 5.56 \cdot 10^{-7}$ m^2/sec; the thickness of a two-layer wall is R_m = 0.5 m.

The calculation was performed for the following conditions: the initial temperature T_0 was 253 K (-20 ^{0}C), the attribution scope T_* was chosen to be the temperature 313 K (+40 ^{0}C). Therefore θ_0 = 0.8.

Below are two typical cases with a heat insulation layer on the outside (I) and the inside (II) of the enclosure (Fig. 1).

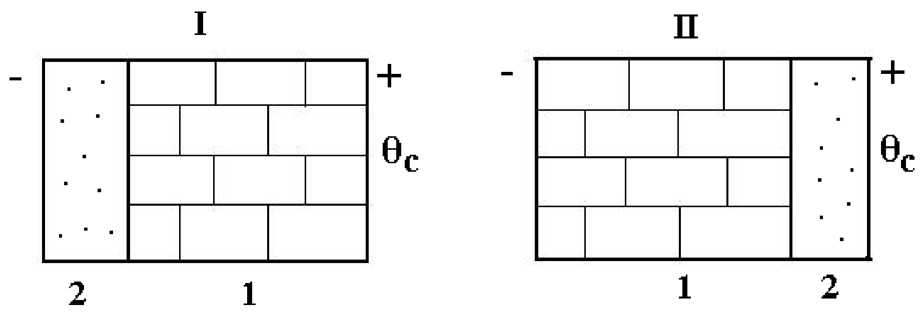

Fig. 1. Schematics of enclosures:
1 is the brick layer; 2 is the heat insulation layer

For the variant I the Biot and Stark numbers were $Bi_{вн}$ = 3.5; $Bi_н$ = 70; Sk = 0.36; for the variant II: $Bi_{вн}$ = 35; $Bi_н$ = 7; Sk = 3.6.

Fig. 2 shows the results of the numerical experiment to determine non-stationary temperatures in a two-layer wall structure after switching on a heat source. The graphs show change in the temperature in time in the most typical sections. Graphs 1—4 correspond with non-stationary temperatures on the outside $\theta(0, Fo)$, in between the layers, on the inside of the heat insulating surface $\theta(1, Fo)$ and a non-stationary temperature of a heating medium $\theta_c(Fo)$.

The parameter Pd has a large role to play in the dynamics of heating of enclosures and it describes the intensity of the temperature rising in time. In order to illustrate it in the graphs there are two curved lines $Pd = 0.5$ and $Pd = 1.0$.

As Pd increases, the enclosures is more heated and the temperature at the same Fo rises. The elements of the enclosure reach the maximum temperature which is of a great practical significance at the final stage of heating ($Fo\to\infty$). The computing program allows a particular assessment of the temperature distribution in enclosures under stationary conditions.

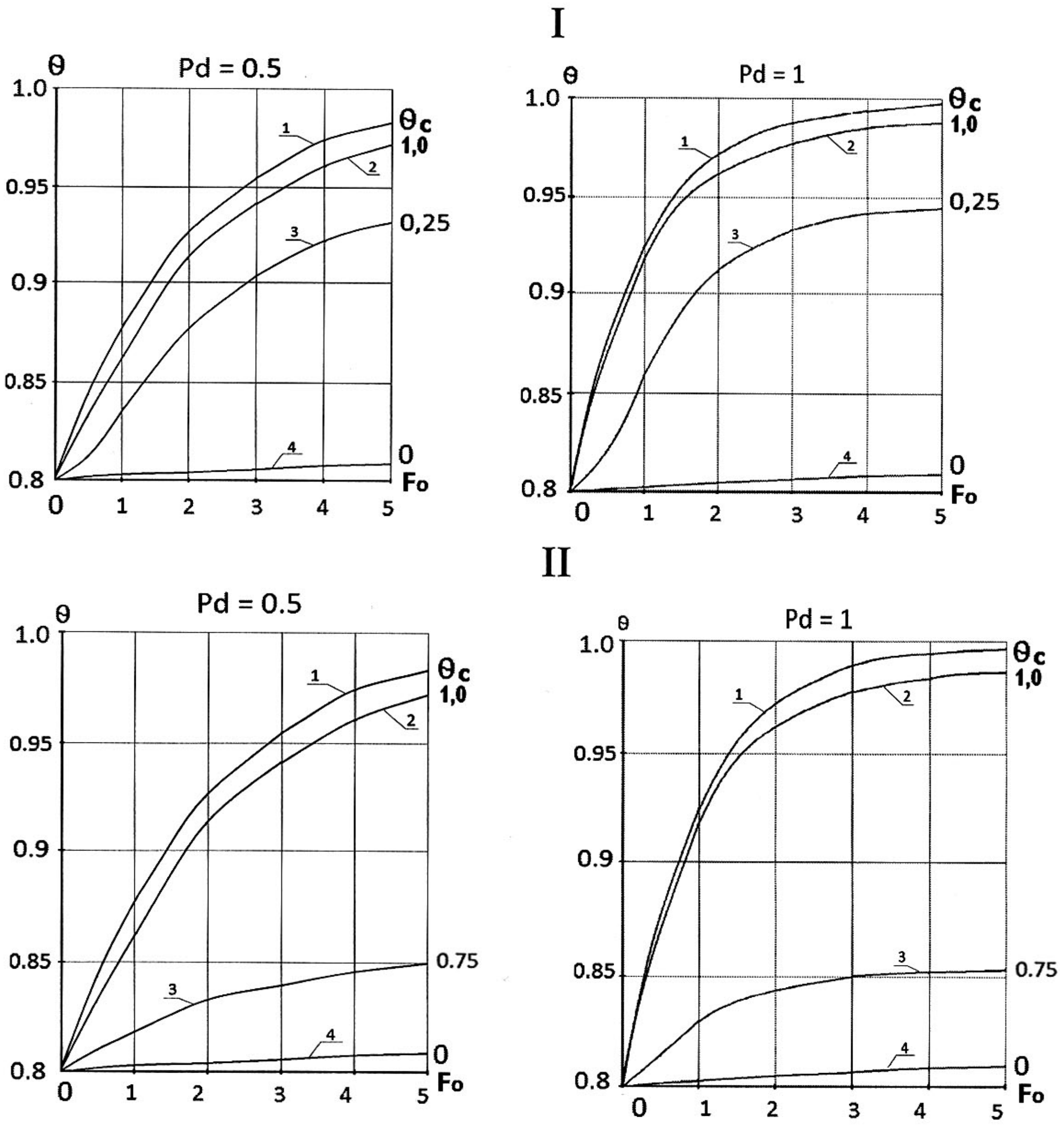

Fig. 2. Non-stationary temperatures of a two-layer plate

Conclusions

1. The current paper makes corrections to the mathematical model that describes heat transfer in enclosures after switching a heat source in a facility.

2. A numerical scheme for solving non-stationary heat transfer tasks is suggested which was emplyed for designing the computing program.
3. The obtained numerical material was used to study non-stationary and stationary heat modes of enclosures.
4. The performed analysis allowed us to determine the parameters that have a significant impact on the dynamics of heating of exterior walls.
5. The presented graphs show the importance of the position of the layers in a structure in the distribution of non-stationary temperatures in typical sections.
6. The Predvoditelev number was shown to have an influence on heating of enclosures after switching on a heat source.

References

1. **Fokin, K. F.** Stroitel'naya teplotexnika ograzhdayushhix chastej zdanij / K. F. Fokin. — 5-e izd., peresmotr. — M.: AVOK-PRESS, 2006. — 256s.

2. **Tabunshhikov, Yu. A.** Matematicheskoe modelirovanie i optimizaciya teplovoj e'ffektivnosti zdanij / Yu. A. Tabunshhikov, M. M. Brodach. — M.: AVOK-PRESS, 2002. — 194 s.

3. **Ivanov, V. V.** Modelirovanie processov teploperenosa v mnogoslojnyx ograzhdayushhix konstrukciyax / V. V. Ivanov, L. V. Karaseva, S. A. Tixomirov // Tr. 3-j Rossijskoj nac. konf. po teploobmenu. T. 7: Teploprovodnost', teploizolyaciya: sb. nauch. tr. / Moskovskij e'nergeticheskij institut. — M.: ME'I, 2001. — S. 131—134.

4. Issledovanie processov radiacionno-konvektivnogo progreva ograzhdayushhix konstrukcij / V. V. Ivanov [i dr.] // Izvestiya vuzov. Severo-Kavkazskij region. Texnicheskie nauki. — 2003. — № 3. — S. 31—32.

5. Temperaturnye rezhimy ograzhdayushhix konstrukcij / V. V. Ivanov [i dr.] // Zhilishhnoe stroitel'stvo. — 2003. — № 3. — S. 17—18.

6. Issledovanie processov nagreva pomeshheniya posle vklyucheniya istochnika teploty / V. V. Ivanov [i dr.] // Nauchnyj vestnik Voronezhskogo GASU. Stroitel'stvo i arxitektura. — 2011. — № 3. — S. 34—39.

7. **Lykov, A. V.** Teoriya teplo- i massoperenosa / A. V. Lykov, Yu. A. Mixajlov. — M.: Gose'nergoizdat, 1963. — 536 s.

8. **Ivanov, V. V.** Processy progreva mnogoslojnyx tel luchisto-konvektivnym teplom / V. V. Ivanov, Yu. V. Vidin, V. A. Kolesnik. — Rostov-n/D: Izd-vo RGU, 1990. — 159 s.

9. Vliyanie uteplitelya na dinamiku teplovyx rezhimov stroitel'nyx konstrukcij / V. V. Ivanov [i dr.] // Zhilishhnoe stroitel'stvo. — 2002. — № 5. — S. 15—16.

9. **Strizhak P.A.** Numerical estimation of the influence of natural convection in liquid on the conditions of ignition by a local heat source / Strizhak P.A. // Journal of Engineering Thermophysics. − 2011. − Vol. 20, N 2. - P. 211-216.

10. **Desta T.Z.** Experimental data set for validation of heat, air and moisture transport models of building envelopes / Desta T.Z., Langmans J., Roels S. // Building and Environment. - 2011. - Vol. 4, N 5. - P. 1036-1046.