Calculation of Properties of the Building Materials Coated with Composite Paint consisted of Hollow Ceramic Microspheres (THERMOSHIELD)

Kabashnikov V.P. *, the Doctor of Sciences,

Nekrasau V.P., Ph.D.,

УП "Institute NIPTIS", Minsk

*GNU Institute of physics, named by B.I. Stepanov, Belarussian National Academy of Science.

The modern building represents complex energy consumption system with various components in which various physical processes of absorption, transformations and transfer of energy proceed / 1-2/.

Now for energy savings in buildings paints with fillers from spherical balls, as hollow, as well as complete are widely used. Presence of balls of the micron size results to the modification of radiating properties of such paints. Energy efficient paints are issued for internal and external application. To estimate influence of such paints on a thermal mode of a building it’s necessary to create the corresponding physical and mathematical models in which, with reasonable accuracy, all kinds of heat exchange are taken into account.

In the given work we formulated the physical and mathematical model for calculation of a thermal mode of a building which in an obvious kind takes into account orientation of fence construction of a building depending of parties of the world, that allows to calculate radiating cooling (heating) of fence constructions, climatic conditions and work of the engineering equipment in premises. The structure of walls, both internal, and external, can be set independently from each other, including with a window /3/. Optical properties of paint Thermoshield are taken into account by a degree of blackness in boundary conditions. These factors can experimentally be determined or calculated from radiative transfer equation.

For the account of influence of a sunlight radiation on a thermal mode of a building the special program which allows to take into account position of the sun in a firmament at any time year, orientation of external walls for the set breadth of district has been written. In our numerical examples calculation of a thermal mode of a building are given for the breadth of Minsk equal to approximately 54.

For a finding of distribution of temperature in external and internal walls in view of their structure and temperature of air in premises we solve system of the equations 1 – 2 with boundary conditions (3) - (8). In process of solution of the given system of the equations convection &

radiating heat exchange with the external air, convection heat exchange with internal air, radiating heat exchange between internal sides of internal & external walls & a window is taken into account.

The given model of a thermal mode of a building can be described by system of the equations:

Boundary conditions is written in a general view: Expressions of boundary conditions for a window coincide with boundary conditions for the first external wall.

Equations for walls

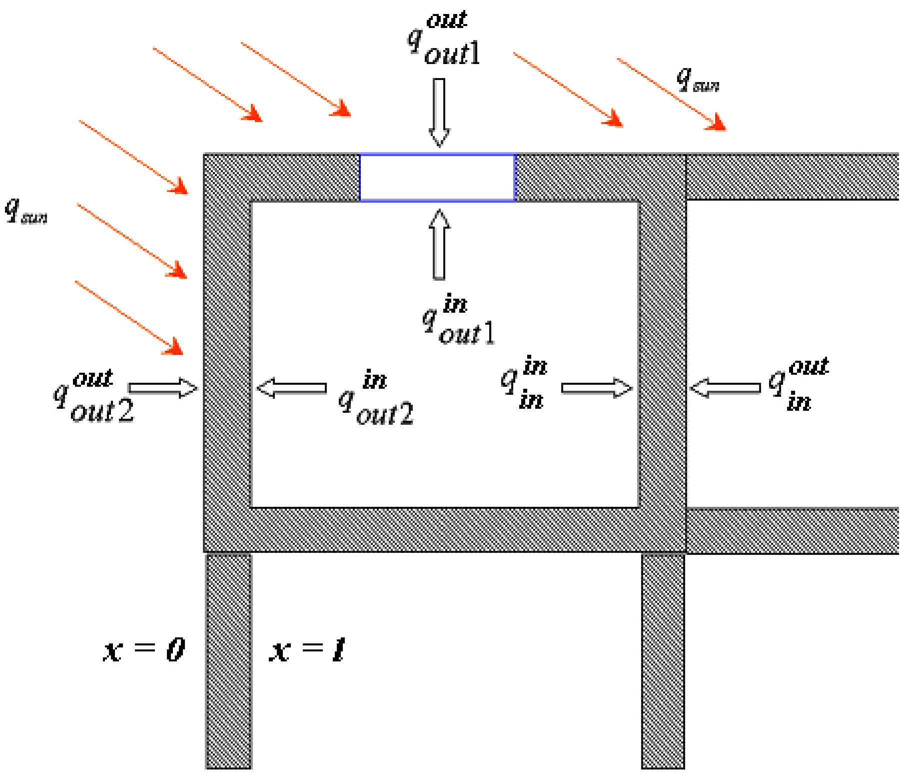

Figure.1 Room Configuration

$$\frac{\partial T_i}{\partial t} = \chi_i \frac{\partial^2 T_i}{\partial x^2}, \tag{1}$$

$i = 1$: external walls with windows,

$i = 2$:external walls,

$i = 3$: internal walls,

$i = 4$: windows

Equations resolved by finite difference method

Equations for determine air temperature in apartment.

$$\frac{dU}{dt}=\frac{1}{\rho_{air}\acute{n}_p V_{room}}\left\{S_{out1}\alpha_{out1}^{in}\left(T_{out1}^{in}-U\right)+S_{out2}\alpha_{out2}^{in}\left(T_{out2}^{in}-U\right)+\right.$$
$$\left.+S_{in}\alpha_{in}^{in}\left(T_{in}^{in}-U\right)+S_{win}\alpha_{win}^{in}\left(T_{win}^{in}-U\right)+q_{source}(t)+q_{sun}(t)\right\}+\frac{Q(t)}{V_{room}}\left(U_{air}^{out}+U\right) \tag{2}$$

Boundary conditions

$$q_{out1}^{in}=\rho_i c_i \chi_i \left.\frac{\partial T}{\partial x}\right|_{x=l}=\varepsilon_{eff}\sigma\left[\left(T_{in}^{in}\right)^4-\left(T_{out1}^{in}\right)^4\right]\cdot\Omega_{1\,from\,3}+$$
$$+\varepsilon_{eff}\sigma\left[\left(T_{out2}^{in}\right)^4-\left(T_{out1}^{in}\right)^4\right]\cdot\Omega_{1\,from\,2}+\alpha_{out1}^{in}\left(U-T_{out1}^{in}\right) \tag{3}$$

$$q_{out1}^{out}=\rho_i c_i \chi_i \left.\frac{\partial T}{\partial x}\right|_{x=0}=(1-R)\cdot q_{\substack{sun\ at\\ wall\ 1}}(t)-\varepsilon_{eff}\cdot\sigma\left[(T_{out1}^{out})^4-T_{sky}^4\right]+$$
$$+\alpha_{out1}^{out}(U_{air}^{out}(t)-T_{out1}^{out}) \tag{4}$$

$$q_{out2}^{in}=\rho_i c_i \chi_i \left.\frac{\partial T}{\partial x}\right|_{x=l}=-\varepsilon_{eff}\sigma\left[\left(T_{out2}^{in}\right)^4-\left(T_{out1}^{in}\right)^4\right]\cdot\Omega_{2\,from1}-$$
$$-\varepsilon_{eff}\sigma\left[\left(T_{out2}^{in}\right)^4-\left(T_{win}^{in}\right)^4\right]\cdot\Omega_{2\,from\,4}-\varepsilon_{eff}\sigma\left[\left(T_{out2}^{in}\right)^4-\left(T_{in}^{in}\right)^4\right]\cdot\Omega_{2\,from3}+\alpha_{out2}^{in}\left(U-T_{out2}^{in}\right) \tag{5}$$

$$q_{out2}^{out}=\rho_i c_i \chi_i \left.\frac{\partial T}{\partial x}\right|_{x=0}=(1-R)\cdot q_{\substack{sun\ at\\ wall2}}(t)-\varepsilon_{eff}\cdot\sigma\left[\left(T_{out2}^{out}\right)^4-T_{sky}^4\right]+\alpha_{out2}^{out}\left(U_{air}^{out}(t)-T_{out2}^{out}\right) \tag{6}$$

$$q_{in}^{in}=-\rho_i c_i \chi_i \left.\frac{\partial T}{\partial x}\right|_{x=0}=-\varepsilon_{eff}\sigma\left[\left(T_{in}^{in}\right)^4-\left(T_{out1}^{in}\right)^4\right]\cdot\Omega_{3\,from1}-$$
$$-\varepsilon_{eff}\sigma\left[\left(T_{in}^{in}\right)^4-\left(T_{win}^{in}\right)^4\right]\cdot\Omega_{3\,from\,4}-\varepsilon_{eff}\sigma\left[\left(T_{in}^{in}\right)^4-\left(T_{out2}^{in}\right)^4\right]\cdot\Omega_{3\,from2}+\alpha_{in}^{in}\left(U-T_{in}^{in}\right) \tag{7}$$

$$q_{in}^{out}=\rho_i c_i \chi_i \left.\frac{\partial T}{\partial x}\right|_{x=l}=\alpha_{in}^{out}(U_{room}^{out}-T_{in}^{out}) \tag{8}$$

$R+\varepsilon_{eff}=1$

The equations to determine temperature internal and external glass of a window block in explicit aspect:

$$T_{win}^{out} \approx \frac{\alpha_{win}^{out} U_1^{out} (\alpha_{win}^{in} + R^{-1}) + \alpha_{win}^{in} U R^{-1}}{(\alpha_{win}^{out} + R^{-1})(\alpha_{win}^{in} + R^{-1}) - R^{-2}}$$

$$T_{win}^{\hat{a}} \approx \frac{\alpha_{win}^{in} U (\alpha_{win}^{out} + R^{-1}) + \alpha_{win}^{out} R^{-1}}{(\alpha_{win}^{out} + R^{-1})(\alpha_{win}^{in} + R^{-1}) - R^{-2}}; \quad (9)$$

where $R^{-1} = \frac{\lambda}{d} + 4\sigma (T_{win}^{in})^3$

The flux of a solar energy in a room through two glasses is determined as:

$$q_{sun}(t) = S_{win} \cdot \cos\varphi \cdot \mathrm{Q}_{\mathrm{eff}} \frac{1-r}{1+3r} \qquad r = \frac{1}{2}(r_{\mathrm{II}} + r_{\perp})$$

The analysis of results for numerical calculations of heat exchange of a building with an environment is complicated, as depends on many external parameters, such as: structure external and internal walls, temperature or change of temperature of external air, temperature of air in surrounding premises, a season (it is clear, is cloudy), speed of a wind, etc. To facilitate work of the user the special program on input of the initial data has been written to visualization of results of calculations.

The program for the solution of the above-stated equations with boundary conditions is written in language - FORTRAN. Program of data input and visualization of calculation - in language Object Pascal.

Results of the decision of system of the equations (1) — (8) are submitted on figure 2.

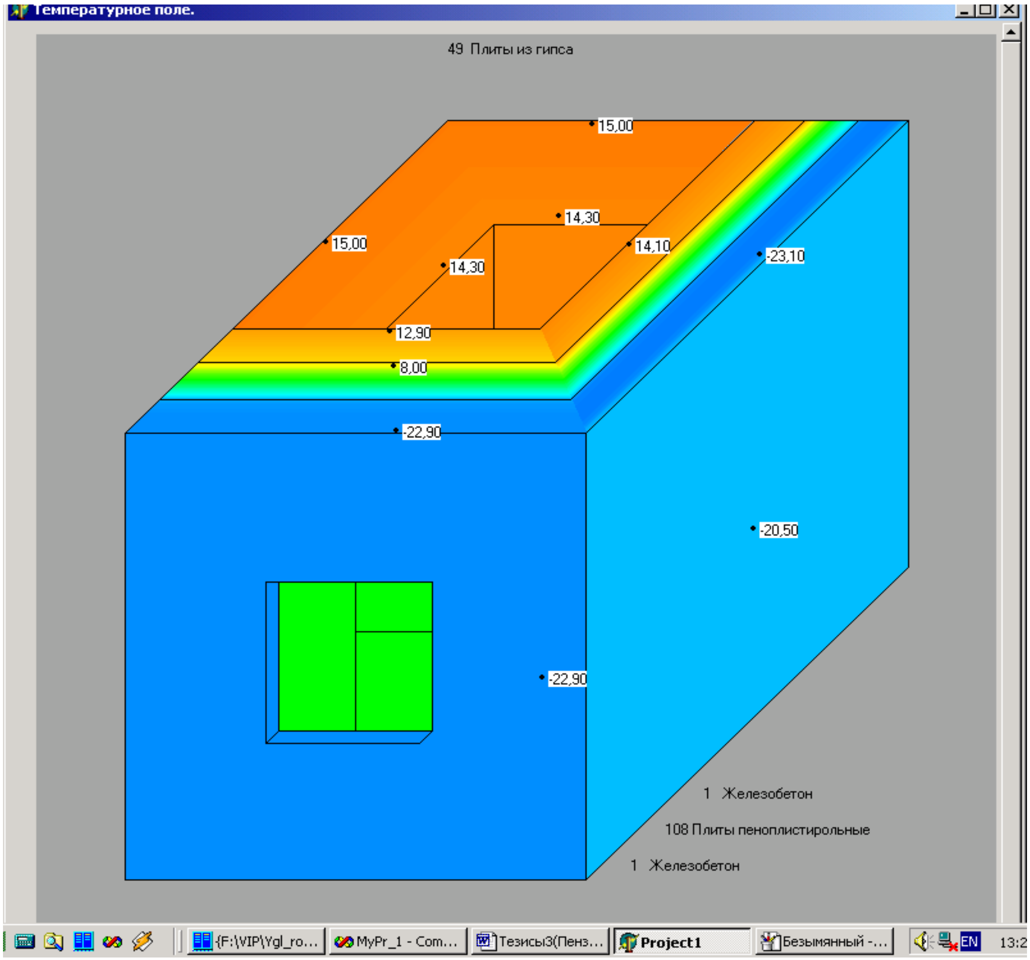

Figure. 2

Distribution of temperature in an angular room of a building which external walls will consist of heavy concrete, пенополистерола. Calculation was carried out for a cold five-day week: January - temperature of external air - 25+5, with, speed of a wind - 3m/s, an atmosphere cloudless, orientation of a wall with a window - the south, a blank wall - the east, basic temperature in a room + 18, system of heating is taken into account in this calculation.

Figure refers to 17 hours of the second day after the beginning of the account.

Convection heat exchange on an external surface of fence construction was determined basically by speed of a wind, blowing of a surface and by the direction of air movement relatively to surface.

At a direction of a wind along a surface the coefficient of convection exchange determined as:

$$a = 5{,}8 \cdot v^{0{,}8} \cdot l^{-0{,}2}$$

For calculation of heat exchange on a surface of external walls at frontal blowing by a wind it is recommended to use the formula:

$$a = 11{,}6\sqrt{v}$$

For verification of mathematical model the comparison of results of numerical calculations with experimental values of temperatures has been carried out. On the fig. 3 comparison of temperature distribution (both: calculated & experimental) for an external surface of a wall is given in dependence on time. Comparison shows good concurrence of numerical calculation to experimental data.

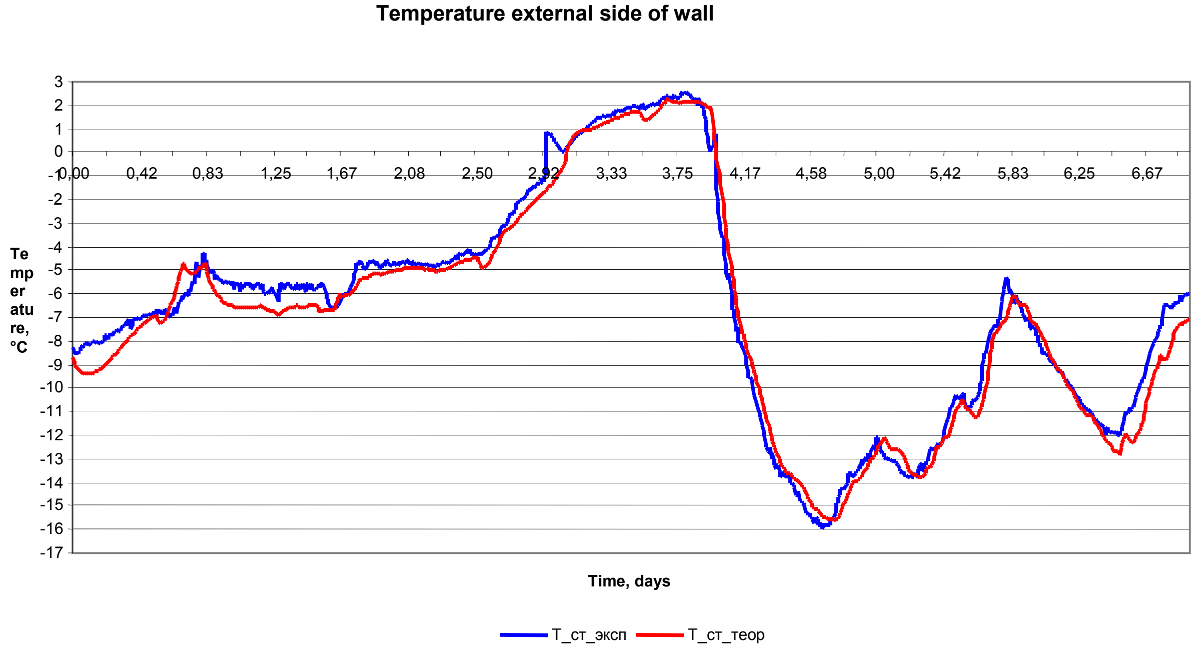

Figure 3. Temperature of external side of a wall.

Covering Thermoshield we shall present as the light-scattering environment with temperature equal to the surface of a wall. The blackness degree of such disseminating surface ε_{eff} we can receive, using the radiative transfer equation /4/.

Degrees of the blackness, dependent on length of the wave & on disseminating surfaces is possible to write down as follows for border t = t_0

$$\varepsilon^{\lambda}{}_{eff} = \frac{I_{\lambda}(t_0,\mu)_{\mu>0}}{B_{\lambda}(T_{media})} = (1-e^{-\frac{t_0}{\mu}}) + E_{01}e^{-\frac{t_0}{\mu}} - \frac{\lambda}{2}(1+R)(\frac{e^{-t_0 p} - e^{-\frac{t_0}{\mu}}}{p\mu - 1}A_1 - A_2\frac{1-e^{-pt_0-\frac{t_0}{\mu}}}{p\mu+1}) \quad (10)$$

$$aA_1 = 1 - E_1 - R(1-E_2)e^{-k\tau_0}, \quad aA_2 = 1 - E_2 - R(1-E_1)e^{-k\tau_0},$$

$$a = 1 - R^2 e^{-2k\tau_0}, \quad R = \frac{\delta - 1}{\delta + 1}, \quad k = 2\delta(1-\lambda),$$

$$\delta = (1 + \frac{2\beta\lambda}{1-\lambda}),$$ β-part of back scattering

$$E_i = \frac{I_{0i}}{B(T)},\ i = 1 - wall;\ i = 2 - surround$$

$t = (\chi + \sigma)x$ — optical depth of the layer,

$\chi, \sigma -$ absorption and scattering coefficient

$\lambda = \dfrac{\sigma}{\chi + \sigma}$ - single-scattering albedo

$$p = \frac{k}{\delta^2 \cdot (1 - \lambda)}$$

Factors of scattering, absorption, part of back scattering could be calculated under formulas Mie.

$$\int_{\lambda_1}^{\lambda_2} \varepsilon^{\lambda}{}_{eff} = \overline{\varepsilon}$$

If factors Mie are known, the value of radiating ability can be determined on nomogramme.

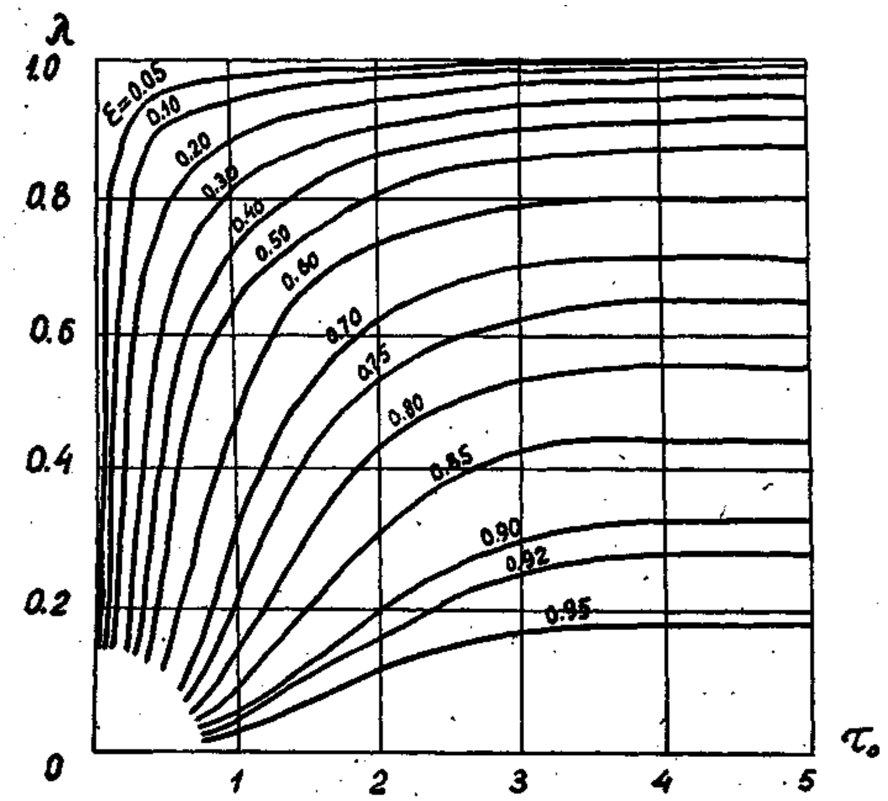

Figure 4

The description of experiment with covering Thermoshield..

As now there are no reliable experimental theoretical specified value $\varepsilon(\beta,\gamma,\chi,\tau)$ for covering Thermoshield, natural experiment for qualitative definition of radiating ability of paint Thermoshield has been put. On a roof of our institute four piles ceramic plate have been established by temperature-sensitive elements. The circuit of carrying out of experiment and an arrangement of temperature-sensitive elements is resulted on fig. 4 and fig. 5. In total it has been established four piles of bars. The external surface of the top bar at each pile has been processed. On the top bar of the first pile the aluminium foil has been pasted, the top bar of the second pile has been painted with two layers of Thermoshield_Nature, the surface of the top bar of the third pile in the beginning was not processed, the fourth - Thermoshield_Nature was used for duplication of experiment of the second pile. Experiment began on September, 16, 2004 and is correct as external boundary conditions for each pile of bars were identical. Simultaneously with temperatures of bars the temperature of external air and temperature of a roof was registered. The roof is made of a ferro-concrete plate with a heater, covered with black roofing material. Thus, from the bottom of each pile of bars there were identical conditions.

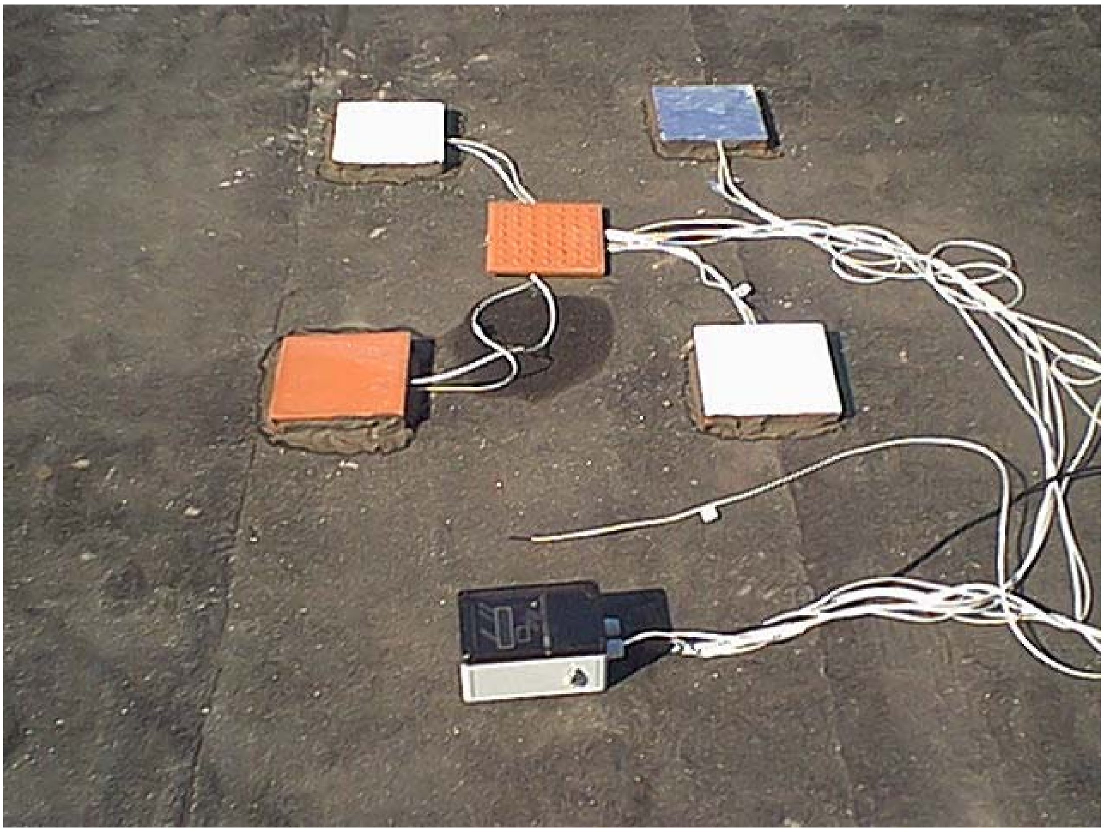

Fig 5. Picture of placement of devices

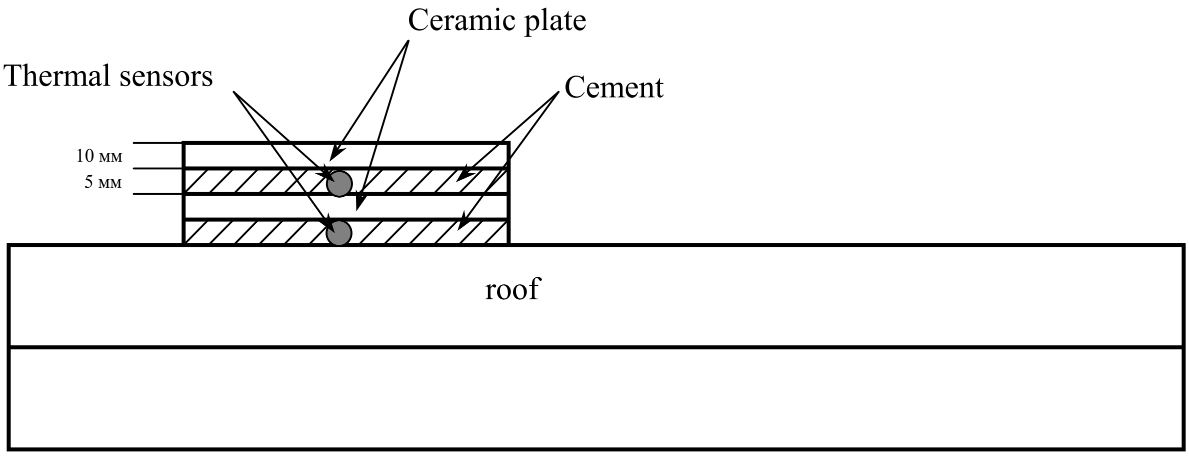

Figure 6

Thickness of each bar was equaled – 10mm., thickness of a layer of a solution between them and a roof-5мм. The solution consists of 7 parts of the fine sifted sand and one part cement.

The temperature-sensitive elements for reduction of influence have been settled in the center of each pile in a layer of a solution. The Data from temperature-sensitive elements automatically have been located & was read out in 10 minutes and was remembered by the special device. Every morning the data from this device were put in PC and were translated in format EXCEL for the subsequent processing. On September, 22 the temperature-sensitive elements of external air has deteriorated. From this day the temperature of a roof a surface of a unpainted bar served as an indirect parameter of temperature of external air and a condition of an atmosphere.

The daily changes of values of a difference of temperatures between temperature of air and the temperature-sensitive elements between bars are resulted on fig. (7). During this period, on September, 16-22, 2004, there were sunny days and the clear sky. From figure it is visible, that bars painted Thermoshield are heated up in the afternoon less and strongly cooled at night.
It testifies to the big factor of reflection R in seen area of a spectrum of sunlight and the big value ε inside infra-red field of a spectrum. Absence of gauges of a thermal stream with data recording and devices with registration of a stream of sunlight does not allow make quantitative conclusions on optical characteristics of covering Thermoshield. As at the cloudless sky at the night of a bar cool down faster and the temperature of them is lower, than at a simple ceramic bar with factor $\varepsilon \cong 0.85$-0.9, it testifies that radiating ability at covering Thermoshield Nature inside Infra-red field of a spectrum is more than value 0.9. (fig. 8). Thus, this covering can be used as an excellent means for protection of buildings from overheat in the afternoon and cooling at night, and also to be applied to painting walls inside premises, with the purpose of increase and alignment of temperature of walls due to radiating transfer of heat.

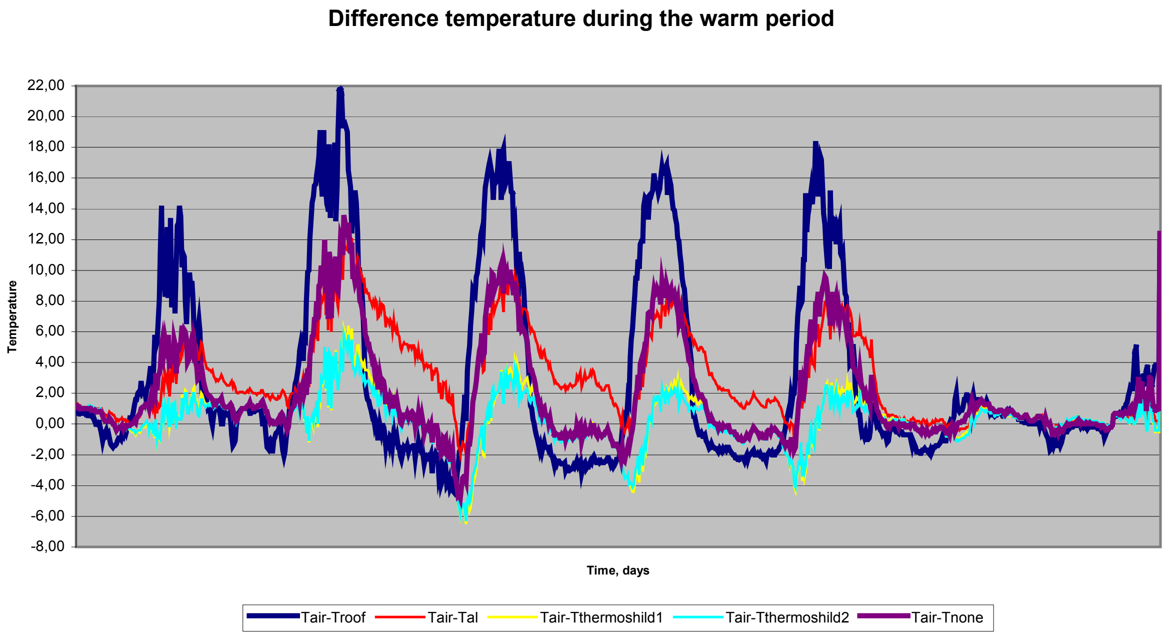

Fig.7 Difference temperature during the warm period

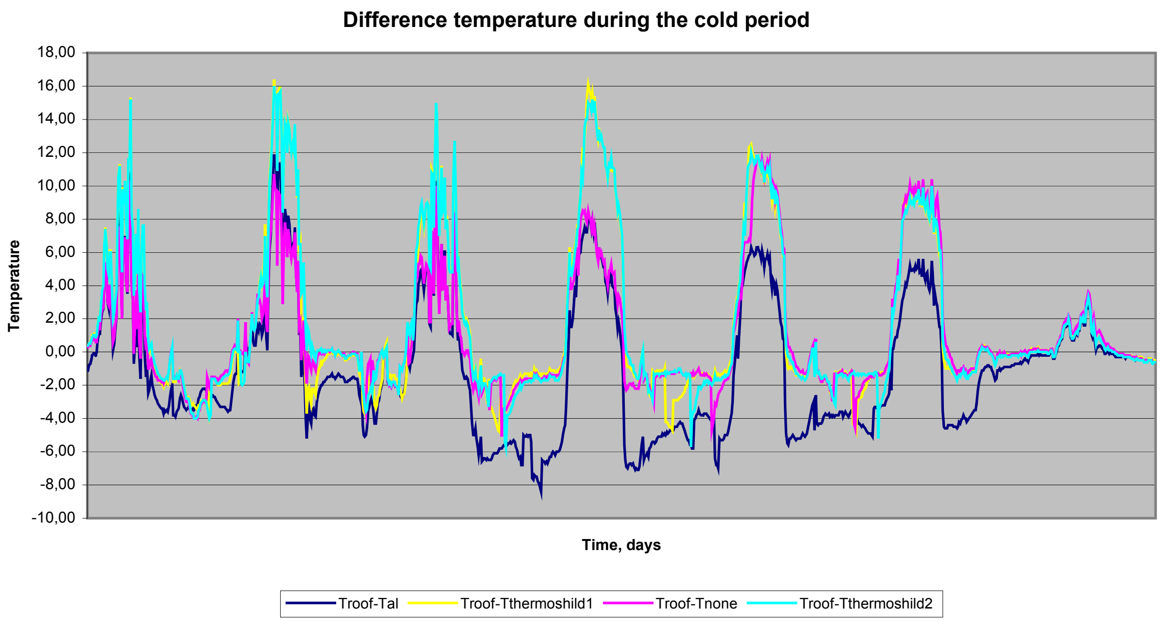

Fig.8 Difference temperature during the cold period

THE CONCLUSION

The developed mathematical model allows to calculate thermal balance of a building depending on:

- speed and amplitudes of change of external meteorological parameters,
- intensity of a direct and scattered radiation;
- heat engineering and constructive parameters of a building,

■ quantity of window apertures and their area, orientation of the building on the parties of world,

■ work of the engineering equipment.

The influence of covering Thermoshield on heat exchange inside and outside of a premise is taken into account by an effective degree of blackness of surfaces.

Thermoshield Nature Coating could be the best mean to protect buildings from overheating in the afternoon and undercooling at night. It could be use as well to paint walls into apartment to increase and alignment wall temperature due to radiating transfer of heat.

The specification

Where $T_{out1}, T_{out2}, T_{in}, T_{win}$ – distribution of temperature in the first and second external wall, an internal wall and a window accordingly, °C; $\chi = \dfrac{\lambda}{c_v \rho}$; λ - factor of heat conductivity, Wt /(m^2·°C); c_v - a specific thermal capacity of a material, Dg / (kg·°C); ρ - density of a material, kg/m^3, U - temperature of air in a room; U_1^H – temperature of external atmospheric air; U_2^H – temperature of air in premises, which surround a researched room; V - volume of a room; $S_{out1}, S_{out2}, S_{in}, S_{win}$ - the area of the first and second external walls, the area of an internal wall, the area of a window accordingly, m^2; α - the coefficient of convection heat exchange, Wt / (m^2·°C); l – the characteristic size of a surface in a direction of air movement, m; v - speed of a wind, km/s; Q - intensity of air exchange between a constant and external (external, street) air, m^3 / sec; $q_{ист}$ - capacity of a thermal emission in room air (Wt); $q_{солн}$– the solar stream getting in window (Wt); Ω – An effective solid angle on which from internal walls the external wall or a window is visible; ε_{eff} - an effective degree of blackness for given fence construction; σ - Stephan - Bolzman’s constant ; r - Frenels’ coefficient of reflection on border “air - glass”; β - a corner between a normal to a plane of a window and a direction on the sun.

The Literature

1. **Tabunshikov U.A.** Thermal protection of fence constructions of buildings and constructions. – Moscow, Stroyizdat, - 1986.

2. **Shi D.** Numerical methods in problems of heat exchange. – Moscow. – "MIR" – 1988 - 544.

3. **Veller A.A., Vityaz I.P., Kabashnikov V.P.,Necrasov V.P.** Thermal behavior of building subject to radiation heat exchange "Abstracts of the reports and communications", v.1, V Minsk International Heat and Mass Transfer Forum, p.156-158

4. **Adzerikho K.S., Nekrasov V.P.** Luminescence characteristics of the cylindrical and spherical light-scattering media // Int/ J. Heat Mass Transfer. 1975. Vol. 18, N 7. P. 1131-1138