SmartEnergyCoating-use experience in structure of exterior wall

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Abstract. A study of SmartEnergyCoating for building envelope structures in a harsh climate is presented. Installation of the layer with energy-absorbing elements in the composition of walls was researched. The feasibility of application of method for energy generation and support of a stable temperature regime for the building structures, pipelines and regulating elements has been proved.

1. Introduction
The conditions for work of building structures in harsh climate are characterized by some features. It may include a long period of low temperatures and a sharp temperature drop during a short time. Temperature jumps reach more than 20 degrees in one day. These conditions are typical for the operation of external building structures, equipment, control systems and other elements. One of the tasks of the design and operation of buildings and microclimate conditioning systems is to ensure the optimal thermal regime for various instrument and equipment. Economically justified project of options provides the specified internal conditions. The use of automated air conditioning systems increases the total cost of building significantly. Therefore, to protect against negative influences, constructive built-in systems and non-standard solutions should be used [1]. In many cases, these measures are sufficient to ensure the necessary internal conditions and the successful functioning of elements and systems.

During last research, an experiment was performed with the installation of SmartEnergyCoating [2-7] on the outside of the outer curtain wall. SmartEnergyCoating has been used as a thermal insulation coating. This way is a possibility of compensation of thermal loads in structural elements also. In this case, the effect is achieved due to heat-compensating elements in the coating layer. In addition to its heat-shielding and heat-insulating properties, SmartEnergyCoating generated energy “from the cold” of the outside structure. Attention was paid to the amplitude of temperature fluctuations of the inner surface of the enclosing structures. In this case inner surface was cooled and heated artificially. So far as the thickness of SmartEnergyCoating is relatively small, the thermal inertia D of each layer does not change significantly. So it was possible to equalize the average daily fluctuations of the temperature at the surface of the wall.

2. Theoretical foundations of the heat balance of the investigated object
According to standards, heat losses compensable by heating are determined from the heat balance. The heat balance of a building and each heated room is found from the equation
where $Q_s$ is the transmission heat loss through the building (room) fences; $Q_{inf}$ - heat consumption for heating the outside air in the volume of infiltration or sanitary standards; $Q_{c.o}$ - thermal power of the heating system, which is the desired value when determining the heat balance; $Q_{ins}$ - heat input due to solar radiation; $Q_{byt}$ - total heat gains due to all internal heat sources, with the exception of the heating system (for household purposes, heat release from household appliances and lighting devices, kitchen stoves, distribution of hot water supply pipelines and directly consumed hot water, people, and other sources located in the room).

An important component of the complex process that forms the thermal regime of a room is heat exchange on surfaces. The heat balance of any surface $i$ in a room under stationary and non-stationary conditions can be represented on the basis of the energy conservation law by the equation:

$$L + K + T = 0$$

Radiant $L$, convective $K$ and conductive $T$ components of heat transfer on surfaces in a room can change in time, have different magnitudes and signs, but equation (2) remains unchanged for all surfaces in stationary and non-stationary heat transfer conditions. Radiant heat transfer is calculated by the equation (3)

$$L = \sum C_0 \epsilon_{1-j} b_{1-j} \left( \tau_1 - \tau_j \right) \phi_{1-j} F_j$$

where $C_0$ — an emissivity of an absolutely black body, equal to 5.77 W / (m$^2$ • K$^4$);
$\epsilon$ — the degree of emissivity, or the relative emissivity of the surface (dimensionless value); for gray surface $\epsilon <1$;
$j$ — the ordinal number of $n$ surfaces;
$b$ — the temperature coefficient;
$\phi$ — an angle of incidence of the rays of the surface $j$;
$F$ — the radiation area of the surface $j$.

In addition to radiation, convection plays an important part in the overall heat exchange in a room. Air exchanges heat with the cooled and heated surfaces of fences and heating and cooling systems. The heated air currents rise upwards, the cooled ones go downwards, causing general mobility and mixing of the air in a room. The supply and removal of air by ventilation systems enhances this process.

In most rooms, as a result of air mixing, a relatively uniform temperature distribution is observed in terms of plan and height, which makes it possible to take the same value when calculating heat transfer on all surfaces. Exceptions are rooms with large heat surpluses and air supply using non-isothermal jets. In the first case, there is an unevenness of temperature in height, and with a local location of heat sources in terms of the room. Above the sources, convective currents of warm air arise, which, collecting at the top, form a layer of heated air under the ceiling ("heat cushion").

The heat exchange in the room is significantly influenced by the aerodynamic processes occurring in it, which occur under the action of non-isothermal jets. Ventilation and heat jets interact with each other, with fences and objects in the room. As a result of this interaction, air circulation arises in the volume of the room, and certain speed and temperature fields are formed. In general, the convection heat flux can be determined by the equation:

$$K = \alpha_k \left( \tau_n - \tau_j \right) F$$

The average values of the coefficient of convective heat transfer on the vertical surfaces of panel fences in the room can be determined [8] by the equation

$$\alpha_k = k f(t)$$

where $k$ — coefficient depending on the flow rate and the shape of a convective jet and a surface in natural convection.

The conductive $T$ component depends on the thermal resistance $R_k$, m$^2$°C / W, the enclosing structure with successively located homogeneous layers should be determined as the sum of the thermal resistances of individual layers:

$$R_k = R_1 + R_2 + ... + R_n + R_{v.p.},$$
where $R_1, R_2, ..., R_n$ — thermal resistance of individual layers of the enclosing structure, m$^2$°C / W, $R_{v.p.}$ - thermal resistance of a closed air space.

With unsteady heat propagation along all three coordinate axes, the differential heat conduction equation will take on a three-dimensional form:

$$\frac{\partial t}{\partial t} = a \left[ \frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} \right] = a\Delta^2 t \quad (7)$$

where $\Delta^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ Laplace operator.

In an inhomogeneous material medium, the differential equation of the volumetric temperature field will have the form:

$$\frac{\partial}{\partial x} (\lambda_x \frac{\partial t}{\partial x}) + \frac{\partial}{\partial y} (\lambda_y \frac{\partial t}{\partial y}) + \frac{\partial}{\partial z} (\lambda_z \frac{\partial t}{\partial z}) = 0 \quad (8)$$

where $\lambda$ is a continuous function $x$ and $y$.

Spatial temperature fields for practical purposes in most cases are studied in separate projections, which can be represented by two-dimensional temperature fields.

3. Implementation

An experiment was carried out with the installation of SmartEnergyCoating on the outside of the outer curtain wall. In this experiment, convection losses on the inside of the SmartEnergyCoating wall connection were negligible as it was tightly attached. A diagram of the main functional element of the SmartEnergyCoating fence, which was used in the study, is shown in Figure 1.

![Figure 1. Diagram of the functional element of the "smart wall" fence.](image)

The figure shows the "cold side" in blue and the "hot side" in red. The principle of operation and energy generation is based on the operation of similar elements installed in the thickness of the coating. The combination of a large number of such elements connected in series by current and in parallel by outlet and inlet can have a significant effect. The semiconductor elements are interconnected with copper jumpers and located between two thin ceramic plates. An electric current flows in a normative direction, starting from one side of the thermoelectric module and exiting from the other side. In this case, heat is absorbed at the contact of the N-type element with the P-type element and is released at the point of contact of the P-type element with the N-type element.

The thermal part of the simulation model is based on the use of the principle of electrostatic analogy with the conversion of thermal quantities into electrical ones. A fragment of the program is shown in Figure 2. In this case, the thermal part of the device is divided into elements similar to electrical ones - with the construction of thermal circuits.
Such modeling allows to do the dynamic analysis of thermal and electrical parameters of a wide range of devices. These elements can contain both internal and boundary sources of heat and cold. Most of them use different physical principles [9-19]. After modeling and identifying the most optimal points without thermal insulation for the highest heat flow. SmartEnergyCoating was installed in the outer wall of the fence. Since in the course of the experiment the required heat flux of cold was created artificially by a fan, the results of the experiment can be considered model, and not natural under harsh climate.

According to the conditions of the experiment, a heat flux was created equal to +25 from the outside and -15 from the inside of the fence of the building structure. According to the measurement data, the specific thermal conductivity was 0.019 - 0.022 W / m2 * K. without accumulation and continuous consumption of generated energy about 2-3 A and 12 V with boosting and transforming devices.

4. Conclusions
As a result of modeling, the following results were obtained. The developed SmartEnergyCoating is capable of generating electricity independently and ensuring a stable temperature regime for the operation of building structures, pipelines and control elements. With a temperature difference of about 40 degrees, the specific parameters of SmartEnergyCoating reach the following values. The thermal conductivity coefficient is 0.019 - 0.022 W / m * K. At the temperature difference in 40 degrees it was reached 3A, 12 volts for 12 hours with small interruptions.

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