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Investigation of energy efficiency of innovate thermal insulating materials and their influence on the building heat regime

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Abstract. A complex model of heat supply system of building was developed by using Matlab. The model allows conducting for a wide range of research related to improving the energy efficiency of buildings. In this work the investigations of energy efficiency of several advanced insulation materials, which is characterized by different thermal characteristics, were carried out. Conclusions about the impact of the thermal protective envelope on the room thermal regime were made. Prognostic heat consumptions values of rooms with different characteristics of thermal insulation materials and main base-load envelopes were determined. Researches were conducted for the winter climatic conditions of Western Siberia: the average daily outdoor temperature is -22 °C, the amplitude of temperature oscillation is 8 °C.

1. Introduction

Adoption of new laws, construction standards and other regulatory documents make it possible to formalize energy savings targets and fix the maximum allowable characteristics of envelopes thermal resistance for residential and municipal buildings and structures.

This factor also encouraged a search of the most universal and optimal insulating material (IM). Such material shall be equally effective used in the new building construction and in modernization of the thermal protective envelope (TPE) of existing objects. To be noticed that market of such materials is characterized by considerable development potential.

2. Advanced materials for thermal insulation of buildings and constructions

Analysis of [1-4] helps to evaluate the conclusion about the absence of consolidated opinion about the universal insulation material with optimal characteristics and properties. However, there are several advanced IM. First of all, liquid ceramic insulation should be noted. Declared effect is achieved by using microscopic evacuated ceramic spheres with dimensions no more than 0.01...0.05 mm. For the first time this polymer coating was designed for effective thermal protection of spacecraft under technical requirements of NASA. This material is applied to the isolated surface, as a paint, and after drying forms a polymer coating, which is characterized by considerable resistant to atmospheric

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precipitation and temperature extremes. Key advantages of such coating: low rates of thermal conductivity allows to reduce the thickness of the layer of material, high adhesive properties allow to apply the material on the surface of any shape and type (metal, brick, concrete, wood), low performance of vapor- and water permeability, ease of applying, environmentally friendly, nonflammability.

One of the most upcoming trend of IM development – use of biomaterials and biotech waste. Modern researches prove the possibility of manufacturing of such materials: silkworm cocoon [5], rice straw [6], kenaf (Hibiscus cannabinus) [7] and sunflower (Helianthus annuus) [8].

The main advantage of these insulators - environmentally friendly and relatively low cost. The extensive usage of these materials can increase the processing depth of agricultural raw materials, providing nearly non-waste production [8].

Several IM are determined for further research in this work (Table 1): expanded polystyrene, polymer coating KORUND and bio insulator based on sunflowers waste.

Table 1. Basic thermophysical characteristics of tested IM

Thermophysical characteristic	Materials			
	Brick	Polymer coating KORUND	Bio insulator	Expanded polystyrene
Thermal conductivity [W/m·K]	0.677	0.0012	0.0844	0.041
Specific heat capacity c [J/kg·K]	880	500	500	1340
Density [kg/m^3]	1640	558	500	40

3. Simulation object

The object of research is an administration building which is located in West Siberia (Tomsk city). The structure of the object is described in [9]. Four rooms were selected in building for achieving goals of the article. In order to create equal conditions of the external disturbing factors influence these rooms located on one side of the building facade. Identical conditions of heat supplying are provided for heating system with parallel connection of heating appliances. Rooms are characterized by identical space planning but differ in insulating materials of envelopes.

Investigation of energy efficiency of IM and their influence on the building heat regime were carried out referred to reference envelope – brick layout. There are several variations of this layout – related to the wall thicknesses λ_{L2Rj}: 0.375 m – for modern buildings and 1.03 m – for old buildings. Surface area of opaque envelopes of each room is 17.85 m, glazing ratio is 0.15. In general terms building envelope is characterized by multilayer structure (Figure 1).

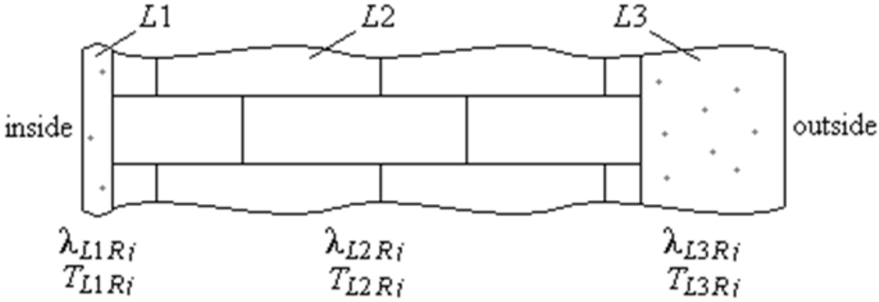

Figure 1. Cross-sectional view of multilayer building envelope: 1 – layer L1 (internal): cement plaster; 2 – layer L2 (main base-load structure): brick layout; 3 – layer L3 (TPE): unique material for each of rooms.

A detailed description of the different variations of envelopes materials and overall thermal resistance are summarized in Table 2.

Table 2. Building envelopes description

Characteristics		Materials of the envelopes			
		Room 1	Room 2	Room 3	Room 4
Structure of building envelope, in brackets – layer thickness $_{LiRj}$ [m]		L1 – cement plaster (0.08); L2 – brick layout (0.375/1.03)	L1 – cement plaster (0.08); L2 – brick layout (0.375/1.03); L3 – polymer coating KORUND (0.003)	L1 – cement plaster (0.08); L2 – brick layout (0.375/1.03); L3 – bio insulator (0.15)	L1 – cement plaster (0.08); L2 – brick layout (0.375/1.03); L3 – expanded polystyrene (0.15)
Overall thermal resistance R_0 [m^2·K/W]	$_{L2Rj}$ = 0.375 m	0.712	3.212	2.489	4.371
	$_{L2Rj}$ = 1.03 m	1.68	4.18	3.457	5.339

4. Modelling results

The thermal model of the building has been developed to research the IM energy efficiency and to find their influence on the thermal regime of the rooms. The application Simulink of the mathematical package Matlab [9, 10] has been selected as a platform for a model.

To achieve the purpose of the present work several series of numerical experiments were performed to research heat consumption of the controlled rooms, which is characterized by different TPE. Simulation initial data: assessment month – February, location of modelling object – Tomsk city, orientation of envelopes – North. Indoor environment temperature in *i*-th room $T_{inR\mathrm{j}}$ is assumed equal to +25 °C. Automatic control system is responsible for maintaining the indoor room climate. Change of the daily outdoor air temperature T_{out} is characterized by periodicity with following parameters: mean value T_{out0} is -22 °C, amplitude of oscillation 8 °C, oscillation period 24 h. Modelling were carried out for several variations of the thickness of the brick layout λ_{L2Rj} - 0.375 m and 1.03 m.

Selection of the IM type directly affects the ability to maintaining building indoor climate parameters in a comfortable range for humans. Stability of maintenance the temperature T_{inRj} (Figure 2) suggests about the effective compensation of many disturbing factors (outdoor air temperature, wind load, infiltration heat loss, insolation heat gains etc.).

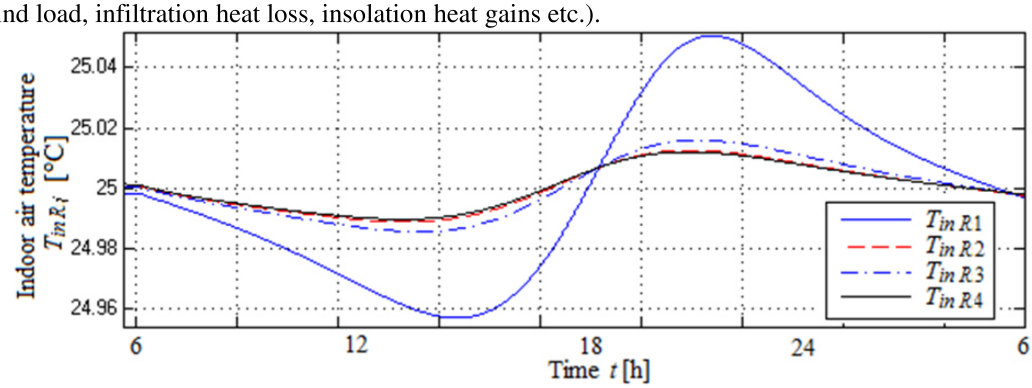

Figure 2. Dynamics of indoor environment temperature in controlled rooms T_{inRj} (λ_{L2Rj} = 0.375 m)

Results shown on Figure 2 approves the advantages of applying the expanded polystyrene and polymer coating KORUND. The least affected of external disturbing factor is room №4: deviation of T_{inR4} from the setpoint 25 °C does not exceed 0.012 °C, whereas the room №4 without TPE is characterized by the deviation of 0.045 °C.

Besides the thermal modes research model allows to perform the analysis of the rooms energy efficiency for several variations of the applying IM and thickness of the brick layout λ_{L2Rj}. Table 3 shows the energy consumption data of the controlled objects.

Table 3. Daily thermal energy consumption for maintaining the indoor climate of controlled rooms

Characteristics		Room 1	Room 2	Room 3	Room 4
Type of IM (layer L3)		no	polymer coating KORUND	bio insulator	expanded polystyrene
Energy consumption Q_{hRj} [kW·h]	$_{L2Rj}$ = 0.375 m	59.6	44.21	45.74	43.84
	$_{L2Rj}$ = 1.03 m	47.58	44.63	44.75	44.63

Data analysis (Table 3) shows the fundamental difference of the parameters Q_{hRj}. The most energy saving effect is achieved by using the IM and at λ_{L2Rj} = 0.375 m: applying the expanded polystyrene allows reducing thermal energy consumption to 26.44 % compared to envelopes with insulation.

A minimum energy saving effect of applying the thermal insulators is observed in case of massive brick walls (λ_{L2Rj} = 1.03 m). Equal parameters of energy consumption were determined in rooms with TPE, consist of polymer coating KORUND and expanded polystyrene. Massive brick walls reduce energy saving effect of TPE to 6.2 %.

5. Summary

Modelling for the winter climate conditions (February) of Western Siberia was conducted. Researches of heat consumption of rooms, which are characterized by individual TPE were conducted. Applying the expanded polystyrene saves up to 15.76 kW·h (26.44 %), while 3 mm thickness polymer coating saves up to 15.39 kW·h (25.82 %) in case of λ_{L1Rj} = 0.375 m. Applying the bio insulator based on sunflowers waste is justified on grounds of economic efficiency taking into account the relatively worse heat-insulating material properties. The most stability of indoor air temperature is achieved by using expanded polystyrene or polymer coating KORUND as insulators: temperature TinR2 deviation from the setpoint value did not exceed 0.012 °C.

Obtained modelling results (heat heat consumption, dynamic of indoor air temperature and the temperature distribution in the building envelopes) can be used to develop energy conservation measures for existing or planned buildings.

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