DETERMINATION OF ENERGY CHARACTERISTICS OF BUILDINGS

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Abstract

Mathematical model of solar radiation availability and thermal conversion of solar energy in a building envelope has been developed. Numerical simulation based on the developed mathematical model has been used to determine energy characteristics of a building. The developed model allows many cases of a building structure to be analysed. In the paper energy characteristics of some room cases are presented. The rooms selected for consideration are especially highly irradiated in summer what causes relatively high cooling demand. The paper considers also heat transfer through opaque elements of a building envelope. Examples of two different coating materials that differ mainly in solar absorptance are presented. Incorporation of Phase Change Materials into building structure is also mentioned.

1 Modelling of energy characteristics of a building

The opaque elements constitute the majority of a building envelope. Their thermal and physical parameters can be selected to assure limited heat transfer through them (less than 10% of the total heat exchanged through envelope and via ventilation with outside environment) during the whole year, even in high latitude countries. In consequence glazing decides on energy transfer through a building envelope. Energy flow through glazing includes the energy transferred by solar radiation and the heat transferred because of the temperature difference between inside and outside environment.

Mathematical model of solar radiation availability and thermal conversion of solar energy in a building envelope has been developed [1]. This model takes into account the variations of ambient temperature, the direct and diffuse solar radiation, the thermal and optical properties of construction materials as well as actual component dimensions and orientation. A ‘representative averaged’ ambient temperature and solar radiation regime (taken as that of Warsaw) [2], together with a fixed room size and room temperature requirement has been elaborated. The model developed includes unsteady heat conduction in solid elements of building envelope, fully detailed equations describing convection from outside and inside, and radiation exchange between the ground, the sky and window, and wall, solar radiation absorption, transmission or reflection on all surfaces, and the effects of orientation and inclination on them. For numerical simulation of developed mathematical model the elementary energy balance method has been used [3].

2 Energy characteristics of a building. Some results of simulation

The west and south rooms were selected for consideration, because of specific solar irradiation conditions, i.e. the highest irradiation level in summer comparing with other rooms location. The rooms under consideration are 3m height , the floor area is equal to 16 m^2, there is one window of 2 x 2 m^2 of total surface. Total heat transfer coefficient of the wall U is equal to 0,3 W/(m^2 K). The window is double glazed with wooden frame, U is equal to 2,6 W/(m^2 K). Because of assumed and elaborated solar radiation representative model, 12 averaged days (one for each month) have been simulated, each day being repeated enough times to ensure a steady (repeatable) solution. Figure 1 presents averaged daily solar irradiance distribution for every month of a year on west and south vertical surfaces. It is evident that in summer irradiance can be very high and it is higher for west vertical surface (maximum 480 W/m^2) than for the south one (maximum 420 W/m^2 in the same month). Figure 2 and 3 present the total energy: solar energy and heat that goes through glazing into or out of the rooms under consideration (left picture) and heating/cooling energy needs (right picture) of the rooms west and south respectively during averaged days for every month of a year. Solar irradiation on west and south oriented surfaces is very high in summer. Maximum hurly cooling demand can reach nearly 4,7 MJ for the west room and 4 MJ for the south room under consideration. Apart from the solar radiation absorbed by the surface material, in a case of glazing solar radiation passes through the glazing directly to the room. Of course this process depends on solar transmittance of glazing. All these conditions cause high solar energy impact to energy balance of a given room and in consequence relatively high cooling demand in summer.

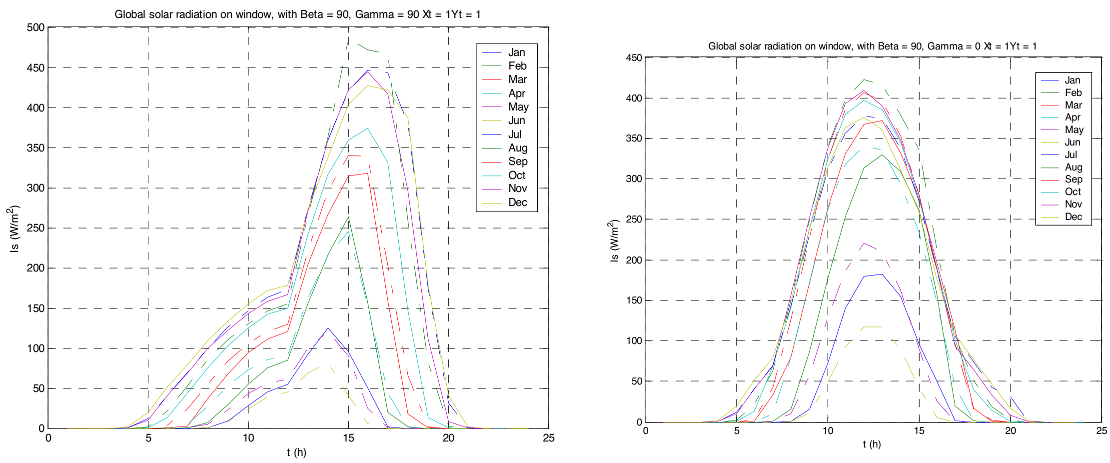

Fig.1. Daily solar irradiance distribution for every month of a year on west (left) and south (right) vertical surface [3]

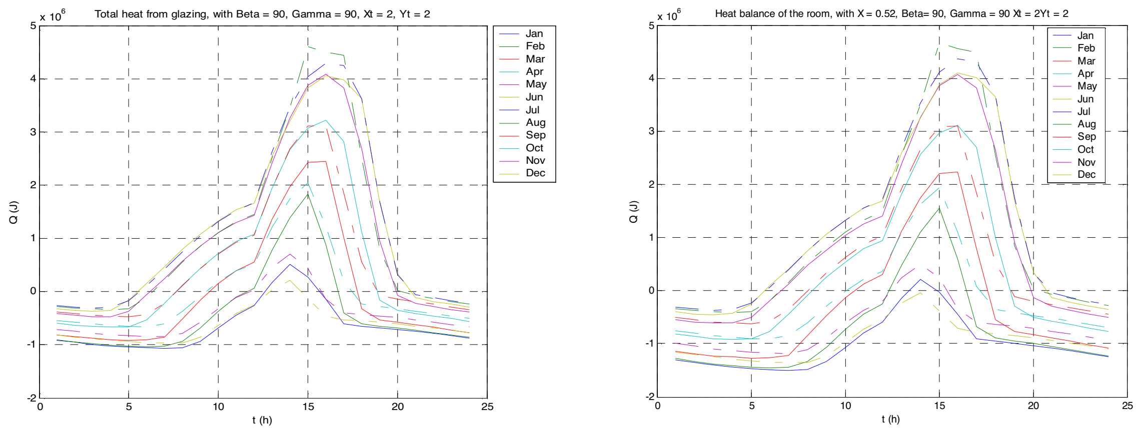

Fig.2. Daily distribution of total energy passes through glazing into or out of the west room (left) and energy heating/cooling requirements of the west room (right) during averaged days for every month of a year [3]

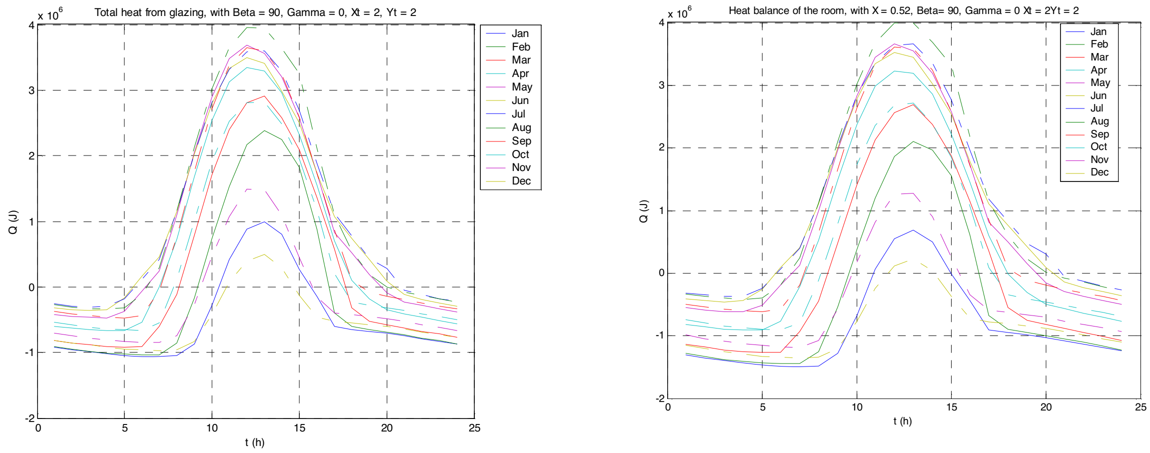

Fig.3. Daily distribution of total energy passes through glazing into or out of the south room (left) and energy heating/cooling requirements of the south room (right) during averaged days for every month of a year [3]

It is interesting to compare the daily solar irradiance distribution in summer (Fig.1) with the daily distribution of total energy passes through glazing and the daily distribution of cooling energy needs of the rooms under consideration, west and south (Fig.2 and Fig. 3 respectively). It is evident that distribution of curves of the daily cooling load is very adequate to daily solar irradiance distribution in a given month. Overheating in summer due to high irradiation level could be a real problem for west and south rooms even in high latitude countries, like Poland. Therefore a special attention should be put during planning, designing and constructing of west and south façades of buildings. However, such situation is evident only when dynamics of a building is considered and the time step of calculation is small enough, at least one hour.

The energy heating/cooling demand of rooms under consideration have been also determined using methodology required officially in Poland [4] to present energy characteristics of a building for energy certification needs. The official methodology is based on averaged mean monthly climatic data. Using such method the dynamics of a building is completely lost. The averaged ambient air temperature is for example in Warsaw not higher than 18^0 C. The required indoor air temperature is equal to 20^0 C. It turns out that with averaged monthly irradiation level and the temperature difference between inside and outside, just mentioned above, there is no need (for presented cases of rooms) for cooling in summer. What is completely opposite to results just presented above.

3 Energy transfer through opaque building elements. Some results of simulation

Many different building materials have been already investigated to improve energy characteristics of a building. At the Institute of Heat Engineering, Faculty of Power and Aeronautical Engineering of the Warsaw University of Technology the national project "Accumulation of thermal energy using PCM for application in low-energy buildings" founded by the Ministry of Science and Higher Education has been developed. The project focuses on reduction of heating and cooling needs of modern buildings through implementation of new conversion and storage techniques. The stress is put on materials like Phase Change Materials PCM to be incorporated into building structure. Very promising methods of incorporation the PCM into building structure are direct incorporation (at time of mixing), immersion and encapsulation. The first method and physical and thermal parameters of PCM are under investigation during indoor laboratory tests under solar simulator. Other issues of solar energy conversion in a building structure have been also considered. Thermal behavior of external layer of a building envelope under solar irradiation is another problem under analysis.

Solar energy incident on opaque buildings elements can be absorbed by a surface of the outside wall layer. The wall surface is characterized by specific solar radiation absorptance and thermal radiation emissivity what in consequence influences the heat transfer phenomena between wall and environment and gives impact to energy characteristics of a building. In the analysis performed during project it has been assumed that building envelope constitutes: thick thermal insulation material with very low heat conduction and construction material with high thermal capacity determined by high specific heat, density and volume of construction material. Calculation performed are based on assumption that all the time the indoor temperature is kept at the same level (by HVAC system) and is equal to 20^0C. Below some results of simulation are presented to show the thermal behaviour of an opaque external wall (2.5 m height and 3 m width) constructed according to energy saving measures. There are two options of external surfaces that differ in solar absorptance and thermal radiation emissivity. The external wall of a room under consideration is the only one that has a direct contact with ambient. Thermal and physical parameters of the considered wall layers are following:

- paint - 0.01 m thickness; 1,0 W/mK heat conductivity; 2000 kg/m^3 mass density; 700 J/(kgK) specific heat;
- insulation – glass wool; 0.20 m thickness; 0.038 W/mK heat conductivity; 24 kg/m^3 mass density; 700 J/(kgK) specific heat;
- brick: 0.24 m thickness; 0.70 W/mK heat conductivity; 1600 kg/m^3 mass density; 840 J/(kgK) specific heat.

Two different paints that cover external wall surface are analysed. The black paint with high solar absorptance of 0,9 and emissivity for thermal radiation equal to 0,8 and white paint with low solar absorptance of 0,1 and the same emissivity for thermal radiation. The emissivity for thermal radiation of the white paint at inside of the room is equal to 0,9.

The numerical simulation has been performed to predict the heat flow changes through the wall by month, by hour in the averaged day of a month of averaged year for the rooms with different location in the building under consideration. Some selected results of simulation are presented in graphical form in the paper. Referring to the main object of consideration, i.e. solar energy impact on energy balance of a building and possible overheating of rooms in summer, the results of simulation for one summer month, i.e. July are presented. The heat fluxes exchanged with inside cavity (room) at boundary surfaces of the external wall under consideration are presented in Fig. 4 and Fig. 5, for walls with black and white paint respectively. In these figures curves show the heat flow into (positive values) the room or out (negative values) of the room (through external wall) marked as "Total" that result of natural convective ("Convect") and radiative ("Rad") heat transfer. For the black paint all day long there are small heat gains with maximum in the night (4,5 kJ/m^2) and minimum at the midday (2 kJ/m^2). The heat gain peak is moved from the day time to the night time. This is an effect of thermal capacity of the building. This situation can be seen and analysed in Fig. 6, which shows changes in time of the distribution of temperature inside the external wall in every 4 hours of the averaged day of July.

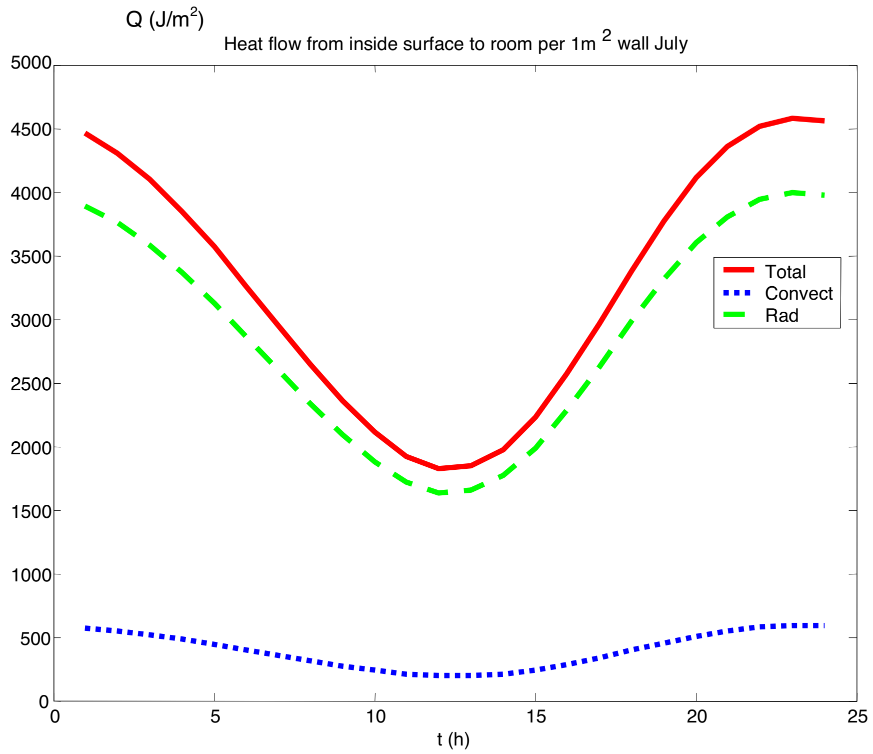

Fig.4. The density of heat exchanged with inside cavity (room) at boundary surfaces of the external wall with black paint at outside surface in the averaged day of July.

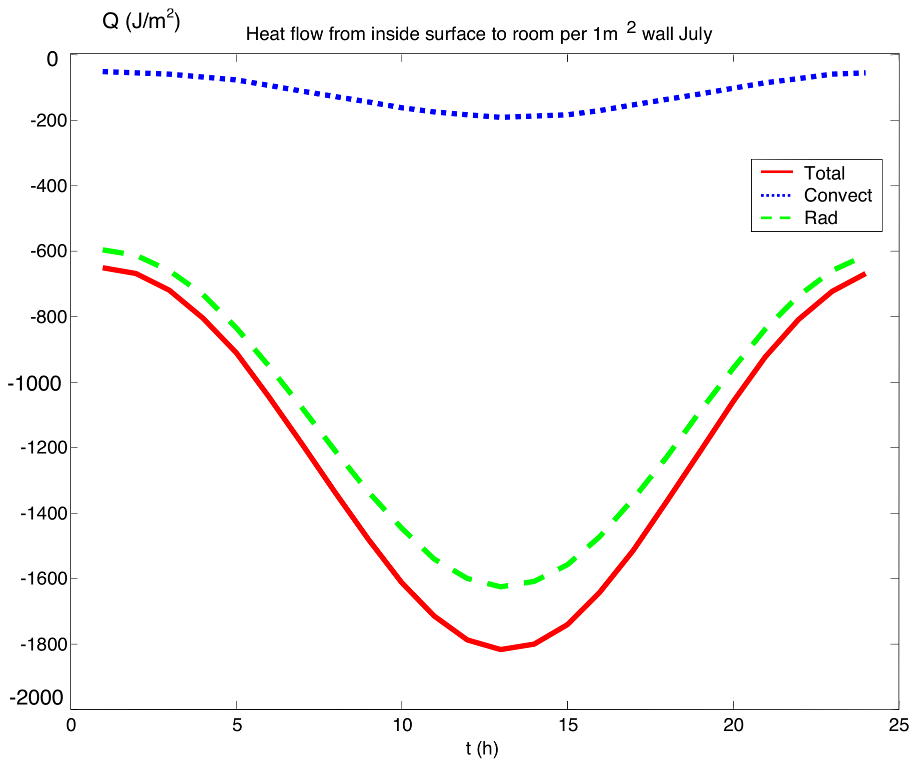

Fig.5. The density of heat exchanged with inside cavity (room) at boundary surfaces of the external wall with white paint at outside surface in the averaged day of July.

Opposite, in case of the white paint (Fig. 5) all day long there are very small heat losses with maximum in the middle of a day (1,8 kJ/m^2) and minimum at the night (about 0,65 kJ/m^2). In this case also the effect of thermal capacity of the building is visible. It must be mentioned that even if building is very well insulated and has high thermal capacity, the role of painting that covers the external surface wall is important and influences energy flow through opaque elements. Of course, here the paint selected for consideration are characterized by extreme ability for absorption of solar radiation.

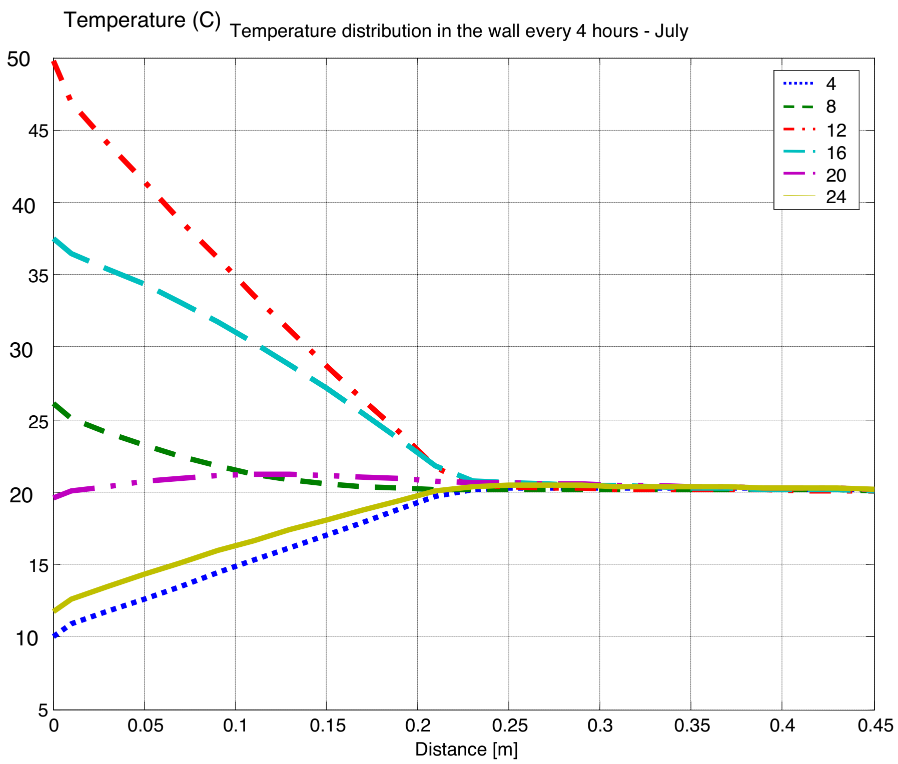

Fig. 6. Distribution of temperature inside the external wall with black paint in every 4 hours of averaged day of July.

As it was mentioned Fig. 6 and Fig.7 present changes in a day time of the distribution of temperature inside the external wall in every 4 hours of averaged day of July, for the wall with black and white paint respectively. It can be seen very easily where is the end of insulation that is thick enough to reduce nearly fully the effect of environment. However, analyzing both figures it is also evident how big the temperature difference is between surfaces with black or white paint. For the black paint of the external surface the temperature of 50^0 C is the maximum one and it is seen at noon (12.00 a.m.), when the solar irradiance and ambient temperatures are very high. The minimum temperature of the surface considered is equal to 10^0 C and it occurs at early morning (4.00 a.m.), when there is no solar radiation and the ambient temperature is the lowest. For the white paint the maximum temperature is equal only to 25^{0}C and it is seen at the same time as for black paint. The minimum temperature is also at the same time and it is at the same level.

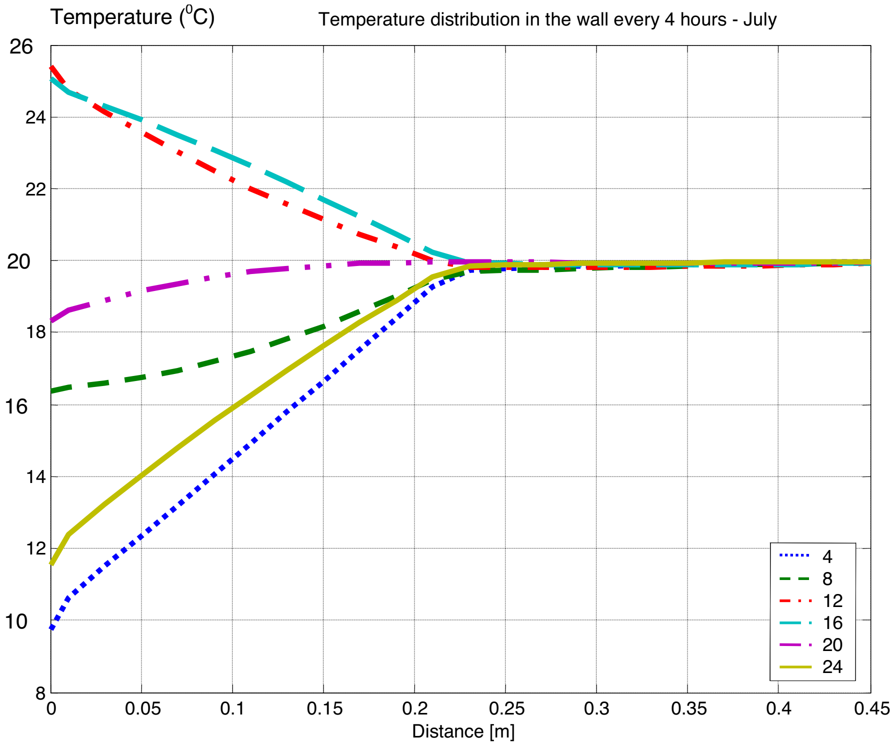

Fig. 7. Distribution of temperature inside the external wall with white paint in every 4 hours of averaged day of July.

Analysing all four figures, i.e. Fig. 4 – Fig.7, it is evident how important is solar absorptivity of the surface of external wall, even if the wall is constructed according to energy saving measures and is very well selected for given climate, here for high latitude country.

4 Conclusions

The analysis performed shows the importance of dynamic simulation of energy balance of a building and access to detailed climatic data: ambient temperature and solar radiation data that are presented on hourly basis. The energy heating/cooling demand of a room under consideration has been also determined using methodology required officially in Poland [4] to present energy characteristics of a building. The official method of calculations is based on monthly averaged input data to determine monthly energy needs. Using monthly averaged climatic data (solar radiation and ambient temperature) and steady state model of energy transfer in the building envelope elements and their surrounding (indoor and out door environment) cause the unreal presentation of the energy characteristics of the building. For presented case of west and south rooms it turns out that applying the official methodology [4] there is no need for cooling in summer and even in some hours of averaged days in some summer months heating is required, what is of course false in our climate.

The other interesting conclusion of the study performed is recommendation for careful choice of the type and color of the paint at external wall surfaces even in buildings constructed according to new energy saving standard measures. The high quality and thickness of insulation can not limit completely the influence of environment if the external surface paint is characterized by high solar absorptivity.

Acknowledgements

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5 References

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