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Usage Effect of the Selective Absorption Facade Instead an Insulation Layer and Influence on Energy Performance of the Family House

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Abstract: In this paper the usage influence of the selective absorption facade instead an insulation layer on heating energy consumption of the family house is simulated. Using EnergyPlus software on the model of existing family house the defined influence has been analyzed. On selected exterior walls (especially southern) the insulation layers were removed and replaced with the selective absorption facade. This procedure resulted in the increased radiation gains as well as increased convection losses. Sixteen simulation scenarios were carried out. Results of these simulations were shown that a lack of insulation layer on southern facade can be compensated by application of the selective absorption surface.

Keywords: Energy consumption, Selective façade, Residential house.

1. Introduction

Decades ago the residential buildings in Europe are very important consumers of the final energy. This share constantly moves around 30% (according current data for EU 28%, [1]). Due to its geographical position and climatic conditions the biggest part of this final energy is spent on heating demands of the residential building spaces in cold months, which amounts 60-70% (for EU this share is 64.4%, [2]). Therefore, it is not needed to emphasize an importance of the energy saving measures in heating sector. Regarding transmission heat energy losses of the residential buildings, the thermal characteristics of the outer walls, windows and doors as well as applied insulation have the most important influence on heating energy consumption. With increasing of insulation layer the building heating losses by conduction and convection are certainly reduced but also possibilities to use heating gains of the winter solar radiation on vertical outer walls. The question arises whether it is possible to reduce heating losses by decreasing insulation layer or even removing this layer especially from south outer wall. Using a simple dynamical model of the building it was shown that under defined weather conditions the heating energy savings can be achieved by removing insulation layer from south outer wall of the residential house, [3]. This effect was weakly expressed due to the stripped façade retains a high thermal emittance (long-wave infrared radiation).

Among other improvements, development of the solar collector systems has brought a new technology of the selective surfaces with high solar absorptance and low thermal emittance. A thin absorber coating in the solar collector is protected from the whether influence and damage by a glass cover. Similar case can be found at passive solar systems especially contemporary design of Trombe wall, where the selective surfaces are applied, [4]. However, such selective coatings can be applied on outer walls of the residential and other buildings. In [5] for defined simulation cases the heating energy saving of 17% is achieved by using the mineral particles coating on outer thermal insulation. In [6] the thermal solar façade with transparent insulation and selective absorbers. Thermal insulation with high reflectance selective coating achieved better heating energy savings than classic one without selective coating, [7]. Façade with high solar reflectance can be used to reduce energy consumption for cooling in summer months, [8]. Selective coatings can be applied on inner walls in order to save heating energy, [9]. In [10] the measured energy consumption data of the residential building with a selective façade is compared with simulation one. After simulation model adjustment the simulations of well and poorly insulated object are carried out. Results show that more significant energy savings are achieved in the case of poorly insulated object. Changed characteristics of the façade absorptance (a) and emittace (ε) during summer and winter period can be realized by its special surface configuration in the form of the grooved cavities, which absorbs winter solar radiation well, as opposed to summer when the building needs cooling process, [11]. Of course, depending on the climatic conditions, the effect of applying the selective facade will not be the same. Due to an intense convection on outer walls under harsher winter conditions, the selective façade will achieve better results in winter environment of higher temperature and solar radiation [12].

Obviously that change of the absorptance and emittance of the outer and inner walls leads to additional heating and cooling energy saving. On the other hand the insulation layer reduces energy losses as well as energy gains of the solar radiation. The question arises as to what effects removing the insulation layers from certain exterior walls at the same time as the application of a selective façade would have on the heating energy consumption of the residential building? Using EnergyPlus software the simulation model of the real (existing) residential house will point on some answers.

2. Simulation model

Simulation model – the existing residential house is modeled by software GoogleSketchUp. House consists of three levels: basement, ground level and first floor. It is placed on sloping ground, relatively protected from the wind influence. The modeled appearance of the house is shown in figures 1 and 2.

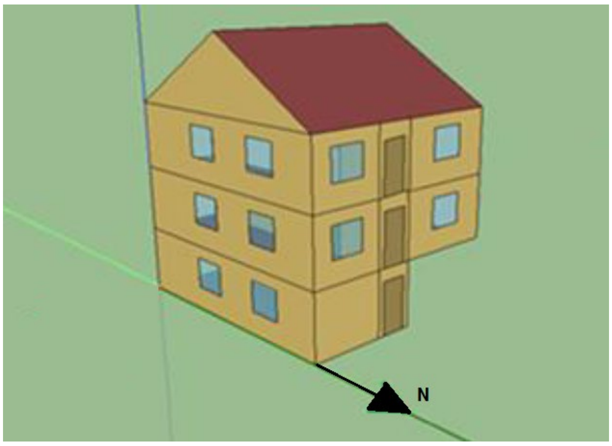

Figure 12 Perspective of the northern and eastern façade

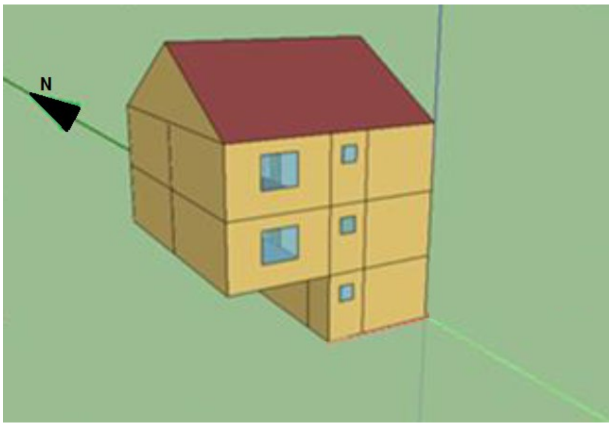

Figure 13 Perspective of the southern and western façade

The interior of the house consists of 13 rooms with a total heating area of 215 m^2 (basement - 85 m^2, ground level - 85 m^2, first floor - 85 m^2). The layout of the rooms is shown in figures 3 and 4. Layout of the rooms in first floor is identical the ground level one. Simulated house is heated by electrical heaters.

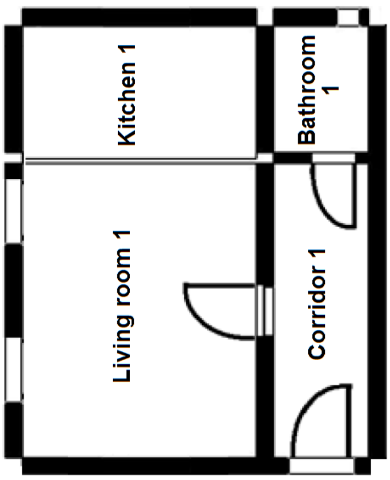

Figure 3. Basement cross section

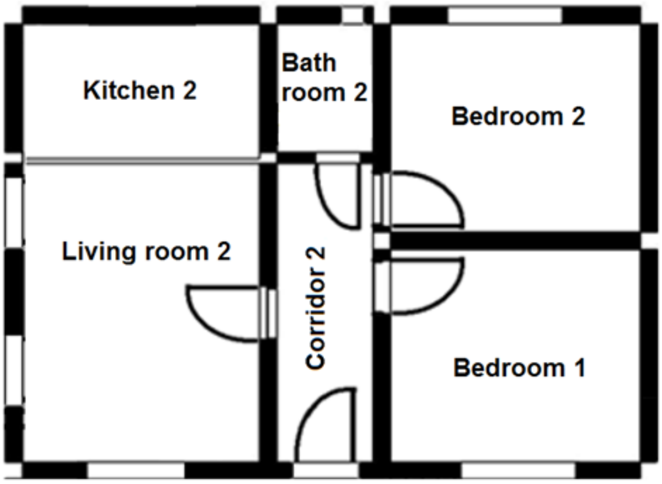

Figure 4. Ground lever cross section

Weather data is taken from the EnergyPlus database for city of Kragujevac (latitude 44.02°N, longitude 20.92°E, mean altitude 209 m). Characteristics of the house envelope applied materials are shown in Table 1. The element structure of the house envelope is shown in Table 2. It is received according to real data (existing object).

Table 1. Applied materials characteristics of the considered residential house

Material	Density [kg/m3]	Thickness [m]	Specific heat [J/kgK]	Thermal conductivity [W/mK]
Lime mortar	1600	0.015	1050	0.81
Cement screed	2100	0.04	1050	1.4
PVC foil	1460	0.00015	1100	0.19
Mineral wool	50	0.05/0.15	840	0.04
Styrodur	33	0.05-0.15	1260	0.03
Ceramic tiles	1700	0.015	920	0.87
Parquet floor	700	0.02	1670	0.21
Tile	1900	0.01	880	0.99
Brick block	1200	0.19	920	0.52
Reinforced concrete	2400	0.04	960	2.04
Gravel	1700	0.2	840	0.81
Concrete	1800	0.15	960	0.93
Interfloor filling	1200	0.16	920	0.6
Pine wood	550	0.035	2090	0.14
Polystyrene	15	0.05-0.15	1260	0.041
Gypsum boards	800	0.012	1090	0.19

In formed outer walls the insulation layer (polystyrene) is placed outside (before lime mortar). Adopted overall heat transfer coefficient of windows is 1.5 W/m^{2}K. Air infiltration and ventilation are adopted as air changes per hour (kitchens – 1.5 h^{-1}, bathrooms – 1.25 h^{-1}, corridors – 0.75 h^{-1}, living and bedrooms – 0.5 h^{-1}). For standard façade the absorptance and emittance are adopted as $a=\varepsilon=0.7$, for solar radiation and $a=\varepsilon=0.9$, for long-wave infrared radiation. In the case of selective façade the adopted coefficients are $a=\varepsilon=0.95$, for solar radiation and $a=\varepsilon=0.2$, for long-wave infrared radiation.

Table 2. Envelope structure of the considered residential house

Building construction	Elements	Thickness [m]
Outer wall	Lime mortar	0.015
	Polystyrene	0.05-0.15
	Brick block	0.19
	Lime mortar	0.015
Inner wall	Lime mortar	0.015
	Brick block	0.19
	Lime mortar	0.015
Ground floor (parquet)	Gravel	0.2
	Concrete	0.15
	PVC foil	0.00015
	Styrodur	0.05-0.15
	Cement screed	0.04
	Parquet	0.02
Ground floor (tiles)	Gravel	0.2
	Concrete	0.15
	PVC foil	0.00015
	Styrodur	0.05-0.15
	Cement screed	0.04
	Ceramic tiles	0.015
Door	Pine wood	0.035
Roof	Tile	0.01

	Air gap	
	Mineral wool	0.05-0.15
	Gypsum boards	0.012
Interfloor (to attic)	Reinforced concrete	0.04
	Interfloor filling	0.16
	Lime mortar	0.015
Outer wall (tiles)	Lime mortar	0.015
	Polystyrene	0.05-0.15
	Brick block	0.19
	Ceramic tiles	0.015
Inner wall (tiles)	Lime mortar	0.015
	Brick block	0.19
	Ceramic tiles	0.015
Interfloor (tiles)	Ceramic tiles	0.015
	Cement screed	0.04
	Reinforced concrete	0.04
	Interfloor filling	0.16
	Lime mortar	0.015
Interfloor (parquet)	Parquet	0.02
	Cement screed	0.04
	Reinforced concrete	0.04
	Interfloor filling	0.16
	Lime mortar	0.015

3. Simulation scenarios

The main goal of carried out simulations was to compare the heating energy consumption of non-insulated and insulated object with standard façade with selective façade one. In the case of object with selective façade in some simulation scenarios the certain insulation layers are removed retaining selective surface to outside. All carried out scenarios are defined in Table 3.

Table 3. Simulation scenarios and the applied insulation thickness

Scenario mark	Roof insulation [cm]	Floor insulation [cm]	South wall insulation [cm]	East wall insulation [cm]	West wall insulation [cm]	Nort wall insulation [cm]
0.1	0	0	0	0	0	0
0.2	5	5	5	5	5	5
0.3	10	10	10	10	10	10
0.4	15	15	15	15	15	15
1.1	0	0	0	0	0	0
1.2	5	5	5	5	5	5
1.3	10	10	10	10	10	10
1.4	15	15	15	15	15	15
2	5	5	0	5	5	5
3	10	10	0	10	10	10
4	15	15	0	15	15	15
5	5	5	5	10	10	10
6	10	10	5	15	15	15
7	15	15	0	0	0	10
8	5	5	0	0	10	10
9	10	10	0	10	0	10

Scenarios with first number 0 refer to house with standard façade while scenarios with first number 1 to 9 refer to house with selective façade. Scenarios from 2 to 9 indicate to removing or reducing the insulation layer from certain walls (especially southern).

4. Results and discussion

After carried out simulations the heating energy consumption for all scenarios could be analyzed. Energy consumption of the non-insulated and insulated object for scenarios 0 and 1 is shown in Table 4.

Table 4. Heating energy consumption of the residential house in case of the variable insulation thickness and façade absorption characteristic

Simulation scenario	Energy consumption per heating season [kWh]	Energy consumption per heating area [kWh/m^{2}a]	Energy saving scenario 1 vs. scenario 0 [%]
0.1 (0 cm)	33365	155.2	
0.2 (5 cm)	22602	105.1	
0.3 (10 cm)	19770	92.0	
0.4 (15 cm)	18444	85.8	
1.1 (0 cm)	21043	97.9	36.9
1.2 (5 cm)	17531	81.5	22.4
1.3 (10 cm)	16434	76.4	16.9
1.4 (15 cm)	15892	73.9	13.8

Data of first four rows in Table 4 (standard object without selective façade) shows that the heating energy consumption decreases with insulation layer increasing but relatively less towards high insulation thickness (ventilation losses becomes dominant in relation to transmission one). In the case of the object with selective façade (four remained rows) trend is similar except that the decrease of energy consumption is less expressed with increasing of the insulation thickness. The last column in Table 4 shows the percentage energy consumption saving of the object with selective façade vs. standard object with corresponding insulation layer (from 0 to 15 cm). The most pronounced relative saving is observed at the non-insulated object, while the object with maximal insulation layer (15 cm) is on opposite side. That would be logical since an insulation prevents heat energy losses as well as outside gains (increased solar absorption).

Simulated heat energy consumption of the object with selective façade in the case of the complete (scenarios 2, 3 and 4) and incomplete (scenarios 5-9) insulated outside walls is shown in Table 5. As well the relative energy saving of defined scenarios vs. standard object (third column) and object with selective façade (fourth column) is shown.

Table 5. Heating energy consumption of the residential house in case of the selective façade, variable insulation thickness and lack of the certain insulation layer according to defined simulation scenario

Simulation scenario	Energy consumption per heating season [kWh]	Energy saving vs. corresponding scenario 0 [%]	Energy saving vs. corresponding scenario 1 [%]
2	17470	22.7	0.3
3	16425	16.9	0.1
4	15916	13.7	-0.2
5	16493	16.6	-0.4
6	15988	13.3	-0.6
7	18708	5.4	-13.8
8	17496	11.5	-6.5
9	17638	10.8	-7.3

From table 5 can be seen that the object with selective façade and lack (or reduction) of the certain insulation layer (on southern wall mostly) shows constantly less energy consumption relative to standard object with corresponding insulation layer (third column). The most pronounced energy saving is observed at the poorly insulated object with selective façade (5 cm) and removed insulation layer from southern wall. (Scenario 2 – 22.7 %). In the other hand, least pronounced energy saving is observed at the well-insulated object with selective façade (15 cm) and removed three insulation layers from southern, eastern and western walls (Scenario 7 – 5.4 %). However, removing certain insulation layers from outside walls compared to completely insulated object with selective façade (fourth column) does not give a positive result. In the cases of scenarios 2-6 the effect of the increased solar gains is practically canceled out by effect of the increased heat losses from the non-insulated southern wall, so the energy saving are zero. In the cases when the insulation layers are removed from two or three outside walls, the increased energy consumption is observed (Scenarios 7-9).

It is interesting to analyze energy consumption savings of the certain scenarios monthly, during heating season (October-April). Relative heating energy savings of the object with selective façade vs. standard one with corresponding insulation level is shown in Figure 5. The smaller the layer of insulation up to the non-insulated object, the greater the relative energy savings. These savings are the most pronounced for months with enlarged solar radiation (October, April, March and November).

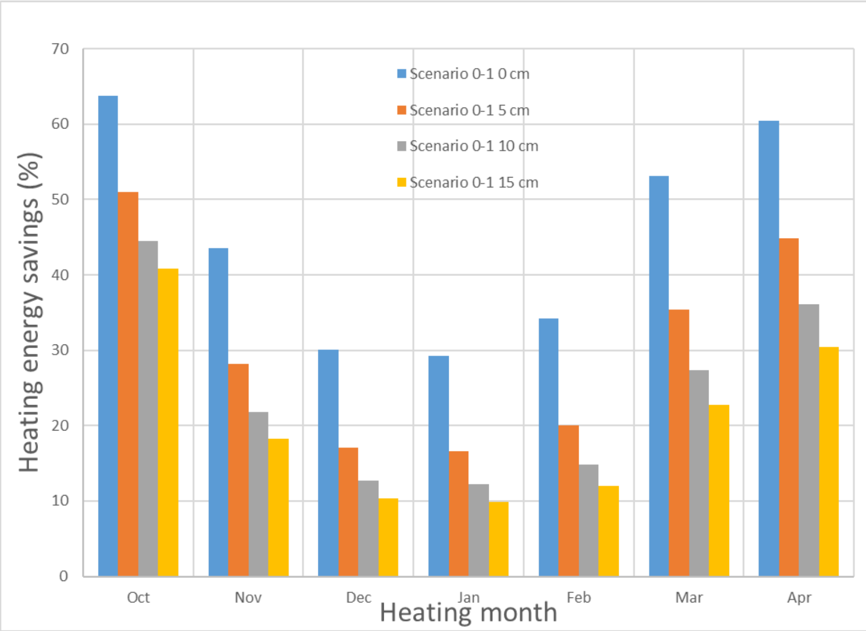

Figure 5. Monthly relative heating energy saving of the residential house with selective façade vs. classical envelope house for different insulation levels

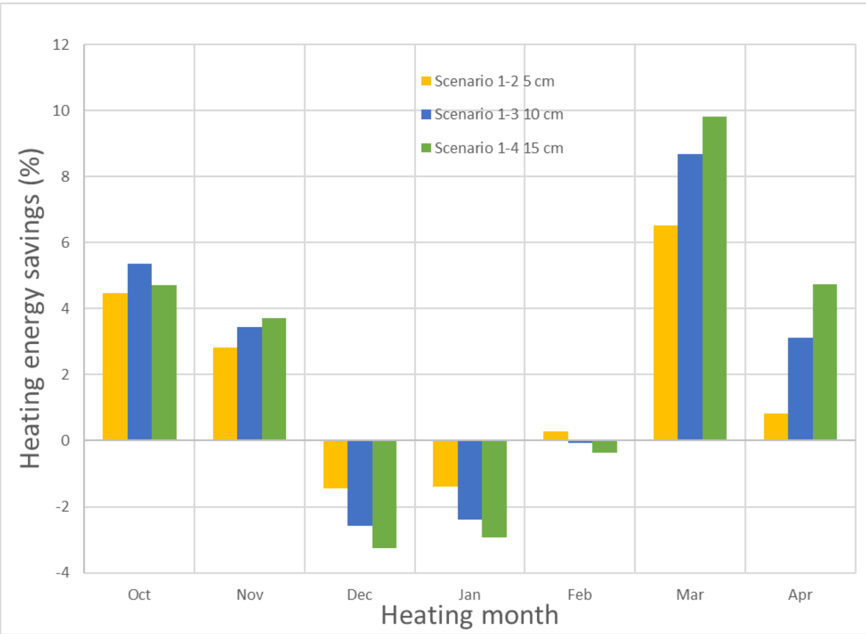

Figure 6. Monthly relative heating energy saving of the residential house with selective façade with lack of the south wall insulation layer vs. fully insulated selective façade for different insulation levels

Relative heating energy savings of the object with selective façade and removed insulation layer from southern wall (Scenarios 2-4) vs. complete insulated one with corresponding insulation level is shown in Figure 6. Although the energy saving for heating season is approximately zero (Table 5), for months with the least solar radiation (December, January) it is negative. In addition to the application of a selective facade, the idea of applying a variable insulation thickness (something opposite to intumescent materials) is imposed to increase energy saving.

5. Conclusion

Selective surfaces and coatings are widely used in the production of solar collectors. They are also applied in passive solar systems (Trombe wall). The application of selective building façade can contribute to a significant reduction of heating energy transmission losses in the winter period. More pronounced positive effects of selective facade application can be observed at latitudes and heating months with significant solar insolation. On the example of the residential house, depending on the climatic conditions, the energy savings of the selective facade compared to the classic one, with the same level of insulation, amount from 13.8 to 36.9%. As the thickness of the insulation increases, the positive effects of applying a selective facade decrease. Selective façade can be combines with the removing or reducing of an insulation layer, especially on southern outside wall. Simulation results have shown that in climatic condition characteristic of our latitudes the mentioned measure can lead to the similar heating energy consumption as in a completely insulated object with selective façade. Those relations are very sensitive to solar radiation amounts, so the energy saving effects are more pronounced in the warmer winter months then colder one with reduced solar radiation (December and January).

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