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Energy performance of the Serbian and Estonian family house with a selective absorption facade

N Lukić[1], A Nešović[1], N Nikolić[1], A Siirde[2], A Volkova[2] and E Latosov[2]

[1]University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia
[2]Tallinna Tehnikaülikool, Energiatehnoloogia instituut, Ehitajate tee 5, 19086 Tallinn, Estonia

E-mail: lukic@kg.ac.rs

Abstract. In this paper the influence of selective absorption facade on heating energy consumption of the family house is analyzed. Two houses built according to Serbian and Estonian building energy performance regulation (minimum requirements) are simulated by EnergyPlus software. For simulation process the appropriate weather data are used (Serbia – Kragujevac and Estonia – Tallinn). Heat transfer by radiation, gains and losses can be a significant part of the energy consumption, during heating season. Using selective absorption facade those gains and losses could be increased and reduced, respectively. Several simulation scenarios of Serbian and Estonian house are carried out. Different weather conditions in case of the defined houses point on specific impact of the applied improvement on family house energy performance. Maximum annual percentage savings of heating energy compared to house without selective facade, in case of Serbian house are obtained as 8.32%. In case of Estonian house maximum savings are obtained as 1.92%.

1. Introduction

Certain analyses have shown that in developed countries around the world, the consumption of final energy in buildings in 2008 was higher than consumption in the industrial and transport sector [1]. In order to preserve the environment, renewable energy sources (primarily solar and geothermal energy) in the residential and public sector should be more use. The application of solar technologies in heating, cooling and ventilation systems in order to reduce the consumption of final energy was considered in [2]. In the literature, a large number of papers can be found relating to the application of solar facades for the same purpose [3-6]. An integral component of solar installations is an absorber. In order to reduce the amount of heat emitted from the surface of the absorber, the use of various selective coatings and paints, whose performance was tested in [7-14]. However, the absorbers of solar facades can be external walls, and therefore [15-18] tested the use of low-emission coatings and paints in order to reach energy-efficient buildings. Similar effects can be achieved by coating external walls on the inside [19-21]. Cozza E. S. and others used coatings in [22] to increase the IR reflection from the facade walls in order to better cool the object in the summer period. A facade with grooved cavities was proposed in [23]. The grooved cavities are configured so that solar flares are reflected from their superficial, while absorption in the winter accelerates. The model was developed for a house that is 41 degrees north latitude, but can be adapted for any climatic area. Investigation of the influence of colored facades with selective properties on the energy balance of buildings located in Freiburg, Germany was done by comparing real data with data calculated using the ESP-r simulation program [24]. The results showed that the influence of solar radiation and heat losses caused by convection are the most dominant factors affecting the energy bill of the building. Another conclusion is made: in weakly isolated houses, greater selectivity can be achieved by using selective facades than in better insulated houses.

The aim of this paper is to examine the possibilities of using selective absorption facades in the construction of Serbian and Estonian houses in order to reduce the energy consumption during the heating season. Defined simulations will be carried out by EnergyPlus. This software is a collection of many program modules that work together to calculate the energy required for building heating and cooling, using a variety of systems and energy sources. It does this by simulating the building and associated energy systems when they are exposed to different environmental and operating conditions. The core of the simulation is a model of the building that is based on fundamental heat balance principles.

2. Model of the family house

The subject of research is the family house shown in Figures 1 and 2. The net area of the house is 180.75 m^2. The net conditioned building area is 171 m^2 (storage room and closet are unconditioned rooms). The total surface of the thermal shell is 432 m^2 and window-wall ratio is 14%. The family house has two floors (ground floor and first floor). Arrangement of the rooms on the ground floor shown in Figure 3. Arrangement of the rooms on the first floor shown in Figure 4. The house is intended for the permanent stay of a six-member family.

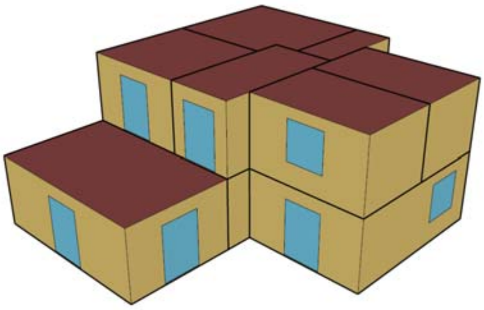

Figure 1. Northwest façade.

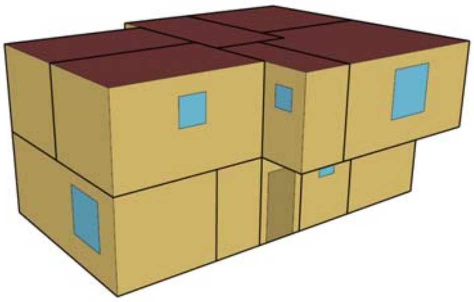

Figure 2. Southwest façade.

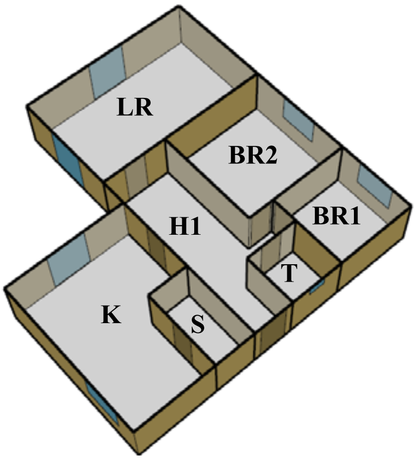

Figure 3. Arrangement of the rooms on the ground floor (K – kitchen, LR – living room, H1 – hall 1, T – toilet, SR – storage room, BR1 – bedroom 1, BR2 – bedroom 2).

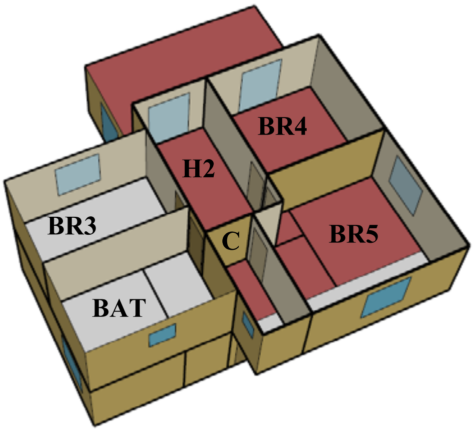

Figure 4. Arrangement of the rooms on the first floor (H2 – hall 2, C – closet, BAT – bathroom, BR3 – bedroom 3, BR4 – bedroom 4, BR5 – bedroom 5).

2.1. Weather files for Kragujevac (Serbia) and Tallinn (Estonia)

To simulate weather conditions for the city of Kragujevac (latitude of 44.02°N, longitude of 20.92°E, the average altitude of 209 m) and the city of Tallinn (latitude of 59.41°N, longitude of 24.83°E, the average altitude of 39.9 m) the EnergyPlus weather files were used [25]. Kragujevac (with the time zone of GMT+1h) is characterized by moderate continental climate with pronounced seasons. Tallinn (with the time zone of GMT+2h) has a humid continental climate with warm, mild summers and cold, snowy winters. Some meteorological data for Tallinn and Kragujevac are shown in the Figures 5-10.

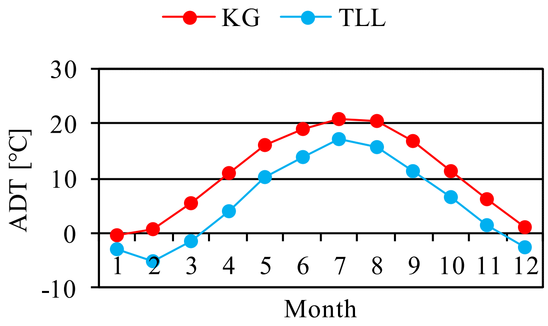

Figure 5. Air drybulb temperature.

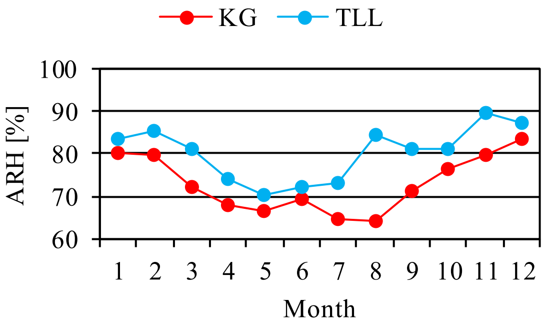

Figure 6. Air relative humidity.

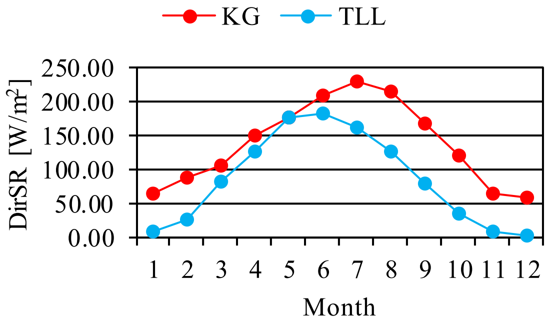

Figure 7. Direct solar radiation.

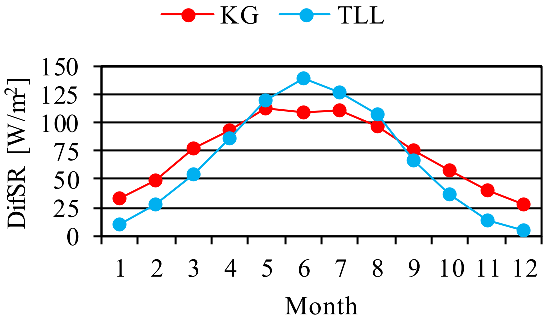

Figure 8. Diffuse solar radiation.

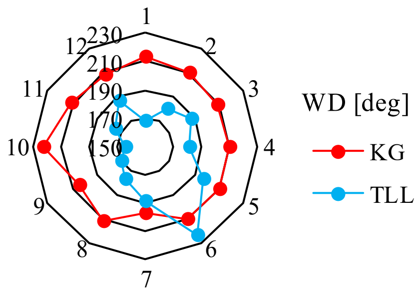

Figure 9. Wind direction.

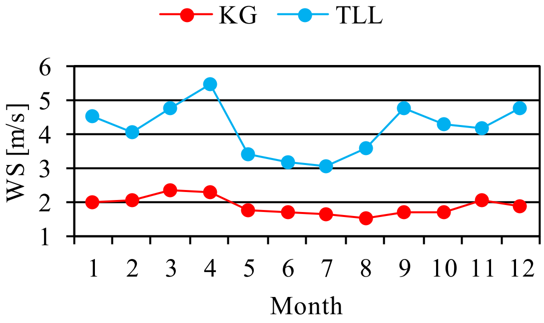

Figure 10. Wind speed.

2.2. Serbian and Estonian building energy performance regulations

Family house is modelled according to the Serbian and Estonian regulations on energy efficiency in the residential sector. In Table 1 (minimum requirements). Some allowed values (heat transfer coefficients for external and internal building elements, internal project temperatures, required air changes depending on the purpose of the room, as well as energy consumption) are shown in these regulations for easier comparison.

Table 1. Serbian and Estonian building energy performance regulations.

Parameter	Description	Serbia	Estonia
Energy consumption [kWh/(m^{2}y)]	Total	-	160
	Only for heating	65	-
Heat transfer coefficient [W/m^{2}K]	Exterior wall	0.3	0.22
	Flat roof (above heated room)	0.15	0.15
	Flat roof (above unheated room)	0.3	
	Floor		
	Interconnected construction (between heated rooms)	0.9	-
	Interconnected construction (above unheated room)	0.3	
	Interconnected construction (under unheated room)		
	Interconnected construction (to outside)	0.2	
	Interior wall (between heated rooms)	0.9	
	Interior wall (to unheated room)	0.4	
	Window	1.5	1.1
	Exterior door (glass)		
	Exterior door (normal)	1.6	
Heating set-point [°C]	Bathroom	22	21
	Other rooms	20	
Outdoor air flow rate For Serbian [h^{-1}] For Estonian [l/(sm^2)]	Kitchen	1.5	0.42
	Toilet		
	Bathroom		
	Other rooms	0.5	
References		[26]	[27]

2.3. Simulation scenarios

According to Table 2, four simulation scenarios are performed. Since, the minimum regulation requirements of thermal characteristics are different for Serbian and Estonian house, all simulations are carried out for two houses, separately. Initial scenario (DHM) has been implied two houses (Serbian and Estonian), built according to current regulations of building thermal characteristics as minimum requirements (the highest allowed heat transfer coefficients). Thermal and solar absorptance (and emittance) are adopted as usual for a building façade, 0.9 and 0.7, respectively. This means that building façade of DHM absorbs solar radiation and emits thermal (infrared longwave) radiation very well. Other three simulation scenarios has been implied two houses with changed absorptance characteristics of the south (S), south and west (S, W) and south, west and east oriented wall. The changed absorptance characteristics means a good absorptance of solar radiation and relatively small emittance of thermal radiation. Defined façade has similar characteristics as selective absorber surface in a solar collector. Depending on intensity of solar radiation, northern latitude, wall orientation, insulation thickness, air temperature, the selective façade effects on heating energy consumption could be positive or even negative. Generally, during winter on northern latitude, vertical surface has better position for solar radiation absorption than horizontal one.

Table 2. Simulation scenarios for Serbian and Estonian house models.

Model	Absorptance and emittance [-]		Thickness of insulation [cm]	
	Thermal	Solar	Serbian house	Estonian house
Default house model (DHM)	0.9	0.7	9.69	13.9
South wall changed (S)	0.2	0.9	9.69; 5; 0	13.9; 5; 0
South and West walls changed (S, W)	0.2	0.9	9.69; 5; 0	13.9; 5; 0
South, West and East walls changed (S, W, E)	0.2	0.9	9.69; 5; 0	13.9; 5; 0

3. Results and discussion

In Figure 11 the percentage savings of the annual heating energy consumption of Serbian house using different insulation thickness and selective façade is given. The maximum insulation thickness (9.69 cm) corresponds with the minimum regulation requirements in Serbia. Thicker insulation layer inhibits heat losses but in the defined case also solar gains on façade surface. The maximum energy savings (8.32%) Serbian house achieves in scenario of S, W and E selective facade and maximum insulation thickness. In case of 5 cm insulation thickness, the selective facades give still positive energy savings, similar for all three scenarios (S; S, W; S, W, E). Serbian house without insulation layer on south wall and selective south façade spends almost the same amount of heating energy as (DHM) with ordinary façade and maximum insulation thickness on south wall (difference is only 1.3%). This means that additional solar gains are approximately equal with additional convective losses in scenario S. Other scenarios give distinctively negative energy savings.

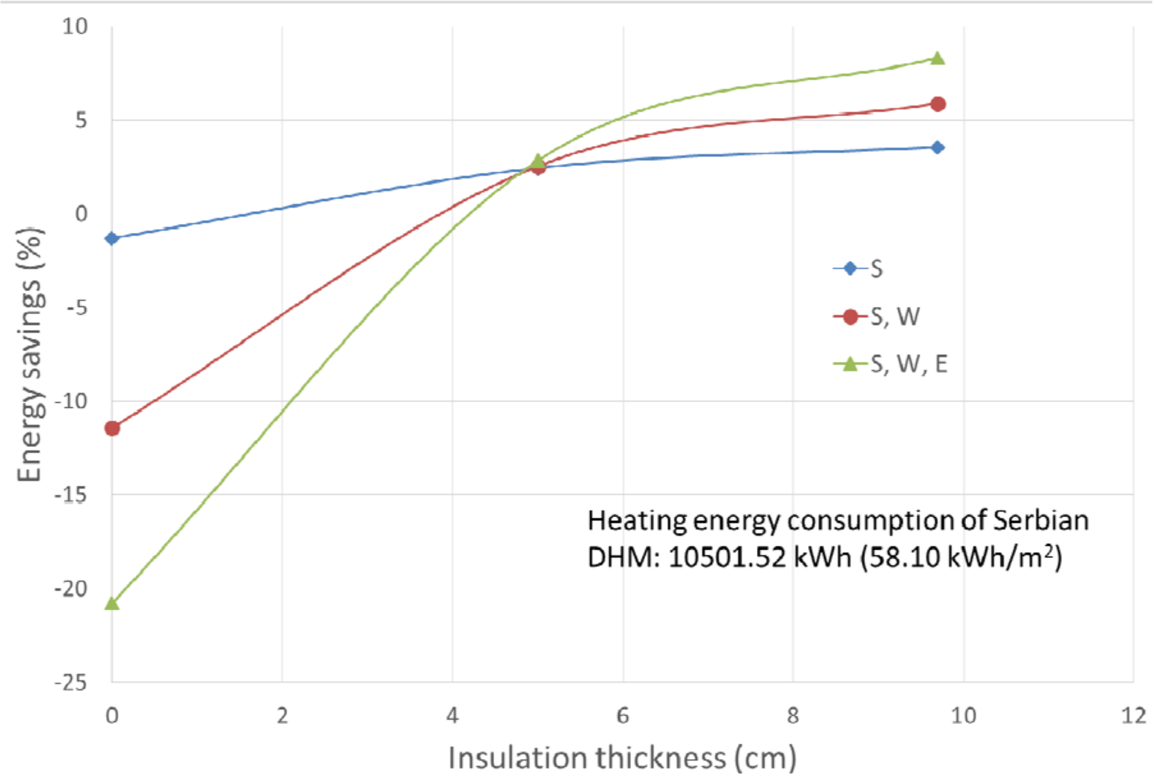

Figure 11. Percentage savings of the annual heating energy consumption of Serbian house using different insulation thickness and selective façade.

In Figure 12 the percentage savings of the annual heating energy consumption of Estonian house using different insulation thickness and selective façade is given. The maximum insulation thickness (13.9 cm) corresponds with the minimum regulation requirements in Estonia. The maximum and insignificant energy savings (1.92%) Estonian house achieves in scenario of S, W and E selective facade and maximum insulation thickness. Decreasing of insulation thickness in any scenario of selective façade leads to significantly increasing of heating energy consumption. In case of Estonian house, during heating season, solar radiation is not a significant factor that reduces heating demands.

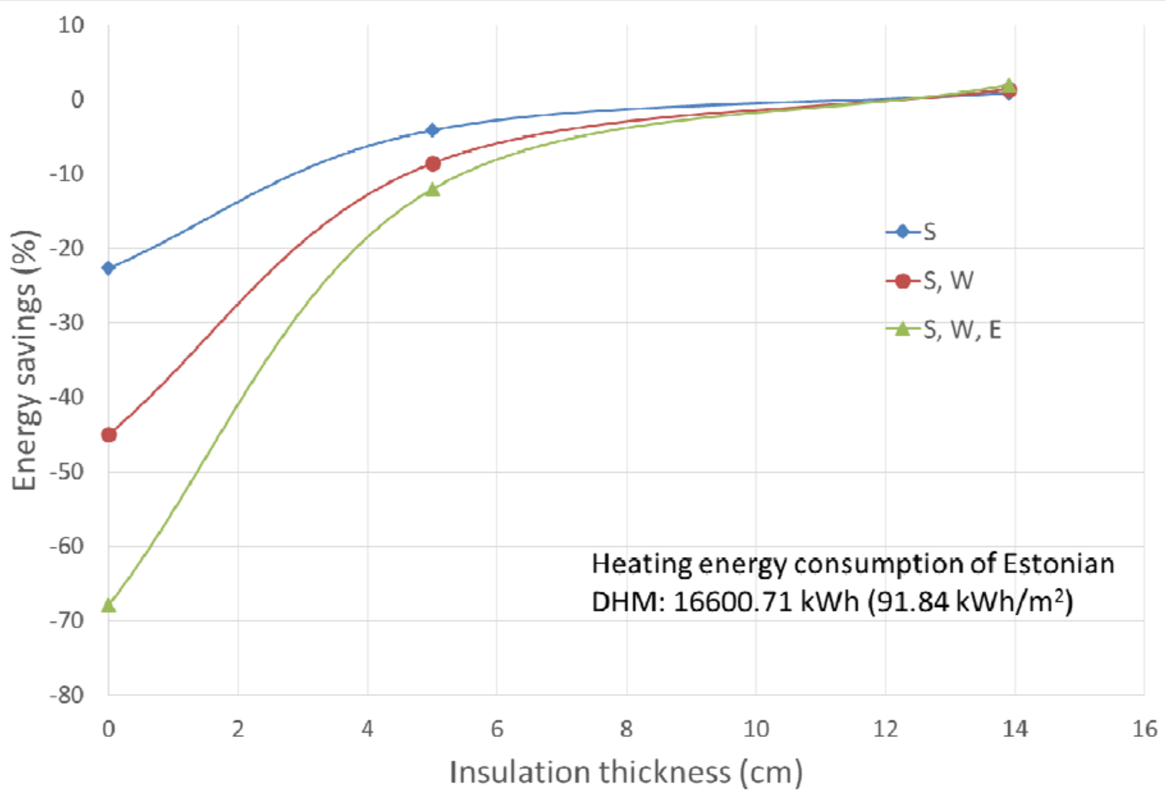

Figure 12. Percentage savings of the annual heating energy consumption of Estonian house using different insulation thickness and selective façade.

In Figure 13 the percentage savings of the monthly heating energy consumption of Serbian and Estonian house using different insulation thickness and selective façade is given. For this review the warmest and coldest heating season months in Kragujevac, Serbia (April and January, respectively) and Tallinn, Estonia (October and January, respectively) are considered. For all presented cases the simulation scenario is S (selective south façade). Figure 13 shows that in case of Serbian house for the warmest heating month (April) the percentage savings are positive even for south wall without insulation layer. The maximum energy savings (8.51%) Serbian house achieves with maximum insulation thickness (south selective façade). For the coldest month (January) only for south wall without insulation layer savings are negative (-4.00%). Also, figure 13 shows that in case of Estonian house for the both considered heating months (October and January) the percentage savings are positive only for maximum insulation thickness. In case of the coldest month (January) and maximum insulation thickness the energy savings effects of south selective façade are insignificant (0.41%).

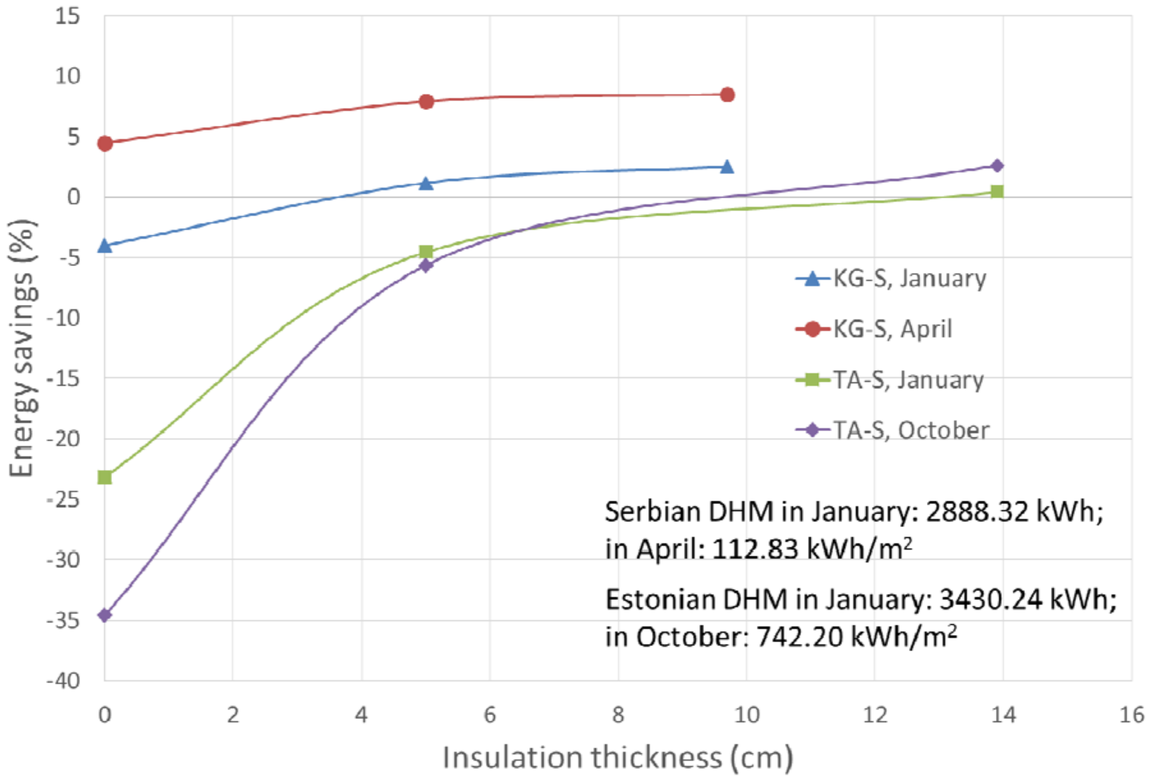

Figure 13. Percentage savings of the monthly heating energy consumption of Serbian and Estonian house using different insulation thickness and selective façade for selected months.

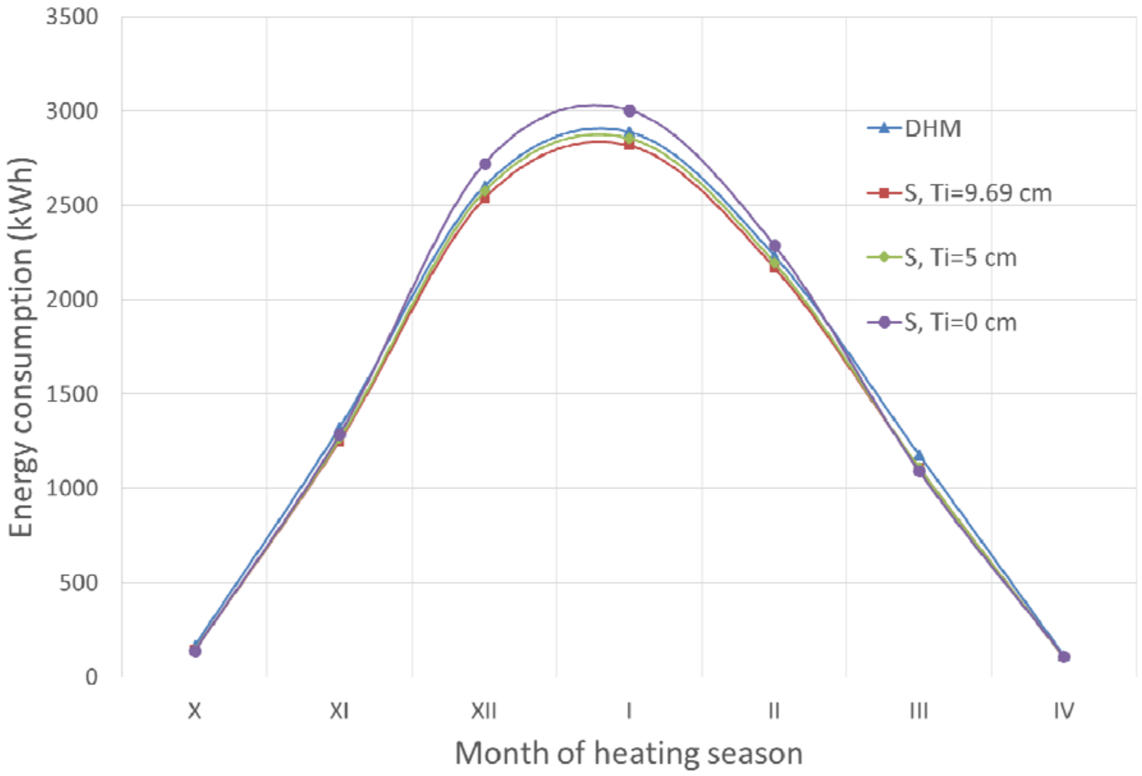

Figure 14. Heating energy consumption per month of Serbian house during heating season (October-April) for DHM and S simulation scenarios.

In Figure 14 the heating energy consumption per month of Serbian house during heating season (October-April) for DHM and S simulation scenarios is given. Figure shows that the south selective façade always gives positive energy savings compered to DHM, except three coldest heating months (December, January and February) in case of south wall without insulation layer.

In Figure 15 the heating energy consumption per month of Estonian house during heating season (October-April) for DHM and S simulation scenarios is given. Figure shows that the south selective façade gives positive energy savings compered to DHM, only in case of maximum thickness of the south wall insulation layer. In cases of insulation layer thickness decreasing the energy savings are negative for all heating months.

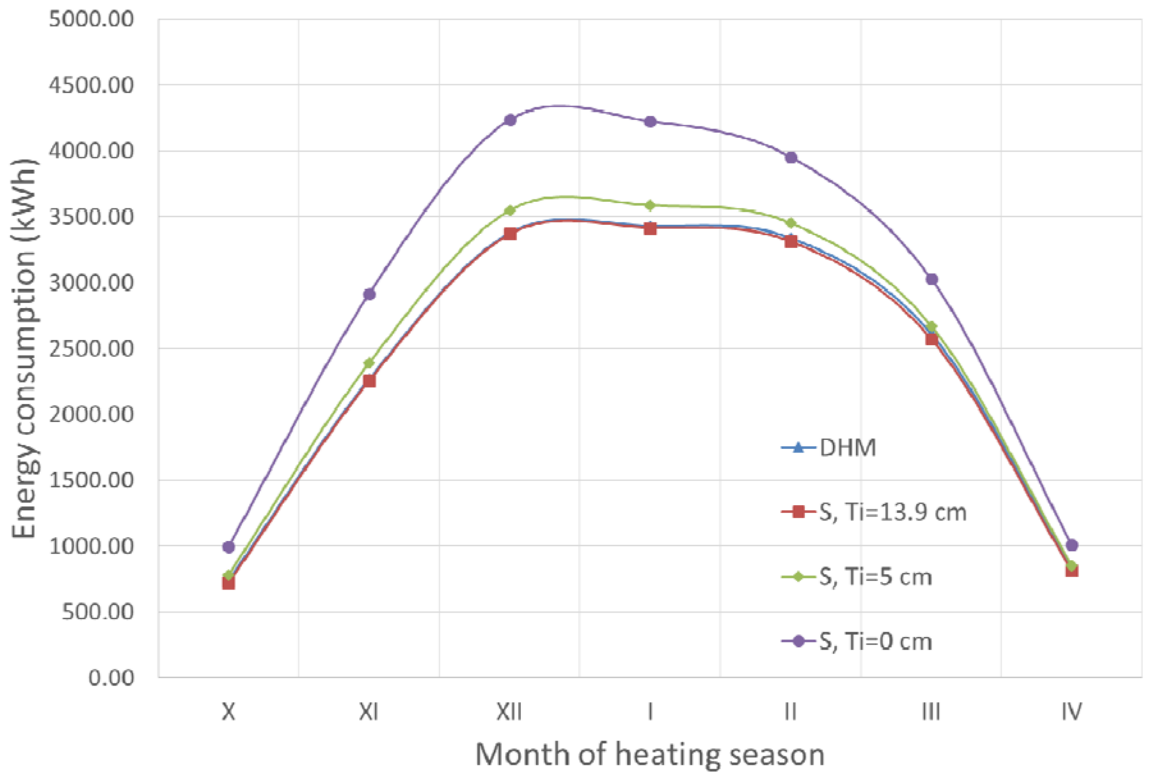

Figure 15. Heating energy consumption per month of Estonian house during heating season (October-April) for DHM and S simulation scenarios.

4. Conclusion

A Changeable (intelligent) building envelope is logical development of the heating energy efficient consumption system. Radiation selective surfaces could be applied as final building façade layer and on that way use solar gains more efficiently in order to decrease heating energy consumption in buildings. On the example of Serbian (location Kragujevac) and Estonian (location Tallinn) family house modelling according to the actual (Serbian and Estonian) regulation of the minimum building thermal envelope requirements, using simulation software EnergyPlus, is shown how selective façade could decrease energy consumption during heating season. Under weather conditions of the enhanced solar radiation and higher outside temperature during heating season, October-April (case of Serbian house) a selective façade could be helpful to decrease heating energy consumption compared to the same house without selective façade. Annual percentage savings of heating energy are done as 8.32%. Simulated saving effects could be also considered through reduction of insulation thickness and investment costs. Otherwise, under weather conditions of the poor solar radiation and lower outside temperature during heating season (case of Estonian house) a selective façade shows the weak effects on energy consumption decreasing. The maximum annual reduction of energy consumption is done as 1.92%. In this simulation case a reduction of insulation layer is not an option. Problem with overheating of a selective façade during summer conditions could be solve with using of reflective curtain.

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