THERMALLY ACTIVATED BUILDING SYSTEMS IN CONTEXT OF INCREASING BUILDING ENERGY EFFICIENCY

by

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One of the possible ways to provide heating to the building is to use thermally activated building systems. This type of heating, besides providing significant increase in building energy efficiency, allows using low-temperature heating sources. In this paper, special attention is given to opaque part of the building façade with integrated thermally activated building systems. Due to fact that this type of system strongly depends on temperature of this construction-thermal element and type and thickness of other materials of the façade, influence of these parameters on energy efficiency was analyzed in this paper. Since the simplest and most promising way of using geothermal energy is to use it directly, for our analysis this source of energy was selected. Building energy needs for heating were obtained for real residential multi-family building in Serbia by using EnergyPlus software. The building with all necessary input for simulation was modeled in Google SketchUp with aid of Open Studio Plug-in. Obtained results were compared with measured heating energy consumption. The results show that thermally activated building systems represent good way to increase building energy efficiency and that applying certain temperatures within this element, low-energy house standard can be achieved.

Key words: *thermally activated building systems, façades, energy efficiency, heating, geothermal*

Introduction

Huge increase of interest in energy efficiency and renewable energy sources for space heating was initiated with the perception (cognition) of ever decreasing fossil fuels and significant global warming in the last decades. On one side numerous research are conducted with the goal to increase energy efficiency of existing heating systems, and on the other side research are conducted in order to utilize renewable energy sources for space heating. Although situation is critical in such measure that requires immediate and systematic application of new technologies, their application is scarce. Heating fluid temperature determines which type of heating system will be installed in the building, typically. Considering renewables, besides solar energy and biomass, one can choose geothermal energy. The simplest way for using geothermal is to use it

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directly. Serbia has high geothermal potential, so this type of energy was selected as primary energy for heating in our study. Using geothermal directly is economically most viable. This does not exclude using solar energy as heating source, but this would require more complex and expensive solution. Main purpose of building envelope is to separate indoor environment from the outdoors, but in this case it becomes complex system which becomes integral part of the building, reacting to outdoor conditions and user needs.

Influence of building envelope on energy consumption, as well as passive strategies for increasing energy efficiency and thermal comfort were examined by various authors [1-3]. For this reason, in this paper, potential of increasing energy efficiency by using building façade with thermally activated building systems as a heating system was analyzed. Potential was investigated for residential multi-family building in Serbia. Building heating energy needs and consumption were simulated with EnergyPlus, version 7.1. The building itself was modeled in Google SketchUp with Open Studio Plug-in. Considering temperature of TABS as well as insulation thickness, goal of the paper was to determine their influence on heating energy consumption of typical building.

Heating with thermally activated building systems

In whole world and in Serbia as well there is a tendency of ever increasing energy consumption. This fact with the cognition of continuous reduction of fossil fuels influenced that in every sector of economy special attention is given to energy consumption reduction. In building sector, approximately 61% of energy is used for space heating, so it is essential to reduce it, as much as possible. One of the indicators for building energy consumption is annual heating energy consumption normalized per floor area. This indicator is used for determination of building energy class. In order to increase building energy efficiency, besides providing better insulation and fenestration, it is necessary to analyze the possibility of improving space heating system, and also possibility to choose the optimal energy source. One of the new technologies used for space heating is to install thermally active barrier in opaque part of the building envelope (water pipes embedded in the concrete slab of a building element). These systems are known as thermally activated building systems (TABS). Purpose of this system is to reduce building heating loads, although some of the heat is transferred to outdoors. In most cases this heating system uses solar energy as energy source [3]. These systems are used for cooling as well, and because they are driven by solar energy, heat storage is necessary. All these measures enable building to be independent in energy related terms, and in some occasions these buildings become passive buildings (fig. 1)

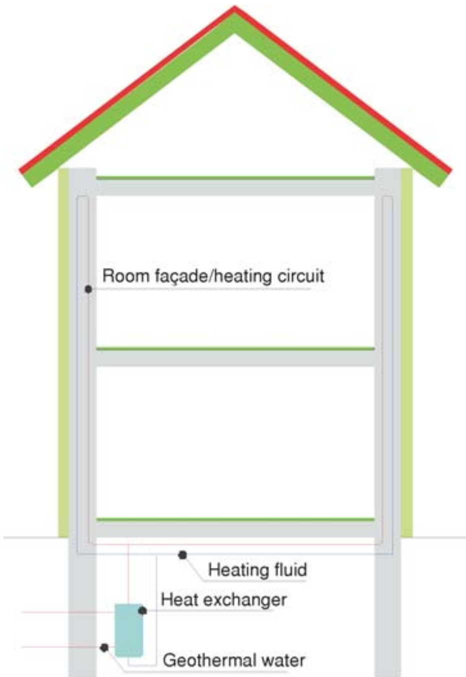

Figure 1. The building with TABS

Since in these systems water temperature is in the range of 30 °C, idea of this paper was to use geothermal energy instead of solar energy.

Geothermal energy is energy created beneath the Earth's surface by decay of radioactive elements, chemical reactions or tectonic movements. Amount of this energy is infinitively large so it is treated as renewable energy source. The main advantage it has over other renewables is that it is considered as clean and environmentally friendly. By geothermal energy we usually assume hydro-geothermal energy (groundwater). Groundwater usually contains active components for medical treatments, but more importantly they can be used as energy (heating) source. In Serbia, there are a lot of springs with temperatures in the range 20-80 °C. Most heating systems designed in Serbia require water temperatures above 40 °C, so heat pumps must be used (in case spring has lower temperature than 40 °C). Although installation of heat pump provides electricity saving 3-4 times compared to classical electrical heating, direct usage of groundwater with low temperature is of interest. TABS is one of the concepts that enables using geothermal energy directly for the space heating and requires special attention in design of new or refurbishment of existing buildings.

Façade with integrated TABS

In order to draw valid conclusion about their use, first it is necessary to analyze transmission losses of outside wall with embedded pipes (TABS) and without this component. For analysis, following construction of outside wall is used: concrete with 15 cm thickness with pipes embedded in concrete, insulated on both sides with 10 cm thick polystyrene. For this type of construction (pipes excluded) U-value of 0.183 W/m^{2}K was calculated by standard procedure (fig. 2).

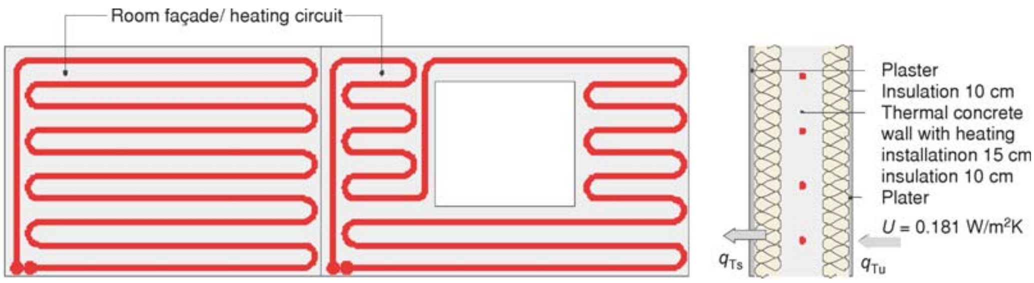

Figure 2. Façade with TABS

In the case of the common wall heat loss per m^2 of wall area is:

$$q_g = U(t_u - t_s) \tag{1}$$

In case with embedded pipes (TABS), heat flux is split between heat flux from the interior towards the TABS q_{Tu} (new transmission loss) and heat flux from TABS towards outdoors q_{Ts} (which is covered by heating medium-groundwater):

$$q_{Tu} = q_g = U_{Tu}(t_u - t_B) \approx 2U(t_u - t_B) \tag{2}$$

$$q_{Ts} = U_{Ts}(t_B - t_s) \approx 2U(t_B - t_s) \tag{3}$$

In this case, total heat flux is:

$$q_{Tu} + q_{Ts} \approx 2U(t_u - t_s) \tag{4}$$

From the above equations it is obvious that wall with TABS has two times greater heat losses compared to the same common wall. Since heat flux q_s is provided from renewables (solar energy, geothermal energy ...) which are free, minimization of heat flux q_i remains to be done, *i. e.* temperature difference $t_u - t_B$ should be minimal. This temperature difference depends on numerous parameters, but the most influential one is available temperature of heating medium. Temperature uniformity across the TABS is achieved by proper pipe layout (installation step) [4, 5].

This statement can be shown with the following example. For wall construction given in fig. 2 the values for heat transfer coefficient are obtained: $U_{Tu} = 0.361$ W/m^{2}K and $U_{Ts} = 0.372$ W/m^{2}K. For indoor air temperature of 20 °C, and winter outdoor design temperature of –14.5 °C, from eqs. (2) and (3) temperature dependence can be determined.

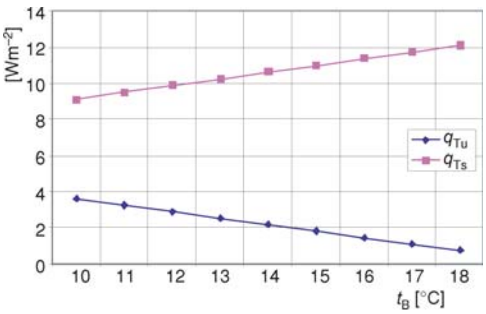

Figure 3. Heat flux as a function of TABS temperature

From fig. 3 it can be seen that increasing TABS temperature from 10 °C to 18 °C would results in decreasing heat flux from space towards TABS for 80%, but also in increasing heat flux to outdoors for nearly 33%. It means that reduction of heat losses achieved with higher temperature of TABS would not significantly change heat flux to environment.

This practically means that for TABS temperature of 20 °C, heat losses on the opaque part of building envelope (walls) can be neglected. Although, temperature within the TABS can be treated as constant value during the heating season, its optimization and control according to outdoor temperature and user behavior can be performed. Additional possibility provided by this system is that each heated zone can be individually controlled, which allows additional energy savings.

Building energy model

Simulation of building energy needs for heating is performed for real residential building located in Niska Banja in Serbia, and for which there is a possibility of using geothermal energy. The building is a 2-story single family building with entrance facing north (fig. 4). Walls are made of 25 cm brick clay, insulated on the outer side with 5 cm thick polystyrene. Windows are double pane separated by air with wooden frame. Floor-to-floor height is 2.8 m. Pitched roof is made of roof tiles. Heated area for the ground floor is 61.67 m^2, and for the upper floor is 65.83 m^2, which leads to total heated area of 127.5 m^2. The building is heated with central hot-water boiler and heating system is without local temperature control. The boiler uses LPG as primary fuel.

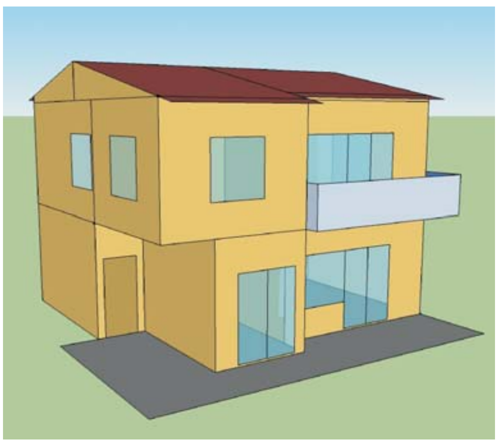

Figure 4. Real building – north-west view

Wall area of heated zones is 193.8 m^2, and area of windows is 35.8 m^2 (window to wall ratio is 18.47%). Two types of wall construction were selected for the analysis:
– common wall without TABS – wall is made of 25 cm hollow brick, with 5 cm polystyrene insulation (existing situation), and
– wall with TABS – 15 cm thermal concrete with 15 cm insulation on both sides is added (fig. 5).

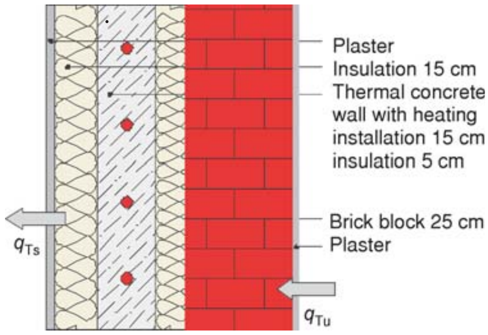

Figure 5. Facade with TABS element

In the first case, wall *U*-value is 0.545 W/m^{2}K, while the *U*-value of the transparent part of the envelope is 3.0 W/m^{2}K.

In the second case replacement of fenestration is not proposed so only the influence of applying TABS can be analyzed. In this case wall *U*-value is 0.162 W/m^{2}K (R-value from indoors to temperature barrier is 2.123 m^{2}K/W, R-value from temperature barrier to outdoors is 4.032 m^{2}K/W).

The research is focused on obtaining building energy needs for space heating (heating demand) for the assumptions:
– heating setpoint is constant during heating season and is set to 20 °C,
– outdoor temperatures were taken from available weather file for City of Nis, and
– TABS temperature is 10 °C, 14 °C, and 18 °C.

The object with its systems is modeled in Google SketchUp by using Open Studio Plug-in for SketchUp, and the whole simulation is carried out in EnergyPlus software (ver.7.1). This software allows integrated heating load simulation for the above defined temperatures as inputs [6, 7]. Heat loads are calculated for user defined timestep of 10 minutes and instantaneously put demand on heating systems. Indoor temperature was measured by installing virtual temperature sensor, while the heating energy consumption was measured with virtual energy meter.

Results and discussion

Heating load simulation was performed with available weather file for City of Nis. Average outdoor temperature during heating season is 5.15 °C, while the average monthly temperatures and number of heating days, for each month are presented in tab. 1.

Table 1. Average monthly outdoor temperatures for City of Nis, taken from weather file [8]

Month	Jan.	Feb.	March	April	Oct.	Nov.	Dec.	Season
Temperature	0.52	2.06	6.53	9.75	8.63	6.84	1.82	5.15
Number of heating days	31	28	31	15	15	30	31	181

Heating design day simulation (outdoor temperature –14.5 °C) revealed that design heating load for the building without TABS is 18 kW. Monthly heating energy requirements were derived by averaging hourly heating demand for each month. In tab. 1 and fig. 6 results obtained for envelope without TABS are presented. Results for envelope with TABS at various temperatures (10 °C, 14 °C, 18 °C) are presented in tab. 2 and figs. 7-9, respectively.

Table 2. Monthly heating energy consumption normalized per floor area

Month	Without TABS	t_B= 10 °C		t_B= 14 °C		t_B= 18 °C	
	q_g	q_{Tu}	q_{Ts}	q_{Tu}	q_{Ts}	q_{Tu}	q_{Ts}
	[kWhm^{-2}]	[kWhm^{-2}]	[kWhm^{-2}]	[kWhm^{-2}]	[kWhm^{-2}]	[kWhm^{-2}]	[kWhm^{-2}]
January	30.34	16.88	12.17	11.60	17.91	6.32	23.65
February	25.50	15.25	9.36	10.48	14.55	5.71	19.73
March	22.12	16.88	5.12	11.60	10.86	6.32	16.61
April	8.57	8.17	0.65	5.61	3.43	3.06	6.21
October	9.31	8.17	1.29	5.61	4.07	3.06	6.84
November	20.99	16.34	4.60	11.23	10.16	6.12	15.72
December	28.56	16.88	10.64	11.60	16.39	6.32	22.13
Annual	145.40	98.56	43.84	67.74	77.37	36.92	110.90

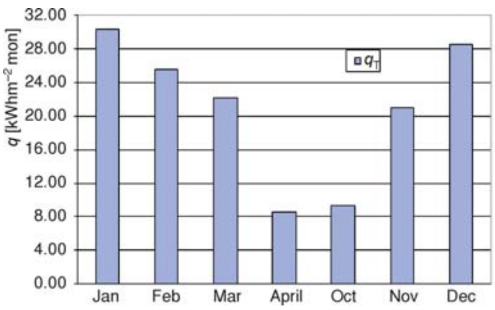

Figure 6. Monthly heating energy consumption normalized per floor area without TABS

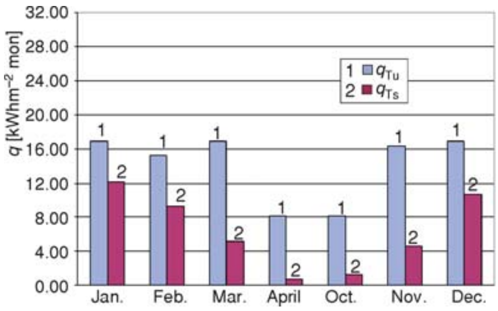

Figure 7. Monthly heating energy consumption normalized per floor area, t_B = 10 °C

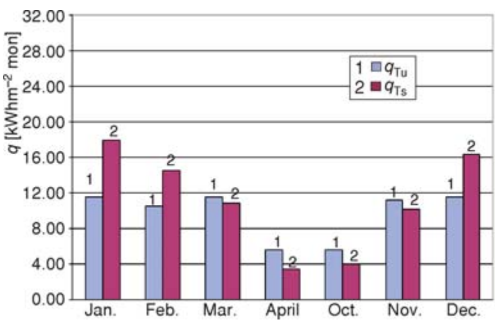

Figure 8. Monthly heating energy consumption normalized per floor area, t_B = 14 °C

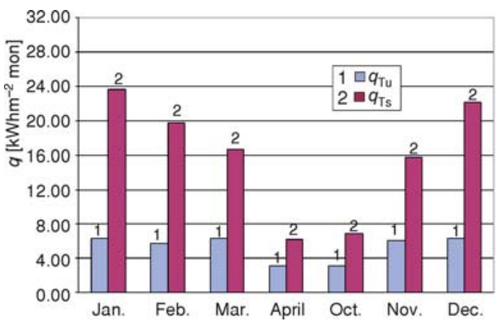

Figure 9. Monthly heating energy consumption normalized per floor area, t_B = 18 °C

From the analysis of the heat flux from TABS towards outdoor, it can be noticed that these values are almost equal and similar in comparison to heat losses in case no TABS is implemented. This means that temperature within TABS does not affect total heat losses, but it shifts them between heat fluxes from TABS towards outdoor and from heated space towards TABS. Since TABS is primarily intended for reducing energy transfer to outdoors, precisely reducing heating energy consumption, it is obvious that by applying TABS this requirement is fulfilled.

Analysis of heating energy consumption reveals that:

- in case of TABS temperature at 10 °C, consumption reduces from 154.4 kWh/m^2 to 98.56 kWh/m^2, which is a 22.2% reduction,
- in case of TABS temperature at 14 °C, consumption reduces to 67.74 kWh/m^2, which is a 53.4% reduction compared to initial case,
- in case of TABS temperature at 18 °C, consumption reduces to 36.92 kWh/m^2, which is a 74.6% reduction compared to initial case, and
- without additional measures for increasing energy efficiency (replacement of fenestration) the building can be classified as low-energy building.

Also, it is very important to say that by applying TABS, wall surface temperature on the inside increases, which leads to better thermal comfort.

From normalized monthly energy consumption values it can be seen that maximum energy consumption is approximately two times larger than minimum energy consumption which is important for TABS control range. TABS temperature can be controlled as a function of outdoor temperature.

Implementing TABS requires significant investments. Since the literature survey did not reveal costs for installing TABS, financial analysis will be based on cost reductions for the existing object. For TABS temperature at 18 ºC, annual energy consumption will be approximately 4700 kWh, which compared to initial case is a energy saving of 13800 kWh. On the other side, real energy consumption for this house, based on data provided by the owner and for similar weather conditions is 15200 kWh. With the current LPG unit price of 1.5 EUR/kg annual savings would be app. 1620 EUR, or 8.4 EUR/m^2 of TABS area. If investment in TABS system, normalized per TABS area, is assumed to be no more than 50 EUR/m^2 simple payback period would be approximately 6 years.

Available energy sources play an important role. As mentioned earlier, in this research geothermal energy is selected. Installation of TABS in opaque part of building envelope simplifies whole heating system, because only heat exchanger is needed to transfer energy from groundwater to heating medium. Direct connection of TABS to groundwater is not recommended due to groundwater's composition.

Conclusions

Based on obtained results and conducted analysis, the following conclusions can be made about applying TABS:

- TABS represents efficient system for space heating because it allows reduction of building energy needs to the level of low-energy houses (36.92 kWhm^{-2} for barrier at 18 °C),
- significant heating energy savings can be achieved (up to 75%),
- energy savings, depending on primary fuel, have simple pay-back period of approximately 6 years,
- all available renewables (low temperature) can be used as energy source,
- geothermal energy available in Serbia can be used fairly simply,
- TABS can be used effectively for space cooling as well,

- although not mentioned panel heating systems are very comfortable heating systems, and
- transparent part of the building envelope, ceilings and floors have influence on building heating demand so applying energy efficiency measures on this part of the envelope would lead increased overall building energy efficiency.

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