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INTELLIGENT SKIN AND OCCUPANCY IN THE CONTEXT OF INCREASING ENERGY EFFICIENCY IN BUILDINGS

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Abstract: The intelligent building skin has multiple roles. One of them is the ability to control energy flows in the building. The concept of intelligent skin is related to its responsive performance, sometimes but not always in relation to the energy performance of the whole building, and can be compared with the biological idea of intelligence and response. This paper analyzes the role of the active facade as the part of an intelligent envelope in controlling the required amount of energy for heating. The active facade has the function to reduce the internal temperature in the rooms that have not been occupied for a long period of time and thus reduce the amount of energy required for heating the building. Energy requirements were calculated with EnergyPlus simulation software for typical residential building in Serbia. It is shown that the appropriate response of the opaque part of intelligent skin to occupancy can result in annual heating energy reduction of up to 8.8% or 3.51kWh/m^{2}a.
Keywords: intelligent building skin, energy flows, energy performance, energy requirements

1. INTRODUCTION

Lately, the interest in sustainable and energy-efficient building design has considerably increased. This is the consequence of significant environmental changes as well as the reduction of energy resources. We are witnesses to the fact that the external conditions change very rapidly and unpredictably. Internal conditions, on the other hand, should be adapted to the needs of people and their sense of comfort. In past, the primary characteristic of building skin was to separate inner from outer space. Instead of blocking outdoor environment, the skin can be used for gaining positive level of indoor comfort and decreasing energy demand. The skin is becoming complex system, which acts as an integral part of the building and reacts on environmental conditions and occupant needs.

The development of intelligent skins with the role of construction that controls the state of the indoor environment in terms of lighting, heating, sound, ventilation and air quality has become the key task for the designer. The performance of these skins is connected with the performance of the whole building, and can be compared to human skin and its ability to adapt to environmental conditions (Wigginton and Harris 2002; Wyckmans 2005). The influence of the building envelope and its design on energy consumption as well as different passive strategies for achieving energy efficiency and thermal comfort were studied by various authors (Oral et al. 2004; Cheung et al. 2005; Bouchlagen 2000). However, apart from the facade structure, users and their behavior have a large influence on energy consumption in buildings (Azar and Menassa 2012). Nguyen and Aiello (2013) suggest that the energy intelligent building should be developed by integrating occupant activity and behaviour, because occupancy-based control can result in up to 40% in energy saving for HVAC system and also up to 40% of the lighting electricity.

The actuality of this theme is the reason why this paper discusses the concept of intelligent skin in terms of the user's influence on the energy required for heating residential building.

The simulation was conducted for a typical residential building in Serbia using energy simulation software EnergyPlus ver. 7.1, and the building was modelled in Google SketchUp using Open Studio Plug-in. Considering two parameters – the outside air temperature and occupancy, the aim is to determine the possibility of reducing the energy required for heating the building.

2. ENERGY CONTEXT OF INTELLIGENT SKIN

Despite the improvement of energy efficiency in buildings over last few years, the level of energy consumption can be further reduced. Savings potential lies in the reduction of energy used for heating and cooling, water heating and lighting. By using the intelligent skins, needs for additional heating or cooling, as well as for other service systems, can be minimized or even entirely avoided.

The skin should be the linking element between energy supply and energy demand of the building. The building is exposed to natural energy flows such as sunlight, sun radiation, cold or wind. The skin should interact with these energy flows providing the energy for the building and its users (Van Timmeren 2009).

Intelligent skin can be defined as a composition of constructive elements, which makes the protective outer zone of a building. Its performance can be adjusted to responding to environmental change in order to maintain building comfort with minimal energy consumption. The energy flow through the skin is automatically adjusted to maximal gain, with minimal relaying on gained energy. The building skin becomes a part of the building system and it is connected to the other building parts, such as sensors and other activators connected to the main board, and controlled by the central building management system (Wigginton and Harris 2002).

The intelligent skin concept includes a combination of external and internal factors of the building. Because of that, different ways of building functions should be considered during the design process of intelligent skins. This way the whole building can become an adaptive and dynamic structure, which reacts on climate changes, occupancy and users demands. Del Grosso and Basso (2010) showed how "variable geometry structures" have the function of kinetic responding to changing situations in their use, operation or location, by modifying their configuration.

The building envelope should be considered to be a part of a living organism and should be flexible, adaptable and dynamic. Therefore, it can be easily compared with human skin (Wigginton and Harris 2002; Tombazis 1996). There are several factors that should be considered in designing the intelligent building skin, and in the context of energy the most important are: adaptability, learning ability, sun, energy strategy and economical aspects.

— *Building management system.* The main activator of intelligent skin is the building management system. It is a central processor unit that receives information from various sensors and determines the activation of different elements. The control system should be capable to track weather changes and to control the functioning of passive and active systems, in order to ensure the most efficient use of energy.

The neuron grid enables control system to collect information from inner and outer sensors trough an electric circuit. This configuration is capable to choose an optimal working regime in order to achieve optimal indoor conditions, with the most efficient use of energy (Wigginton and Harris 2002).

— *Lighting.* Considering the fact that artificial lighting consumes a significant amount of electrical energy, a maximum utilization of daylight is recognized as one of the key goals in low-energy design. The benefits include better light distribution, which improves the quality of lighting and visual comfort. There are different active systems that respond to the angle of the sun's rays, providing the optimum position for the motorized light-directing and light-reflecting devices. One system redirects incoming daylight and it is based on optical reflection, refraction and diffraction, so that the largest part of the interior is illuminated. In order to implement the strategy of daylighting effectively, fundamental is the responsive artificial lighting control system, with sensors placed in the building skin.
— *Sun controllers.* The most common solar control systems with the aim of mitigating harmful effects of sun, including overheating, radiation and glare, are computer-controlled louvers, blinds and other protective shades, all of which can be regarded as energy absorbers. Many buildings are equipped with the blinds that can be lowered, raised and tilted according to the detected presence of the sun. They are often embedded into the double façade cavities, as a protection, to keep the heat out of the occupied zone and to participate in the solar flow.
— *Ventilation.* One of the strategies for reducing energy consumption is the greater use of natural ventilation in buildings where the façade plays a key role. Complex systems of natural ventilation are based on the stack effect or on a combination of wind and stack effect. The air is driven through the building by vertical pressure differences. There are the corresponding shafts for fresh air infiltration and exhausted air removal (Baird 2001). Natural ventilation can be automatically regulated for increased effectiveness by operable elements of the building envelope, such as retractable roofs, motorized windows and pneumatic dampers.
— *Heating.* The outer layer of the building, its skin, is the most important factor which affects energy consumption in most buildings. Therefore, many buildings use intelligent technology to reduce the energy load resulting from heating. During the winter, the aim of intelligent skin should be to minimize the heat flow from the inside to outside (heat loss) and to maximize the heat flow from outside to inside (solar heat gain). This can be achieved: - by eliminating the uncontrolled air infiltration, while maintaining minimum ventilation level necessary to satisfy indoor air quality; - with blinds, that allow maximum solar heat in space, while preventing the glare from the low sun angles; - with ventilated facade, which creates an insulating buffer; - with energy active facade.

The intelligent skin has a specific role in manipulating energy flow, in the way of light, heat, air and sound. This idea began as an application of the sustainable low-energy concept, with simple folding and sliding shutters or with movable louvers and has continued with a multitude of devices for shading and glare protection, light deflection, heat and energy management (Del Grosso and Basso 2010).

Some of the functions of intelligent skin are: - increasing shading and cooling control with higher thermal comfort and usage of natural light; - better indoor air quality and decreasing of cooling caused by natural ventilation, in the way that façade becomes active air controller; - decreasing operative cost, with minimizing energy consumption for lightning, heating and cooling; - improving indoor microclimate in order to create better living comfort; - electrical energy production from renewable sources for own needs.

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≡ on the transparent part of the facade, which are most common, and include smart windows and shading systems that can dynamically change optical and thermal properties

≡ on opaque parts of the facade, which include the application of thermal barrier system, which supplies energy into the external walls (Figure 1). This system is composed of polypropylene U-pipes in a meandering pattern, forming the semi-surface inside external walls and connected to the heating or cooling circuit system pipes (Krecké 2010; Krzaczek and Kowalczuk 2011).

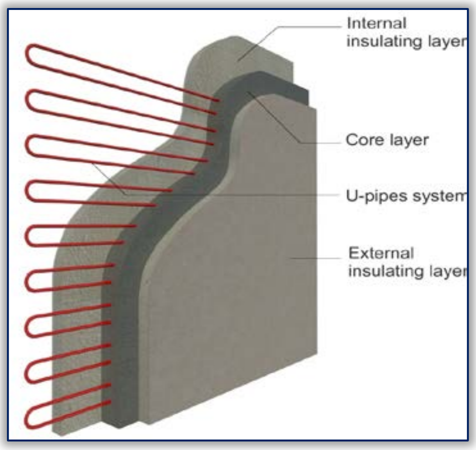


Figure 1. Thermal barrier inside external walls

≡ on the whole facade, by applying double-skin facade, which consists of the outer and inner layer, and the ventilated cavity between them. In winter, the double-skin facade acts as a buffer zone between the building external environment, by minimizing heat loss and improving the U-value. The blinds are usually located in the cavity, and have a role to reduce heat gain due to solar radiation, but also can be used for preheating ventilation air (blinds absorb heat and then transfer it to the surrounding air by convection and radiation). This type of facade is rarely used for residential buildings.

3. MODELLING OF RESIDENTIAL BUILDING WITH ACTIVE FACADE

Hot water heating systems are still the most widespread form of centralized heat supply to residential buildings (unlike the cooling and ventilation systems that have mainly local character). Therefore this research deals with improving energy efficiency in heating residential building, as a part of the operation of intelligent skin system. The tendency was to examine the extent to which intelligent skin, as the part of architectural entity, can have influence on reducing the heating energy requirement. In order to achieve this, the heating system is provided by the active facade. The active facade, as a form of intelligent skin, is the part of the facade in which the process of air or water heating takes place and separates the inner from outer space. In this way the facade also covers heat loss from a building and maintains the desired room temperature. This type of heating system allows for the minimal amount of heat to be brought inside the building. The active facade uses a low temperature heating system and therefore renewable energy sources, usually solar energy, can be used as a heat source. The active facade can be also used for cooling the building, which is another advantage of this system.


Figure 2. Model of the building – South-East view

Simulation of heat energy requirements is conducted for the residential building with typical spatial and functional characteristics of housing in Serbia. The building has six floors, with four units on the floor and the entrance on the north side (Figures 2). Each floor consists of two one-bedroom apartments, one two-bedroom and one three-bedroom apartment (Figure 3), with a total living area of 267m^2, so that the total heated area of the building is 1602m^2. The floor-to-floor height is 2.8m, and the building has a flat roof.

The building envelope consists of active facade, with 202.2m^2 of wall area of the heated rooms and 44.8m^2 of glazing area, (window-to-wall ratio is 18%). Total area of the heated envelope is 1482m^2. The values of heat transfer coefficients for walls and windows are adopted as maximum allowable values according to the current Buildings Energy Efficiency Ordinance in Serbia (walls: U = 0.3 W/m^{2}K, windows: U = 1.5 W/m^{2}K).

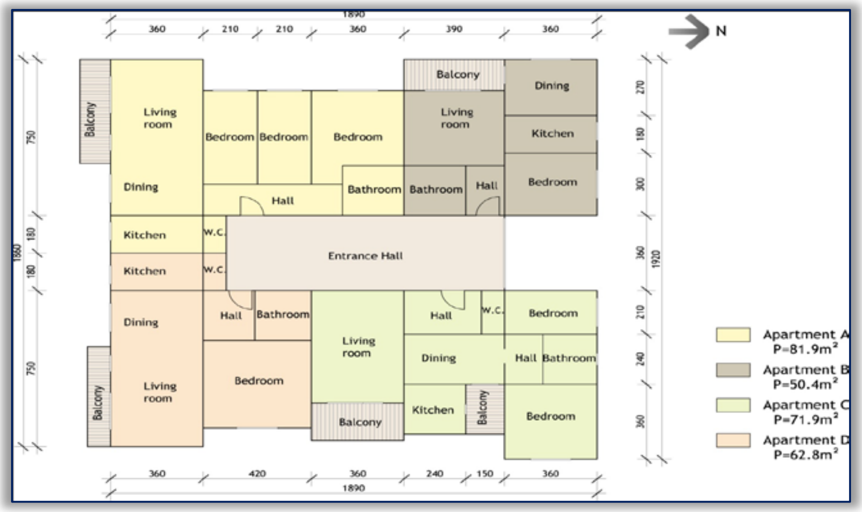


Figure 3. Bilding floor plan

The active facade consists of plaster, insulation, thermal concrete with heating pipes, insulation and plaster, where it is adopted for simulation that the material of the building skin has no mass (Figure 4).

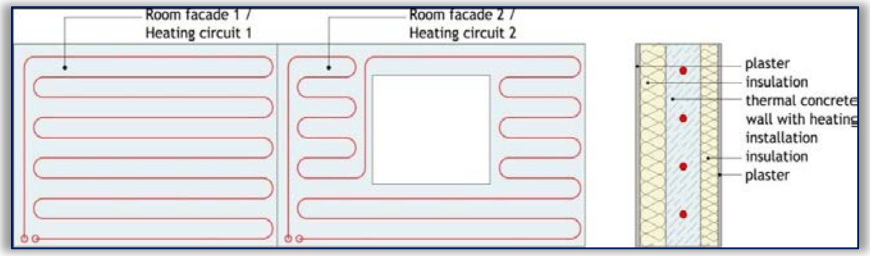


Figure 4. Active facade – heating pipes installation scheme and cross-section

The thickness of these layers can be different and is adjusted to the pipe pitch and water heating temperature. Such active facade provides the desired temperature to the interior space by heating the thermal concrete. In order to ensure the intelligent functioning of this facade, the outer wall of each room is single regulated heating circuit with temperature sensor for indoor temperature. This allows each room to maintain the desired projected temperature.

The goal of this research was set to calculate building energy needs depending on occupancy of rooms in the building. The active facade would have a role of lowering the indoor temperature in the rooms that are not used for a longer period and thus reduce the amount of heat required for heating the building. Among different occupancy patterns, only the time period when users go to work or school is taken. Usually it occurs in the period from 9 to 15 o'clock, and that time interval is adopted as variable period of using certain rooms. These rooms are not totally excluded from the heating system because of the inertia of the heating by active wall.

The simulation is conducted for three occupancy regimes:

1. All apartments are fully occupied. Indoor temperature for these conditions (without turning off) in all rooms is 20°C, except the bathroom where the temperature is 24 °C.
2. Part of the apartments is not occupied in the period from 9-15 o'clock because of the absence of the tenants. Those are bedrooms in the apartments A, B and C (Figure 5), with the total floor area of 283.3m^2 (18% of the total area of the building), and 389m^2 of the facade (24% of the total area). The temperature in these rooms is lowered to 15 °C in the specified time period.
3. Greater part of the apartments is not occupied from 9-15 o'clock because of the absence of the tenants. Those are all the bedrooms in the apartments and the whole apartment B (Figure 6). Their size is 729.2m^2 or 45.5% of the total surface, and 756m^2 of the facade, or 47%. The temperature in these rooms is lowered to 15 °C in the specified time period.

The building with its HVAC and other systems was modeled in Google Sketch Up by using Open Studio Plug in and the simulation was done in Energy Plus version 7.1. This simulation engine allows for an integrated simulation of loads and systems for the exact temperature and comfort conditions (Crawley at. al 2005). Loads are calculated at a user-defined time step and passed to the building systems at the same time step. For the energy simulation purposes, all the rooms are presented as separate thermal zones that enable defining occupancy and heating set point schedules. Regarding the loads of the building Zone HVAC: Ideal Loads Air

System was used for all zones. The temperature was measured by placing a virtual sensor Zone Mean Air Temperature and consumption by using virtual gauges Heating: Energy Transfer. The weather data were taken for Nis, for the heating season 2004/2005, due to data availability.

4. SIMULATION RESULTS AND DISCUSSION

The heat load simulation of modeled building was done for the heating season of 2005. The average temperature of the outside air during the heating season was 5.54°C. Therefore, the day with identical average temperature (19.01.2005) was selected as the reference mode. The other two simulations were done for the days with lower outside air temperatures: for 09.01.2005 with average temperature of -2.00°C and 15.01.2005 with an average temperature of -8.93°C.

In this way, the influence of outside air temperature on the energy needed for heating the building at different operating regimes was obtained.

The diagrams of changes in required energy for heating the building during analyzed days for all three regimes are shown in Figures 7, 8 and 9.

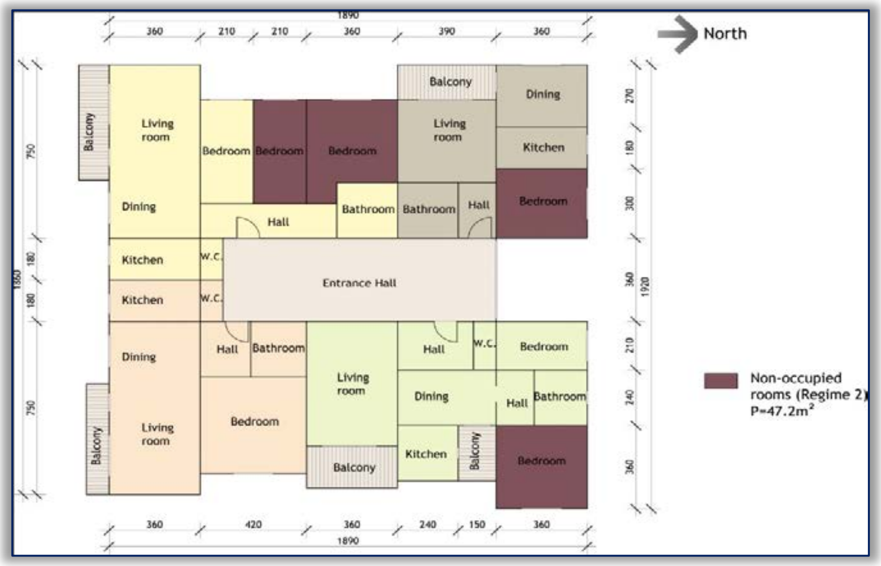
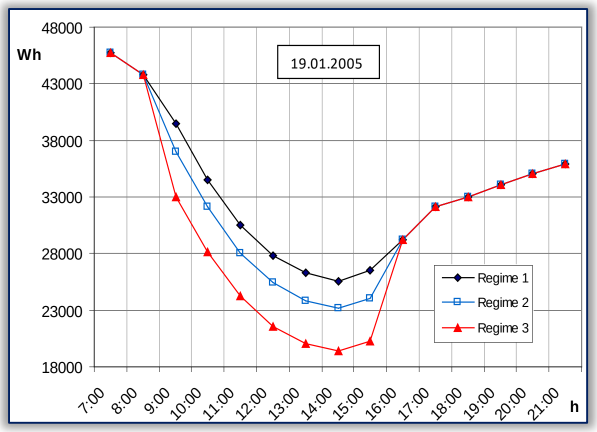


Figure 5. Rooms that are not occupied in regime 2

Figure 6. Rooms that are not occupied in regime 3



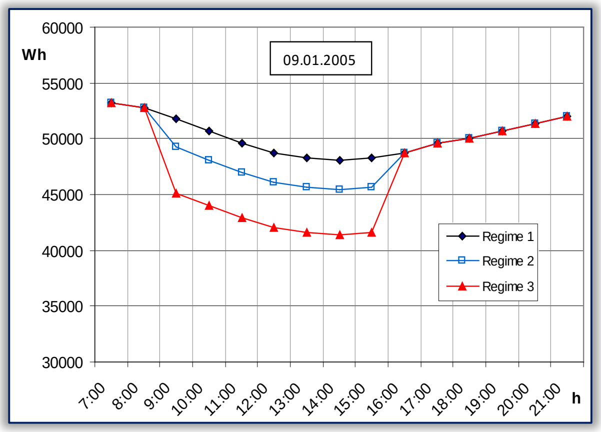


Figure 7. Energy required for heating the building on 19.01.2005

Figure 8. Energy required for heating the building on 09.01.2005

Based on the presented values the total daily amount of heat required for heating the building was calculated for the selected days, and also for the whole heating season, for all three occupancy regimes, as well as achieved energy savings (Table 1).

Table 1. Energy required for heating the building

Date/temperature	Regime 1	Regime 2			Regime 3		
			Savings			Savings	
-/°C	kWh	kWh	kWh	%	kWh	kWh	%
19.01.2005/5.56 °C	499.56	482.54	17.02	3.41	455.56	44.00	8.81
09.01.2005/-2.00 °C	753.58	735.57	18.01	2.39	707.03	46.55	6.18
15.01.2005/-8.93 °C	986.98	968.21	18.77	1.90	938.61	48.37	4.90
annualy/5.52 °C	89421	87245	2176	2.43	83795	5626	6.29

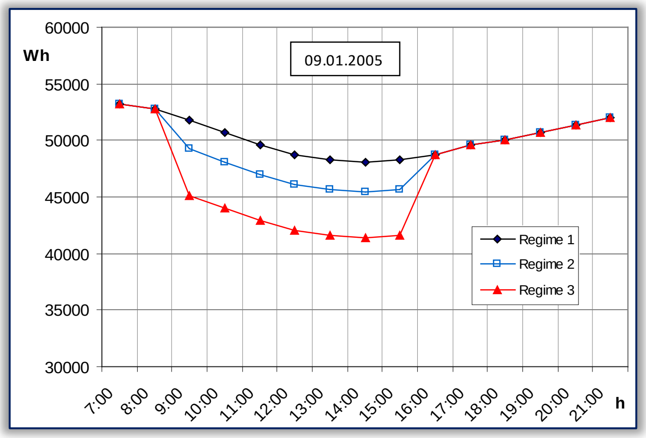


Figure 9. Energy required for heating the building on 15.01.2005

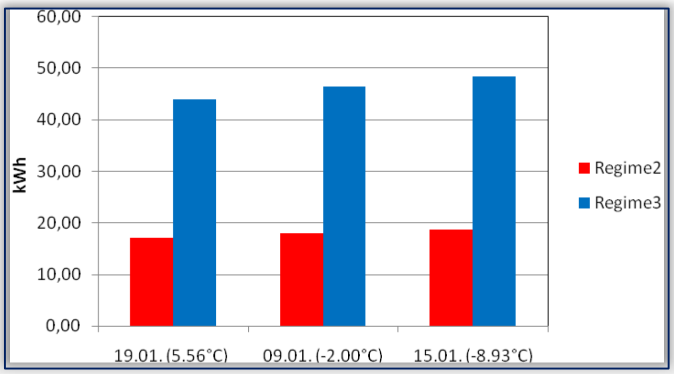


Figure 10. Savings of energy required for heating the building

By analyzing the presented values of change in the energy required for heating the building it can be concluded that the highest percentage savings are expected to be achieved at the highest temperature of outside air. It was found that the savings for the regime 2 range from 1.9 to 3.4%, and for the regime 3 from 4.9 to 8.8%. However, the absolute values of savings are greater at lower outside temperatures, and range from 18.77 to 48.37 kWh, which shows that they do not depend much on the outside temperature (Figure 10), the building occupancy is more dominant parameter instead. During the whole heating period the total amount of savings achieved for regime 2 is 2175 kWh (2.43%), and for regime 3: 5626 kWh (6.29%). In order to generalize results the savings are calculated per m^2 of heating surface and they account for the regime 2: 1.36kWh/m^{2}a, and the regime 3: 3.51kWh/m^{2}a.

The conducted analysis shows that by the proper regulation of the room temperature according to occupancy of certain rooms, significant savings can be achieved. The active facade, as the part of intelligent skin in this case could have a significant role, if the most efficient way of its regulation is chosen.

5. CONCLUSIONS

The envelope's performance as an environmental filter is extended with the ability to adapt to different outdoor and indoor conditions by choosing the most appropriate response in each situation and developing the ability to learn. Intelligent skins are gaining more importance and will certainly become an integral part of the new buildings in near future. The main aim of this system is to provide comfort for building occupants, and therefore comparison of the intelligent skin with the human skin reactions provides the right answers to understanding its function.

The active facade can be successfully used as an intelligent skin. It ensures that every part of the interior space is separately heated and regulated. Among the various possibilities of the application of the active facade as intelligent skin, this paper shows that its interaction with the use of residential space has positive energy effects on the central heating system.

The analysis showed that the active facade can recognize residential space occupancy and provide significant energy savings by acting on each partial heating system. The real value of annually savings can reach up to 8.8% or about 5657kWh. Translated to the savings per m^2 of heating surface they would be up to 3.51kWh/m^{2}a.

The interruption in room occupancy can be registered manually by the user, or by placing the appropriate sensors in the intelligent skin. This way the skin could learn when to turn off the heating of certain rooms, and when to turn it on again, which would show the real intelligence of the facade, and provide greater savings.

All this shows that the active facade with thermal barrier could be successfully used in achieving the intelligence of the building. If these savings are amended by regulatory measures of transparent part of the facade, more significant savings could be achieved. However, in order to evaluate individual influences, it is necessary to consider each of the measures that would an active facade take separately due to more efficient control of operation, and also because of the investment amount.

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