

## DOUBLE OR SINGLE SKIN FAÇADE IN A MODERATE CLIMATE An EnergyPlus Assessment

by

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*The research analyses the double skin façades concept and their impact on the energy efficiency of buildings. This kind of façade system has the ability to increase the energy efficiency and flexibility of buildings, while improving the quality of the indoor environment. The best way to develop and evaluate this complex type of building structure is the use of total building performance simulation in combination with experimental data. The overall research plan is based on experimental work, the process of validation and the numerical simulation of the validated model. Thus, the task of this part of the research is a comparative analysis between the current state of a building with double skin façades and models with traditional envelope type. The main question that arises is whether and how the double skin façades may contribute to the decrease in the energy consumption of the building by increasing the quality of the thermal comfort of the occupants. The simulation software tool, EnergyPlus in combination with airflow network algorithm, is used for modelling and all necessary energy calculations. The validated model in the analysis is used for comparative evaluation with models with traditional façades. The simulation results for all the models analysed assess what their impact is on the energy consumption for heating and air-conditioning of the building. Comparing to models with traditional façade, the energy analysis shows justification in the climatic conditions of Belgrade. Additionally, simulations results highlighted the necessity for an adequate control strategy of the double skin façades application.*

**Key words:** *double skin façade, EnergyPlus, energy modelling, energy consumption, energy performance*

### Introduction

Development of energy simulation of the thermal performance of buildings is developing in parallel with the progress of digital computers [1-3]. The main objective of these simulations is to precisely calculate the thermal load (heat gains and losses), as well as overall energy analysis of the building in terms of estimated consumption of all forms of energy. With time, the frame of simulation packages spread and became more integrated, fig. 1. The primary influences on this sequence of events were increased demands for better energy performance of facilities, increased customer requirements for indoor air quality (IAQ) and thermal comfort (due to an increased awareness of the link between IAQ and the health/productivity of the user of the building), as well as reduction of environmental impact, and the finiteness of fossil fuels. As a result, today's programs for energy simulation allow the development of a sustainable approach to the design and operation of facilities.

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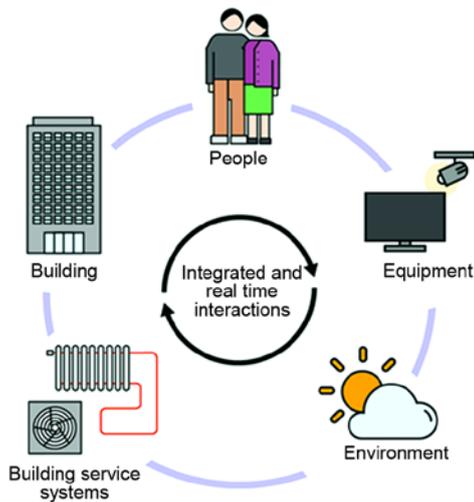


Figure 1. Dynamic interactions between systems

It is generally known that level of the thermal comfort is obtained with well-designed HVAC systems regardless from outdoor conditions. The most important ones are: outdoor air temperature, solar radiation, and wind effect. These components are dominant and virtually define the heat transfer that occurs between the building and its environment. In general, climate conditions are affecting heat losses and cooling loads.

Today's high office buildings mostly have façades with a high percentage of glass surfaces, for aesthetic effect and also due to construction and structural analysis of the entire facility. The biggest problem that occurs in these facilities is the exceptional dependence on, and variability of, the process of heat transfer from the current meteorological parameters.

It should also be noted that in buildings with a single glass façade, orientation plays a significant role in the amount of received and released heat. Despite the benefits (brighter and lighter construction), these façades generally encourage increased energy consumption, due to higher heat losses in winter and gains in summer.

In order to alleviate the increase in energy consumption, and at the same time retain aesthetic, highly transparent façades, engineers began to develop the concept of double skin façade (DSF). Here, the façade cavity acts as a *buffer zone*, which largely protects the facility from variable external influences. This is confirmed by the results of recent studies [4-12], which analysed the effects of heat transfer and natural ventilation caused by the presence of a DSF. But, as well as a positive impact, there are studies which show negative effects and increased energy consumption, especially due to summer overheating [13, 14]. The general conclusion is that the main advantages of the concept of DSF are achieved only through proper design, maintenance and management in the process of exploitation. Properly defined and applied seasonal control and operational strategies certainly lead to increased energy efficiency and thermal comfort in the building. Without adequate management and maintenance, a DSF inevitably leads to increased energy costs. Of course, the climate and the immediate surroundings of the facility play an important role in determining whether and how this concept is justified. It should also be noted that the application of a DSF necessitates higher initial investment costs.

Forecasting the energy demands and assessing the effectiveness of the DSF concept is complex. They can not be determined solely on the basis of knowledge of the characteristics of the materials used (optical and thermal properties) as the main influencing factors on the performance of DSF are the thermal and flow processes in the space between the façades. Difficulties in determining the performance, as well as poor and inaccurate assessment of the effectiveness, lead to uncertainty and erroneous conclusions. However, the energy efficiency and economic justification for applying DSF depends on these conclusions.

Current opinions on DSF are divided into positive and negative. There are contradictions when it comes to experimental research. The main reasons are, above all, lack of experience, the small amount of experimental research, a lack of understanding of operational strategies, as well as the different climatic areas for which results were obtained. Most experimental

studies were carried out on small laboratory models, while most of the analysis of multi-storey buildings were without actual measurements. In order to obtain a credible and reliable estimate of the effectiveness of the DSF, it is essential that the process of evaluation and forecasting of energy consumption is carried out by means of experimental validation of the proposed model.

### Methodology

Buildings consist of many dynamically combined elements that are unsteady non-linear and complex. This demands an integrated approach that respects all building elements as a complete system, not as independently designed subsystems. To achieve energy efficient design and operation of buildings in this complex setting, the concept of total building performance simulations (TBPS) has been developing worldwide since the late 1970s. Considering the complex energy demands of buildings, TBPS tools are needed to integrate all elements. The TBPS is intended to analyse the energy use and comfort levels, from one side, and to understand the relationship between energy consumption, comfort quality and design criteria, on the other side. In case of energy analysis and prediction for DSF buildings, TBPS has the potential to provide this type of information to several contributors in the design process: building designers, material researchers, control and building services engineers and consultants [15, 16]. The TBPS tools most commonly encountered in scientific and professional literature are: EnergyPlus [17, 18], TRNSYS [19], and ESP-r [10]. The EnergyPlus modelling tool is the most advanced and comprehensive TBPS tool nowadays. In combination with CFD simulation and MATLAB software, it represents the most comprehensive and accurate tool for modelling and real time management of buildings, tested through the ASHRAE standard [21]. EnergyPlus has been developed since 1996 in the LBNL in the USA. This is a fully integrated building, envelope, HVAC and renewables simulation program which enables energy performance analysis. It uses weather data available for more than 2100 locations worldwide.

For this research, previously obtained experimental results [1] were used in order to validate the simulation model made in the program tool EnergyPlus 8.2 [17, 19] combined with airflow network algorithm [22].

The experimental research conducted highlights the key advantages and disadvantages in the application of the DSF concept. The results of the experimental research show how the energy characteristics of the facility with DSF depend on the current meteorological conditions and regulation of the façade. The conclusion of the experimental work is that, to achieve the desired performance it is necessary to have the appropriate type and design of façade, with quality management and control in the operational phase. Also, the results of the experiment were used for detailed analysis of the thermal characteristics and the air flow behaviour in the cavity, as well as to fine-tune the model to achieve as closely as possible the real presentation of the real building.

Model validation is a phase that supersedes model fine-tuning. The validation process quantified the accuracy of results obtained by simulation, in comparison with the results obtained through measurements [23, 24]. The criteria of eligibility, when the model is verified, are defined with the recommended statistical indicators. The general conclusion of the DSF model verification is that the simulation results represent a good forecast of the real (measured) values. Therefore, such a finely tuned model is highly reliable in terms of future prediction of the thermal performance of a building with DSF.

This paper presents the energy assessment of the validated DSF model [24] through comparative analysis with models with traditional façades.

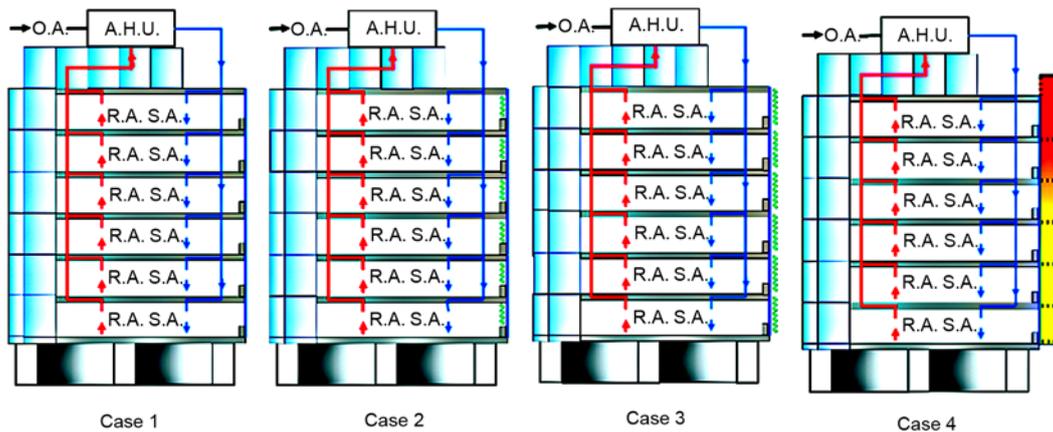
### Model and simulation set-up

The basic model of the object with DSF is the validated model [24]. All parts of the building have been retained as they are in reality, and the details can be found in section [23]. The considered DSF, which is located on the north-east of the facility, is divided into six (6) vertical zones, which are associated with the virtual mobile flaps. The base layer of the facade was made in the traditional way, the *window-wall-ratio* (WWR) is 45%. The value of the heat transfer coefficient to the outer wall (the base layer of the façade) is  $0.28 \text{ W/m}^2\text{K}$ , and for the flat roof and the floor is  $0.19 \text{ W/m}^2\text{K}$ . Other characteristics of glass and blinds are given in [23].

Blinds are placed in the space between the façade and they are regulated so as to be located in a fixed position of  $45^\circ$  when the outdoor temperature is higher than  $25^\circ\text{C}$  and when the horizontal intensity of solar radiation is greater than  $300 \text{ W/m}^2$ . The internal heat gains from equipment are taken from ASHRAE standard [25], and are  $16.1 \text{ W/m}^2$ , and gain of light are set to  $12 \text{ W/m}^2$ . As for the number of people in the room, the number of users per zone is set to 20 people per zone, according to ASHARE Standard 62.1-2013 [26], the requirements of fresh air by the user has been adopted and is  $30.6 \text{ m}^3/\text{h}$ .

As for the HVAC system in the building, the system with heat pump (direct expansion) for all air conditioned zones is adopted. The system for HVAC works during working hours from 7 a. m. to 7 p. m. Internal temperatures are defined according to design conditions,  $21^\circ\text{C}$  (heating season, October-April) and  $26^\circ\text{C}$  (summer season May-September). During non-working hours and during the night, a drop in temperature during the heating season to  $17^\circ\text{C}$  and the temperature increase during the summer season to  $29^\circ\text{C}$  are allowed for. During energy simulation and evaluation of energy consumption of the models, a typical meteorological year IWEC time [27], for the location of Belgrade was used.

A detailed description is shown in fig. 2.



**Figure 2. Description of the case studies; O.A. – outside air, R.A. – return air, S.A. – supply air, A.H.U – air handling unit (for color image see journal web-site)**

The models represent the following:

- (1) Case1 – represents a classical built building without protection from solar radiation,
- (2) Case 2 – represents a classical built building with blinds placed inside,
- (3) Case 3 – represents a classic built building with blinds set outside, and
- (4) Case 4 – represents the current facility with DSF.

It must be noted that all models have the same net usable air-conditioned area and the same supply system of thermal energy (heat + air conditioning). All models have been formed on the basis of the characteristics given in [25].

#### *Cases of the building with a traditional facade*

Cases 1-3 represent classic building built with traditional facade. The main differences between the models are the types of solar radiation protection, which are divided into: no blinds, blinds set inside the building and blinds set outside. The models with blinds have their control system, and they are placed in a fixed position of  $45^\circ$  when the air temperature is higher than  $25^\circ\text{C}$  and when the horizontal intensity of solar radiation is greater than  $300\text{ W/m}^2$ .

The aim of establishing these models is a comparative analysis to determine the ratio of energy consumption of the building, with DSF and without it.

#### *The case of the existing DSF building*

As detailed in section [25], the existing model of the building is formed based on all available information. For this model (case 4), the experimental analysis is described in detail in [25] and validation process was carried out in [26]. The DSF of the case 4 is made on the principle of continuous multi-story façade with only natural ventilation in the cavity. The shading device (blinds) are mounted in cavity space and automatically regulated by the building management system (BMS). Motorized ventilation inlet and outlet dampers are not installed at the bottom and top of DSF. As a result, the façade is opened all the time and can not be regulated to current outside conditions.

It must be noted that in accordance with the experimental results, the current model has plenty of room for further improvement. That is, the current state of the facility does not always yield an increase in energy efficiency, which leads to the conclusion that the DSF is not fully utilized. The main problem is the lack of regulation flaps on the inlet and outlet of the DSF, which in winter would allow for the closing the space between the façades thus reducing heat loss. When there is a control model of protection against solar radiation, blinds placed in the space between the facades are set at an angle of  $45^\circ$ , when the outside air temperature is over  $25^\circ\text{C}$  and when the intensity of the horizontal solar radiation is greater than  $300\text{ W/m}^2$ .

### **Simulation results**

Figure 3 shows the energy consumption per month for heating, cooling, and fans according to the results derived from simulations models 1, 2, 3, and 4, or the relationship between the consumption for a traditional façade and the current state of the building with DSF.

It is noted that, when the heating is on, cases with traditional façade have the same value of energy consumption, as a result of the same control strategy and regulation of blinds. The strategy envisages that the protection from sunlight is always raised during the heating season, in order to absorb as much heat gains from the Sun.

Figure 4 shows the energy consumption for heating of the previous mentioned models. In the heating season, the positive impact of the presence of DSF is noted, which in each month reduces the consumption of thermal energy. This is primarily a result of the newly created *buffer* zone in the space between the façade, which contributes to the increase of indirect heat gains. Also, for added protection from the wind for case 4, heat losses were reduced due to infiltration. As for energy consumption needed to run the fan, values are constant for all cases, since the requirements for fresh air are the same.

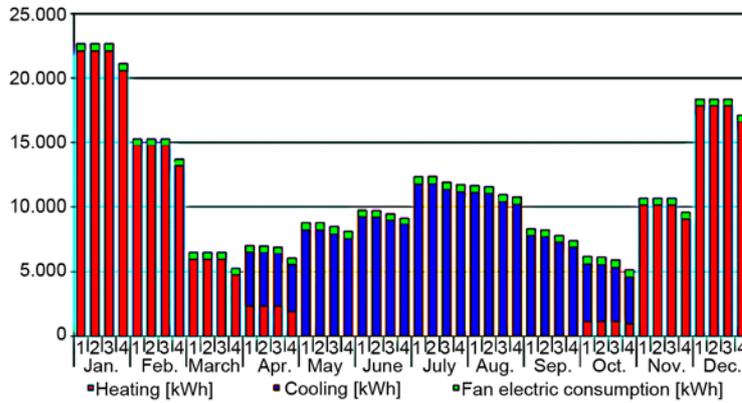


Figure 3. Comparative analysis of monthly consumption (cases 1, 2, 3, and 4)

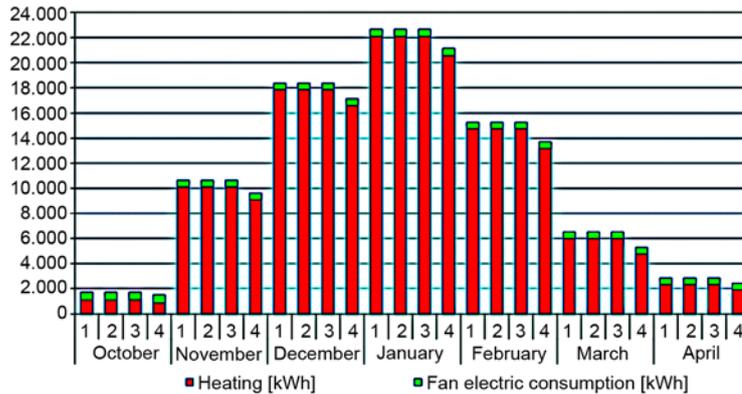


Figure 4. Comparative analysis of heating consumption (cases 1, 2, 3, and 4)

It is evident that the energy consumption in all months of the heating season is lower for the existing building model with DSF. To confirm the presence of the vertical gradient in DSF,

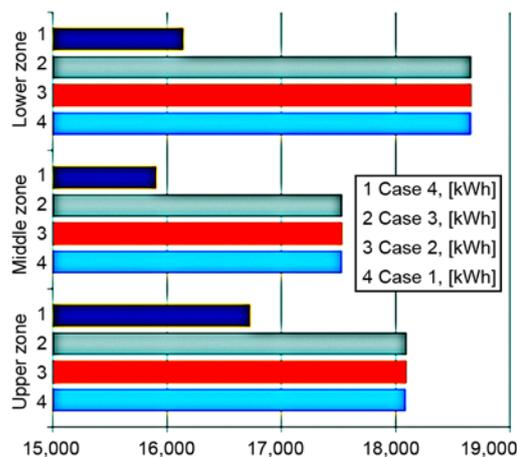


Figure 5. Comparative analysis of energy consumption for heating, for three experimentally analysed zones (cases 1, 2, 3, and 4)

fig. 5, shows the consumption of energy generated by simulation model 4, for the three experimental zones (lower, middle, and upper).

It is observed that the highest energy consumption is in the lower zone, since it is under the greatest influence of cold outside air. As we move upward, the consumption is reduced, while for the upper zone we have a little increase in consumption, which is caused due to the impact of the flat roof. By this we mean the increased surface of the barrier, which is in direct contact with outside air.

Observing the summer and transitional period in fig. 6, it can be noted that the current state of the DSF has lower consumption for cooling than all models of the facility with traditional façade. As for these models, the power consumption decreases from case

1 to case 3, which confirms the conclusion that the best position for blinds on a traditional façade is outside.

The main reason for the reduction in energy consumption during the summer season is better protection from solar radiation in the facility with DSF. This is confirmed in fig. 6, in which comparative analysis of solar radiation transfer in the air-conditioned areas of the building is presented.

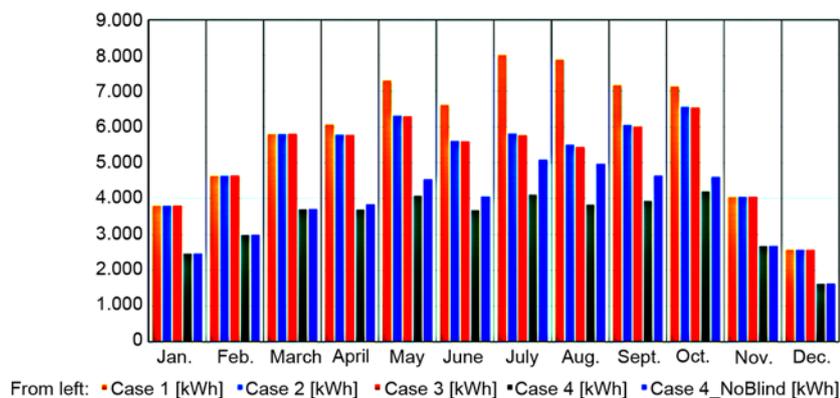


Figure 6. Comparative analysis of the solar radiation transfer in air-conditioned areas

There is an obvious trend of reduced solar irradiation, even in the case of DSF without blinds. This represents the major contribution of the DSF in reducing heat gains. Of course, in the implementation of protective measures attention must be paid to the part which relates to the reduction of the intensity of daylight.

Figure 7 shows the energy consumption for cooling of the analysed cases. As for energy consumption to run the fan, values are constant for all cases, since the requirements for fresh air are the same in all zones. Figure 3, confirms the previously mentioned greater efficiency of the existing building model with DSF, compared to the traditional façade. The results of the analysis confirm that during the summer months (July and August), the values of energy consumption for case 4 in relation to case 3 are still lower. The reason is, first of all, the north-eastern orientation of the observed façade. With a different orientation of the façade, these results may be different. It should also be noted that in the case of DSF, the regulation

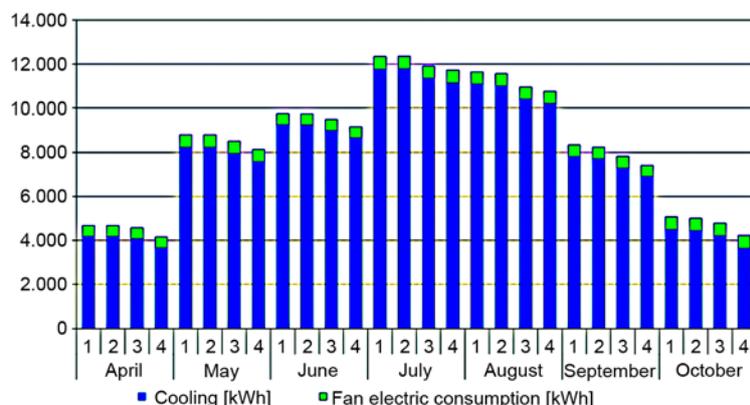
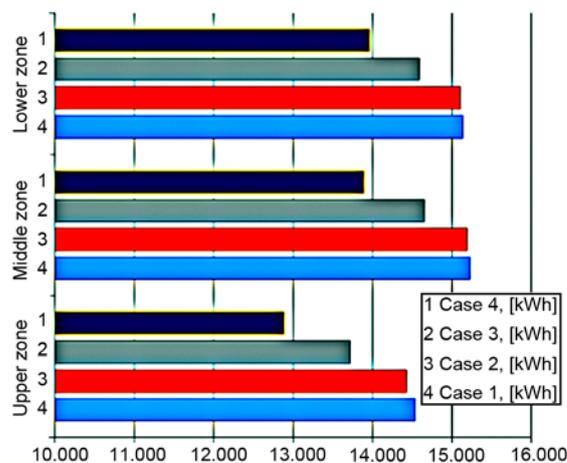


Figure 7. Comparative analysis of energy consumption for cooling (cases 1, 2, 3, and 4)

of the façade plays a significant role in indirect heat gains through natural ventilation. This effect also reduces the need for cooling of the building.

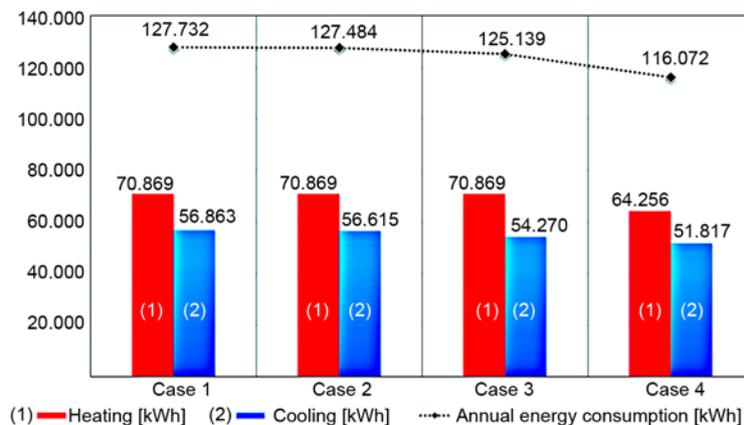
The main problem that occurs during the summer season is the presence of a negative vertical gradient and increasing energy consumption in the upper parts of the building. Confirmation of this claim, which is experimentally proven, is shown in fig. 8, where an increase in energy consumption for cooling in the upper zones of the building model with DSF is observed.



**Figure 8. Comparative analysis of energy consumption for cooling, for three experimentally analysed zones (cases 1, 2, 3, and 4)**

this analysis the average measured value was used. The same case is for the surface temperatures and air velocity.

Continued numerical modelling (with a confirmed model) has enabled a deeper analysis of the potential of the application of the DSF concept. The energy simulation model of the current state of the facility and the model with traditional façade were observed in this



**Figure 9. Comparative analysis of annual energy consumption (Cases 1, 2, 3, and 4)**

Looking at the analysed models and their annual energy consumption for heating and cooling, the downward trend from case 1 to case 4 is obvious, fig. 9.

### Conclusion and future research

The combination of the software tools EnergyPlus and airflow network algorithm proved to be a good and reasonable choice when it comes to the relationship between accuracy and time required for the simulation. Simulations typically lasted about ten minutes, which can be considered a relatively short time to obtain results. The software tool presumes that the air temperature in the zone is uniform and therefore provides only one simulated value. Measurements were obtained for two values of temperature across the width of the façade, and for

way. Through a comparative analysis with models that have a traditional façade, conclusion on the savings potential of the DSF concept for a moderate continental climate have been formed. However, it was also concluded that there is still more room for potential savings if adequate seasonal operational control and management strategies façade are applied.

Table 1 shows a more detailed, comparative analysis of the savings of the analysed models. The results of cost savings for all model variants with traditional façade (cases 1-3) and their relationship with the current facility (case 4) are shown.

**Table 1. Comparison of cases 1, 2, 3, and 4 – the percentage savings in energy consumption**

Case comparison	Case 1	Case 1	Case 1	Case 1	Case 2	Case 3
		Case 2	Case 3	Case 4	Case 4	Case 4
Heat consumption energy for heating, [kWh]	70,868.5	70,869.2	70,868.9	64,255.8	64,255.8	64,255.8
Heat consumption energy for cooling, [kWh]	56,863.0	56,614.8	54,269.8	51,816.6	51,816.6	51,816.6
Total annual heat consumption, [kWh]	127,731.5	127,484.0	125,138.7	116,072.3	116,072.3	116,072.3
Savings percentage – heating, [%]		0%	0%	9%	9%	9%
Savings percentage – cooling, [%]		0.4%	5%	9%	8%	5%
The total percentage of annual savings, [%]		0.2%	2%	9%	9%	7%

As for the cases with traditional façade, the energy consumption for heating is the same, because the blinds are always in the raised position during the heating season. Comparative analysis showed minimal differences between cases 1 and 2, and saving is achieved in energy consumption for cooling (0.4%) due to the presence of internal blinds in case 2.

In further comparison, case 3 has shown even greater savings in energy consumption for cooling (5%) compared to case 1, which confirms the assumption that the external position of blinds is the most effective in reducing heat gain.

Comparing the existing building model (case 4) and the most efficient model with traditional façade (case 3), the conclusion is that the DSF concept achieves savings in energy consumption for heating (9%) and for cooling (5%). However, it was also concluded that there is still more potential for savings if adequate seasonal operational control and management strategies for the façade are applied. This direction is the main goal of future research.

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