INFLUENCE OF GLAZING TYPES AND VENTILATION PRINCIPLES IN DOUBLE SKIN FAÇADES ON DELIVERED HEATING AND COOLING ENERGY DURING HEATING SEASON IN AN OFFICE BUILDING

by

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Double skin façade represents an additional skin on the outside wall of the building with the idea of reducing building's energy demand. The zone formed by adding a skin can be sealed or ventilated either naturally or mechanically. This paper shows the results of delivered heating and cooling energy for an office building during heating season with 3 different ventilation strategies and 90 double skin façade configurations. The results were obtained by using EnergyPlus simulation program. In all observed cases, adding double skin façade leads to a decrease in delivered heating energy by as much as 55.80%, but delivered cooling energy might increase if proper glazing type is not selected. The best results were obtained by using triple glazing as inner skin of double façade.

Key words*: double skin façade, EnergyPlus, four pipe fan-coil, delivered energy, office building*

Introduction

Double skin façade (DSF) represents an additional skin on the outside wall of a building. This additional skin can be either opaque or transparent, and it depends on the architectural concept of the designed building. In recent years, there has been a growing tendency to use DSF in Serbia, as is the case throughout the world, although it has been implemented only in few buildings. The main reason for this is that, currently, there is a limited direct experience of benefits in using them.

Importance of proper design of DSF was recognized by the International Energy Agency (IEA) Solar Heating and Cooling (SHC) and Energy Conservation in Buildings and Community Systems (ECBCS) Programmes, under SHC Task 34/ ECBCS Annex 43: Testing and Validation of Building Energy Simulation Tools, Project E: Buildings with Double-Skin façades. Through a joint effort, the literature review on DSF [1] and a final report on empirical validation of building simulation software for modeling DSF [2] were written. In [2] only several building energy simulation programs (BESP) were used: VA114, ESP-r, TRNSYS-TUD, IDA, BSim, while others were not rejected, only not used due to certain circumstances. Domestic authors have recognized the importance of DSF influence on energy demand for

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cooling and heating as well, first Todorović *et al.* [3, 4] and more recently Andjelković *et al.* [5]. They presented the inter-space temperature calculation method and its variation in order to calculate heating losses and cooling loads through DSF by taking into consideration diffuse solar radiation, heat flow from wall's surfaces to inter-space by longwave radiation, and air velocity in inter-space on heat transfer coefficient [5].

Influence of DSF ventilation, DSF ventilation control strategies, implementation of blinds in DSF, the way to model natural ventilation in DSF, how to calibrate model, *etc*., on building heating and/or cooling demand have been examined by many authors. Gratia *et al.* [6] compared buildings (with and without double skin façade) with a high level of thermal insulation in order to show how to use DSF according to internal and external climate conditions, and to compare performances of the buildings in these two cases, by using TAS software. The authors showed that DSF decreased the heating and increased the cooling load of the building. The same authors examined the influence of natural ventilation of DSF driven by wind and stack effect in a medium sized office building [7]. Cetiner *et al.* [8] found out that DSF configurations are more energy efficient than SSF for an office building in Istanbul, Turkey, for the same type of glazing applied in both configurations (double low emission glass), and that using solar control devices reduces energy efficiency. Yilmaz *et al.* [9] proposed heat loss calculation in DSF, and documented that SSF heat loss is 40% higher than that of DSF for the same building. Hien *et al.* [10] examined the effect of DSF on energy consumption, thermal comfort and condensation for a typical office building in Singapore. They determined cooling loads for five scenarios ranging from SSF to fully ventilated DSF using TAS and CFD simulation, and showed that DSF with a purely stack effect is good enough to extract solar heat gain inside the cavity, however, adding mechanical ventilation did not result in greater energy savings due to maintenance costs. Perez-Grande *et al.* [11] investigated the influence of glass properties on the performance of DSF. They concluded that glass selection could increase the total heat transfer into the building by factor of five, for certain outside conditions. Manz *et al.* [12] proposed a three-level modeling approach for buildings with DSF. Gavan *et al.* [13] examined the influence of ventilated DSF with venetian blinds on energy performance, and proposed control of blind angle and airflow through DSF zone. Gratia *et al.* [14] used TAS software to examine the influence of adding DSF on the N-S and E-W oriented office building with 3 levels of insulation and different natural cooling and heating strategies. Authors found that for each case adding DSF would lead to reducing heating loads and increasing cooling loads. Hoseggen *et al.* [15] investigated whether to apply DSF in an office building in Norway. Results showed that adding DSF would decrease heating energy demand on one side, and would not significantly increase the number of hours with excessive temperatures. Hamza [16] measured the impact of DSF configurations on building cooling loads using IESVE 5.1 software. The author concluded that in hot areas east and west façades should be avoided if possible. He also demonstrated that not every combination of glazing in DSF is better than the reflective single skin façade. In addition, there is a reduction in peak and annual cooling load if tinted or reflective glass were used in DSF compared to benchmark configuration. Jiru *et al.* [17] presented the application of zonal approach for modeling airflow and temperature in both mechanically and naturally ventilated DSF. Saelens *et al.* [18] described how to optimize energy performance of a single story naturally ventilated DSF according to net energy demand of the building under typical Belgium conditions. Kalyanova *et al.* [19] performed an empirical validation of various BESP for modeling DSF. They concluded that none of the models appeared to be consistent enough when comparing simulations with the measured data. Leao *et al.* [20] examined three glass combinations for eighteen office room sizes in Brazilian climate using EnergyPlus software. Authors concluded that northern regions in Brazil do not have appropriate climate for using DSF. Chan *et al.* [21] examined various combinations of glass types in DSF and their impact on cooling energy demand using the EnergyPlus software. They concluded that the configuration of DSF with single clear glass as the inner pane and a double reflective glazing as the outer pane can provide 26% savings in annual cooling energy compared to SSF with single absorptive glazing. Kim *et al.* [22] analyzed difficulties and limitations in performance simulation of DSF with EnergyPlus. They applied the methodology of experimental set-up and calibration of simulation model in EnergyPlus. They performed simulations for six ventilation modes and ten airflow regimes in DSF and gave the model for determining convective heat transfer coefficients and vertical airflow in the DSF cavity. Kim *et al.* [23] tested three control options for airflow in DSF and performed simulation using TRNSYS. They also validated the model by field measurements. Pappas *et al.* [24] presented a validated modeling process for analyzing thermal performance of naturally ventilated DSF using EnergyPlus as BESP and CFD software. They calibrated the model with experimental results from others.

This paper compares both delivered heating and cooling energy of an office building during the winter period with different DSF ventilation strategies (no ventilation/natural ventilation/mechanical ventilation) and different glazing types for inner and outer skin of DSF. The glazing types were chosen from the Serbian Ordinance on Energy Efficiency of Buildings [25], which will come into force on September 30, 2012. This ordinance currently covers only annual heating energy consumption, and all the buildings are categorized in classes from A+ to G, where A+ represents the building with the lowest energy consumption. C-class is taken as the referent value for all building types and for office buildings, it has the following values: for new buildings 55 kWh/m^{2}a, for refurbished buildings 65 kWh/m^{2}a. The building and the HVAC systems are modeled/simulated using the EnergyPlus software.

Method

Description of the office building and HVAC systems

The influence of different ventilation strategies and glazing types on delivered heating and cooling energy during heating season was investigated for the building shown in fig. 1. The building is a two-story office building with offices aligned on two façades (north and south) separated by central corridor. There is a total of 40 (20 per each floor) offices which represent separate thermal zones. Corridors on both stories are separate zones as well. Double skin façade is attached to south façade of the building with a depth of 0.6 m and is modeled as an unconditioned zone. The outside masonry wall is insulated with 6 cm polystyrene and has U-value of 0.488 W/m^{2}K. The concrete roof is insulated with 15 cm stone wool and has a U-value of 0.258 W/m^{2}K. The building is not surrounded by other buildings.

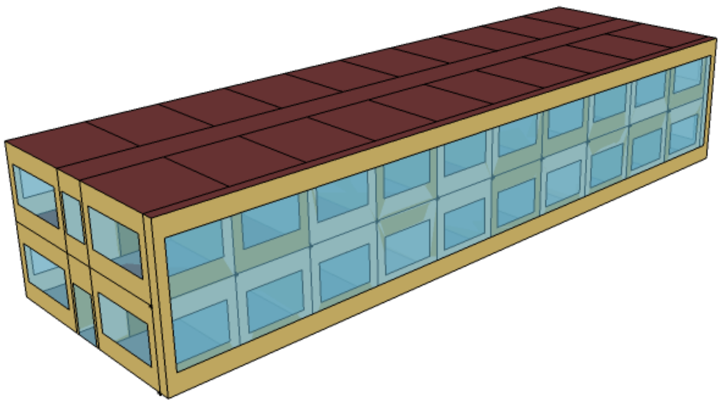
Figure 1. Isometric view of the office building with double skin façade

The building is occupied only during weekdays, from 7:30 to 22:30 h. It is assumed that one person occupies 5 m^2 of area, although the office occupancy is scheduled throughout the day. Lighting level is assumed at 30 W/m^2, although daylighting control is modeled for each office. Lighting system is available only during the occupied period of the building.

Offices and corridors are equipped with four pipe fan-coil units since the orientation of the building suggested that during transitional periods, from summer to winter and vice versa, simultaneous cooling and heating needs may occur. As a heating source, a natural gas fired boiler is used, while as a cooling source, an air cooled chiller is used. Operation and availability of all primary and secondary systems and components are adjusted to building occupancy, while for the weekends the technical minimum is used (reduced heating).

Double skin fa□ade ventilation principles and glazing types

For the purpose of this study, three different ventilation principles were selected:

(1) No ventilation – cavity of the DSF zone is completely sealed;
(2) II: Natural ventilation – cavity of the DSF is naturally ventilated, and for this purpose built in algorithm for natural ventilation of EnergyPlus is used [26];
(3) III: Mechanical ventilation – cavity of the DSF is mechanically ventilated by adding a fan into the DSF zone. Since there was no available information, 20 air changes per hour were selected, and considered with proper fan schedules.

Table 1. Glazing types used in study

ID	Description	Gas
1	Clear, 6 mm	–
2	Double clear, 6-8-6 mm	Air
3	Double clear, 4-12-4 mm	Air
4	Double clear, 6-12-6 mm	Air
5	Double clear, 6-16-6 mm	Air
6	Triple clear, 6-12-6-12-6 mm	Air
7	Double low emission, 4-12-4 mm	Air
8	Double low emission, 4-16-4 mm	Air
9	Double low emission, 4-15-4 mm	Argon
10	Double low emission, 4-12-4 mm	Krypton
11	Double low emission, 4-12-4 mm	Xenon
12	Triple low emission, 4-8-4-8-4 mm	Krypton
13	Triple low emission, 4-8-4-8-4 mm	Argon
14	Double reflective, 6-15-6 mm	Argon
15	Double reflective, 6-12-4 mm	Argon

Table 1 gives 15 different glazing types from [25]. Based on glazing types given in tab. 1, 5 glass types of the same manufacturer were selected. Optical and thermal properties of glass materials required for EnergyPlus model were taken from [27] and are given in tab. 2.

Table 2. Optical and thermal properties of glass materials

Name	Clear	Clear	Low emission	Reflective	Reflective
Thickness [m]	0.004	0.006	0.004	0.004	0.006
Solar transmittance at normal incidence	0.842	0.788	0.675	0.289	0.219
Front side solar reflectance at normal incidence	0.776	0.074	0.139	0.27	0.269
Back side solar reflectance at normal incidence	0.076	0.074	0.168	0.122	0.101
Thermal conductivity [Wm^{-1}K^{-1}]	1	1	1	1	1

Climatic data

Simulations were performed with climatic data for city of Nis during heating season, which starts on October 15th and ends on April 15th. City of Nis is located in south-east Serbia. Geographical coordinates: longitude 21°54 E, latitude 43°20 N, and the altitude is 202 m. For the simulations *.epw file for city of Nis was used [28].

Results and discussion

Since in [25] there are only limitations for U-values of fenestration surfaces in heated zones of the building, simulations of the baseline scenario (building without double skin façade) were performed. For each simulation all fenestration surfaces on the building were of the same type as shown in tab. 1. There were 15 baseline scenario simulations, out of which 9 were eliminated due to greater window U-value than allowed. Those were simulations with glazing types 1, 2, 3, 4, 5, 6, 7, 14 and 15. Delivered heating and cooling energy for baseline simulations 8-13 is shown in fig. 2.

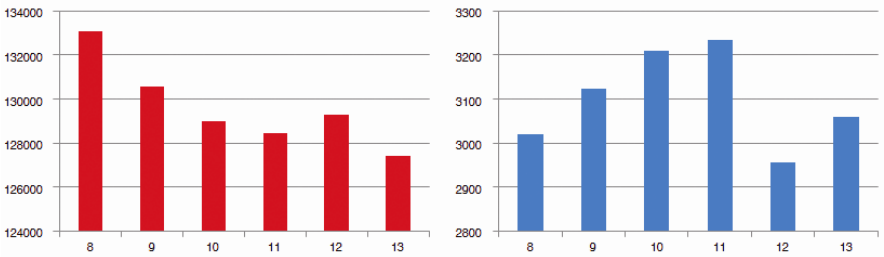

Figure 2. Delivered heating energy (left) and cooling energy (right) for baseline simulations

The double skin façade zone was treated as an unheated space. The inner skin of the DSF zone was regarded as the boundary between the heated space and "outdoors", thus the windows on the inner skin could only be of types 8-13 from tab. 1. The outer skin of the DSF zone was the boundary between the unheated space and outdoors, thus it did not have limitations regarding the window U-value. This practically means that windows on the outer skin could be of every type given in tab. 1. A total of 90 different glazing configurations for DSF zone were created and, for each of these, 3 ventilation strategies were applied. This resulted in 270 simulations. The results were summarized by the applied ventilation strategy.

DSF not ventilated

Since DSF is not ventilated (completely sealed), it represents a "green house", and a good buffer in case of delivered heating energy, but with an increase in delivered cooling energy. The results of all simulations for this ventilation principle are presented in tab. 3.

Configuration 13-11 resulted in the smallest delivered heating energy in the amount of 56444.44 kWh, and configuration 8-14 in the largest delivered heating energy in the amount of 70511.11 kWh, which is a deviation of 24.48%.

Configuration 12-14 resulted in the smallest delivered cooling energy in the amount of 1982.6 kWh, and configuration 8-11 in the largest delivered cooling energy in the amount of 7225.4 kWh, which is a deviation of 264.44%. All other combinations fall within this deviation.

DSF naturally ventilated

In the case of natural ventilation [26], a slight increase in delivered heating energy was observed, but a reduction in delivered cooling energy was also noted, compared to case I. The results of all simulations for this ventilation type are summarized in tab. 4.

Configuration 13-11 also resulted in the smallest delivered heating energy with the amount of 56765.1 kWh, and configuration 8-14 in the largest with the amount of 70549.8 kWh, which is a deviation of 24.28%. Delivered cooling energy kept the same trend as in the first ventilation strategy, but with the following values: configuration 12-14 had the smallest value of 1967.6 kWh, configuration 8-11 had the largest value of 6976.2 kWh (254.55% deviation).

Table 3. Delivered heating (H) and cooling (C) energy (*1000 kWh) in case DSF not ventilated

O \ I	8		9		10		11		12		13	
	H	C	H	C	H	C	H	C	H	C	H	C
1	61.597	5.942	60.039	6.040	58.967	6.169	58.639	6.206	59.950	5.160	58.733	5.288
2	61.864	5.384	60.400	5.412	59.447	5.439	59.150	5.442	60.225	4.701	59.100	4.724
3	60.443	6.326	59.019	6.357	58.089	6.424	57.792	6.430	58.872	5.466	57.856	5.529
4	61.525	5.536	60.142	5.554	59.192	5.569	58.886	5.614	59.939	4.823	58.839	4.874
5	61.383	5.623	59.917	5.640	59.042	5.694	58.717	5.692	59.742	4.892	58.694	4.943
6	61.889	5.028	60.531	5.053	59.661	5.036	59.364	5.028	60.211	4.444	59.228	4.431
7	60.636	6.013	59.311	6.008	58.467	6.038	58.139	6.027	59.050	5.231	58.058	5.262
8	60.228	6.343	58.903	6.323	58.064	6.300	57.850	6.283	58.700	5.508	57.714	5.483
9	59.600	6.782	58.269	6.799	57.489	6.758	57.247	6.735	58.036	5.914	57.136	5.871
10	59.194	7.129	57.897	7.068	57.144	7.037	56.903	6.986	57.694	6.142	56.792	6.088
11	59.106	7.225	57.811	7.163	57.003	7.127	56.786	7.109	57.522	6.226	56.644	6.219
12	59.642	6.416	58.403	6.369	57.592	6.320	57.375	6.344	58.050	5.640	57.178	5.592
13	59.175	6.836	57.967	6.771	57.186	6.713	56.972	6.690	57.589	5.946	56.775	5.879
14	70.511	2.070	68.872	2.107	67.775	2.139	67.417	2.154	67.869	1.983	66.569	2.023
15	70.394	2.105	68.758	2.143	67.661	2.178	67.272	2.190	67.756	2.013	66.483	2.054

Table 4. Delivered heating (H) and cooling (C) energy (*1000 kWh) in case DSF naturally ventilated

O \ I	8		9		10		11		12		13	
	H	C	H	C	H	C	H	C	H	C	H	C
1	61.620	5.911	60.048	6.011	58.989	6.139	58.636	6.178	59.955	5.135	58.739	5.263
2	61.923	5.288	60.475	5.355	59.526	5.383	59.202	5.391	60.248	4.650	59.163	4.677
3	60.514	6.250	59.081	6.285	58.156	6.313	57.841	6.321	58.939	5.405	57.880	5.433
4	61.611	5.468	60.183	5.492	59.252	5.512	58.935	5.516	59.963	4.767	58.899	4.786
5	61.442	5.549	60.026	5.573	59.105	5.587	58.791	5.591	59.809	4.834	58.756	4.850
6	62.003	4.940	60.630	4.927	59.765	4.918	59.472	4.945	60.286	4.365	59.297	4.357
7	60.731	5.861	59.395	5.898	58.534	5.889	58.250	5.877	59.143	5.134	58.156	5.128
8	60.350	6.171	59.024	6.153	58.182	6.134	57.901	6.160	58.779	5.353	57.807	5.377
9	59.717	6.611	58.422	6.581	57.592	6.551	57.330	6.530	58.162	5.724	57.229	5.690
10	59.354	6.877	58.078	6.835	57.272	6.792	57.016	6.767	57.820	5.934	56.898	5.932
11	59.211	6.976	57.906	6.927	57.133	6.929	56.879	6.902	57.674	6.057	56.765	6.008
12	59.822	6.170	58.528	6.126	57.754	6.125	57.505	6.101	58.211	5.420	57.318	5.375
13	59.366	6.552	58.119	6.493	57.352	6.438	57.109	6.413	57.799	5.696	56.925	5.634
14	70.550	2.034	68.931	2.090	67.811	2.123	67.425	2.138	67.878	1.968	66.614	2.007
15	70.428	2.087	68.799	2.128	67.686	2.162	67.299	2.177	67.776	1.998	66.506	2.039

Compared to baseline scenarios (fig. 2) all configurations resulted in the decrease of delivered heating energy from 46.98% (DSF configuration 8-14 compared to baseline scenario 8) to 55.72% (DSF configuration 11-11 compared to baseline scenario 11), but with an increase in delivered cooling energy of up to 131% (DSF configuration 8-11 compared to baseline scenario 8), except glazing types 14 and 15 on outer skin, where the decrease of 34.42% in delivered cooling energy was noticed (DSF configuration 13-14 compared to scenario 13).

DSF mechanically ventilated

Mechanical ventilation increased delivered heating energy, but significantly decreased delivered cooling energy. In addition, a slight shift in combinations with extreme values of both are noticed as shown in tab. 5.

Table 5. Delivered heating (H) and cooling (C) energy (*1000 kWh) in case DSF mechanically ventilated

I / O	8		9		10		11		12		13	
	H	C	H	C	H	C	H	C	H	C	H	C
1	63.292	5.292	61.575	5.426	60.416	5.587	***60.044***	***5.635***	61.416	4.646	60.081	4.804
2	64.726	4.423	63.075	4.506	61.961	4.577	61.594	4.608	62.730	3.916	61.454	3.990
3	63.299	5.185	61.673	5.276	60.572	5.400	60.210	5.433	61.456	4.553	60.194	4.675
4	64.555	4.498	62.918	4.577	61.814	4.647	61.441	4.715	62.582	3.976	61.311	4.086
5	64.457	4.544	62.828	4.620	61.722	4.728	61.358	4.755	62.497	4.012	61.233	4.120
6	65.913	3.792	64.301	3.878	63.217	3.924	62.855	3.942	63.797	3.439	62.561	3.486
7	64.577	4.564	62.974	4.632	61.886	4.729	61.526	4.751	62.605	4.040	61.364	4.142
8	64.334	4.734	62.748	4.798	61.682	4.850	61.324	4.868	62.391	4.186	61.173	4.243
9	64.027	4.905	62.457	5.006	61.409	5.051	61.056	5.068	62.113	4.369	60.916	4.420
10	63.813	5.074	62.264	5.126	61.229	5.167	60.878	5.181	61.931	4.473	60.748	4.518
11	63.744	5.117	62.200	5.166	61.168	5.205	60.818	5.218	61.869	4.508	60.684	4.597
12	65.016	4.357	63.467	4.402	62.430	4.437	62.072	4.494	62.998	3.928	61.815	3.966
13	64.747	4.551	63.215	4.591	62.193	4.622	61.847	4.633	62.767	4.052	61.600	4.084
14	***73.075***	1.760	71.254	1.813	69.997	1.861	69.585	1.883	69.984	***1.725***	68.555	1.778
15	72.904	1.796	71.081	1.851	69.822	1.901	69.410	1.922	69.835	1.756	68.404	1.811

Configuration 11-1 resulted in the smallest delivered heating energy in the amount of 60043.9 kWh, and configuration 8-14 in the largest delivered heating energy in the amount of 73074.9 kWh, which is a deviation of 21.7%.

Configuration 12-14 resulted in the smallest delivered cooling energy in the amount of 1724.6 kWh, and configuration 11-1 in the largest delivered cooling energy in the amount of 5635 kWh, which is a deviation of 226.75%.

Compared to baseline scenarios (fig. 2) all configurations resulted in the decrease of delivered heating energy from 45.08%% (DSF configuration 8-14 compared to baseline scenario 8) to 53.25% (DSF configuration 11-1 compared to baseline scenario 11), but with an increase in delivered cooling energy of up to 75.25% (DSF configuration 8-1 compared to baseline scenario 8), except glazing types 14 and 15 on the outer skin, where the decrease of 42.01% in delivered cooling energy was noticed (DSF configuration 10-14 compared to baseline scenario 10).

Conclusions

From all of the results it is clear that in all cases adding a DSF zone to the south wall of the building, independent of the ventilation principle and glazing type applied, leads to the decrease of delivered heating energy of up to 55.80%, which is in compliance with the results from [6, 8, 9, 14]. Delivered cooling energy during the heating season will increase by up to 139.25% if inadequate glazing type is chosen. This is in compliance with the results from [16].

The smallest delivered heating energy is obtained by applying glazing type 13 as the inner skin of DSF, except if applying mechanical ventilation for the DSF zone. Even in this case, all combinations based on glazing type 13 have smaller average deviation (3.49%) than the combinations based on glazing type 11 (3.93%).

The best results, from the delivered cooling energy point of view, are obtained with combination 12-14 as expected due to the best solar protective properties of this glazing type. Nevertheless, the deviation in delivered cooling energy is significant and the lowest average value of this deviation is achieved with a group of simulations based on glazing type 12 as the inner skin.

The answer to the question which combination of ventilation/glazing type is the best from the energy use standpoint can not be generalized, because there are numerous factors that influence delivered cooling and heating energy. In this case, only general guidelines can be given, and all comparisons should be done on the primary energy level for each particular case.

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