OVERALL ENERGY PERFORMANCE OF GLAZING FACADES AND EFFECT OF DIFFERENT WEATHER YEARS FOR ENERGY CALCULATION

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ABSTRACT

The main goal of presented study was to analyze selected solutions of glazing facades. All cases differ in thermo-optical properties (such as thermal resistance, solar transmittance), geometry, construction and orientation. Building performance simulation models (thermal and air flow) were generated using a simulation software ESP-r. According to the workflow, proposed by authors, the optimal solution of glazing façade system was find out for each of four cardinal direction. In the proposed method two criteria were used: heating/cooling loads during the year and total heating/cooling energy delivered to the zone. All obtained results were analyzed statistically. The basic weather database was workout according to WYEC2 standard.

The second part of this study consist of analyses according to different weather scenarios. Standard WYEC2 data set was modified by using various indexes for temperature, solar radiation and wind speed. Optimization algorithm was proceed again according to the same workflow. Based on the final results the effect of different weather database (WYEC2 sets) was estimated.

The general final conclusions are that:

- the different weather sets have a significant impact on thermal processes and energy balance for exposed glazing elements,
- the choice of final optimal solutions slightly depends on assumed meteorological database with different indexes (for south and north orientation only) even the measured input data are the same.

INTRODUCTION

Nowadays, there are more and more research work devoted to the proper estimation of boundary conditions for energy performance simulation e.g. (Crawley 1998). This problem is particularly valid for a new design buildings, expecting to be used through several dozen years. One of the reason was the validity of standard climate database worked out using previously measured weather parameters (usually during last 30 years). On the other hand the same author suggests (Crawley 2008) that only projected climatic conditions can give a proper results and avoid inaccuracy in estimation of future energy requirements. Even though the discussion about climate change is out of the scope of presented paper, the authors noticed that interpretation of existing meteorology database can has a strong influence on the final results of energy simulation.

ENERGY EFFICIENCY OF HIGHLY GLAZED FACADES

Energy balance

In terms of thermo-physical parameters, a transparent elements of building envelope are still one of the weakest component. The assessment of their energy efficiency should include both summer and winter. For some specific location of Central and North Europe the net energy balance is negative in winter (Manz & Menti 2012). It means that energy losses are higher than energy gains. Recent research works are devoted to improve not only thermal transmittance (Fang et al. 2010) or heat gains control (Papaefthimiou et al. 2009) but also to effective usage of a transparent partitions as an elements of PV system (Park et al. 2010).

Double skin facade systems have still great potential to decrease energy consumption in wide ranges of research areas. Even some new technologies are constantly developed and improved. Additionally, that systems contribute towards creating a more comforTable and eco-friendly office environment which in turn, further reduces maintenance costs as it saves the building's energy resources (Shameri 2011).

Modeling and simulation

Thermal simulation of dynamic building behaviour under changeable climatic conditions is perceived as essential to accurate assessment of any transparent components efficiency. A range of different approaches for determining conduction, convection and radiation heat transfer were proposed by many authors and reviewed in by J. D. Spitler (Hensen & Lamberts 2011). Advanced dynamic models for energy calculation have been incorporated into several simulation programs e.g. ESP-r (Clarke 2001). The ESP-r software is additionally capable of modelling the energy and fluid flows within combined building and plant systems. ESP-r uses an advanced numerical method to integrate the various equation types which can be used to represent heat and mass balances within a building. In a paper (Bartak et al. 2001) authors presented the methodology, results and recommendations of a design study for double-skin facade with ESP-r. Based on the obtained results it was stated that air temperature inside DSF mainly depends on heat gains and amount of air flow. It means that the most important weather parameters for energy performance analysis are: solar radiation and wind speed. Additionally, authors proposed to consider external temperature which determines heat transfer between zone and internal space of DSF. Presented investigations are not only a part of wider optimisation analyses but sensitivity analyses as well include different weather year for energy calculation.

Energy performance evaluation

Based on the type of construction, a transparent facade can be classified as a single (SSF) or double (DSF) skin structure. The energy efficiency of highly glazed buildings should be evaluated considering heating and cooling season. For DSF e.g., it means the ability to pre-heat the ventilation air during the winter and ability to reduce heat gains in summer season (Saelens et al., 2003). Energy performance evaluation of the glass facade is to determine the intensity of heat exchange processes between the facade and the environment. Due to the dynamic nature of the processes involved, there are many possibilities to assess theirs intensity.

Single skin facade usually works as a passive system, what means no ability to store a solar energy and dynamically control heat exchange processes between building and external environment. The pre-heating efficiency of active, double transparent facades can be define as (Serra et al., 2010):

$$\eta = \frac{T_{exh} - T_{amb}}{T_{amb} - T_0} \tag{1}$$

where T_{exh} is the temperature of the air extracted from the facade; T_{amb} is the temperature of the air inside the cell; T_0 is the temperature of the outdoor air.

Negative value of η means that facade generates no heat gains, but cools the indoor air. The value higher than 1 means the opposite. If η reaches intermediate value (0÷1), the facade is able to partially pre-heat the ventilation air.

During summer season the dynamic insulation efficiency ε could be estimated as the ratio between heat flux that is removed by the air flowing in the air gap Q_r and total heat flux through the external skin Q_{inc} (Corgnati at al., 2007):

$$\varepsilon = \frac{Q_r}{Q_{inc}} \tag{2}$$

Another criterion representing energy efficiency of high glazed, double skin facades is a minimum value of total heat flux $f(\bar{X})$ between zone and facade during a day (Heim et al., 2012) or another time interval which can be assumed as a typical occupancy time (Serra et al., 2010):

$$f(\bar{X}) = \int_{\tau_1}^{\tau_2} \left(\sum_{n=1}^{m} q_n \right) d\tau \tag{3}$$

The most frequently used value, which allowes to compare the effects of active (DSF) and traditional (SSF) glass facades is heat gains and losses (Bliuc et al., 2009). To evaluate energy loads of highly glazed envelope of the building it is nessesary to consider gains from solar radiation and losses resulting from heat transmission and air infiltration (Cetiner et al., 2005).

OPTIMISATION PROCEDURE

Parameters of optimisation

Energy performance of buildings with highly glazed envelope depends predominantly on climat conditions. In order to ensure low energy consumption under variable weather conditions it is necessary to consider the orientation, material properties and thermal charactericties of the glazing.

The first factor taken into account was the thermal insulation of the glass components which has the greatest impact on facade performane during heating season. Construction of the facade (single or double skin) and influence of buffer zone have been also considered. In summer months energy performance is determined by solar gains, therefore optical properties of glass such as transmittance need to be selected properly. To find appropriate values of mentioned parametres optimisation has to be done.

The optimisation criterions are minimum value of instantaneous heating or cooling loads and total energy delivered to the zone.

Workflow

For all established optimization criterions appropriate workflows were made, separately for heating/cooling loads during the year and total energy delivered to the zone.

The first one was considered seasonally and the following three stages were distinguished. Initially, analyzed cases with different heat transmittance U, during the heating season. Subsequently, the most efficient case from previous step were re-analyzed to determine the most favourable transmission τ in summer. If the selected transmission differed from that analyzed in the first step, it was necessary to introduce a third stage. For chosen τ two most effective cases from first stage were compared again under winter conditions. That workflow where used for the first mentioned criterion - heating/cooling loads during the year (Fig. 1).

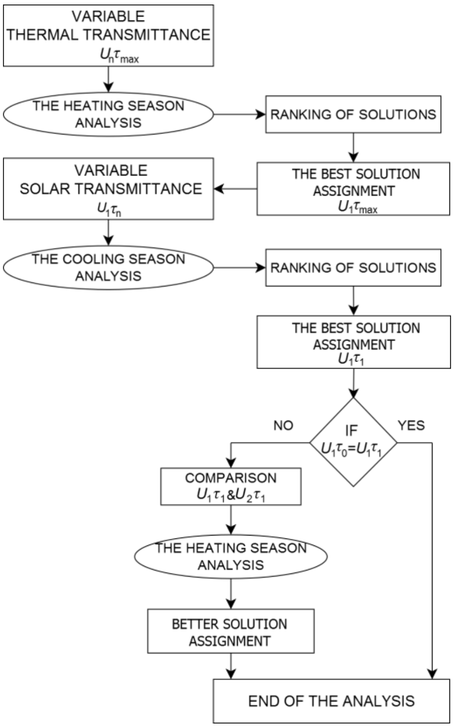

Figure 1 Workflow for individual seasons

In order to choose the best solution according to the second criterion, similar workflow has been created [Fig. 2]. Likewise, initially determined the most effective thermal transmittance and then for chosen *U* value, transmission *τ* was estimated. Both steps of analyses were carried out for the whole year.

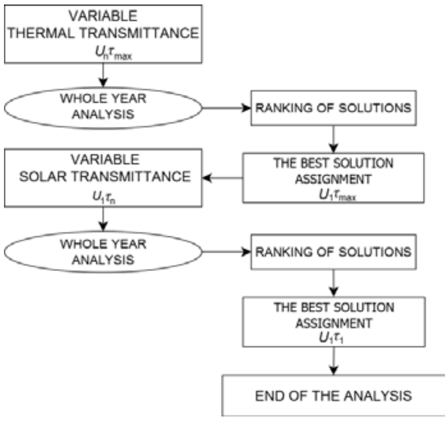

Figure 2 Workflow for the whole year

Optimisation procedure

The aim of the study was to determine parameters of the most energy efficient high glazed façade under different weather conditions.

The first criterion (heating/cooling loads) was adopted to choose such a case that will require the lowest power of heating/cooling system and that the power will be balanced in a specified period of time. The obtained hourly values of instantaneous power of the system were analysed statistically and presented in a form of normal distribution. It was assumed that the case with the highest frequency of zero loads will be the case that require the lowest power of the system. Separately, based on the minimum value of standard deviation of the normal distribution, due to the constant power of the systems, the most effective case was determined.

The second criterion (energy delivered to the zone) was the minimum sum of monthly values of energy required to maintain the comfort conditions in the temperature-controlled zone. In that paper, the sum of energy for heating in winter season and energy for cooling in summer season were considered.

Whole optimisation procedure were carried out for the four cardinal direction, four sets of climate data and for each of them three best solutions were assign.

CASE STUDY

Geometry

In order to investigate the performance of the façade, vertically cut part of the free-standing building were used in analysis. In the simulations eight-storey building were used. Each floor was defined as a temperature-controlled area and the additional (only for DSF), adjacent area of the façade. Structure of the facade covers all floors except of the ground floor and was raised one meter above the height of the top floor (Fig. 3). Dimensions of the zones were assumed in accordance with the dimensions of the reference room, proposed by the U.S. Department of Energy (BESTEST, 2003), for the validation of computational simulation tools *BestTest*. Each temperature-controlled zone has following dimensions: 8m×6m×2,7m and façade is 1m depth.

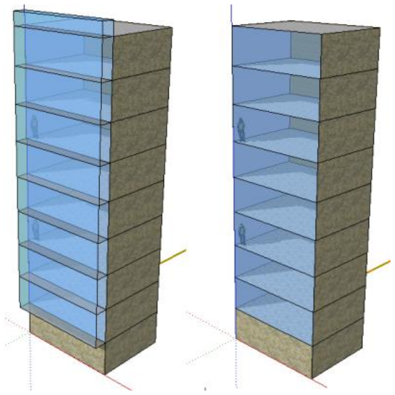

Figure 3 View of the building with double and single skin facade

Construction

It was assumed that since only vertical cut part of a building was modelled, three of the walls were considered as internal and built from heavy mass, reinforced concrete with a thickness of 0,2 m. The last one wall was exterior glass envelope, which thermal and optical properties are presented in Table 1 and Table 2.

All double skin facades consist of double glazing internal coating and single glazing external skin. Single skin facade marked as *UY* is made of double glazing and *UX* symbol represents triple glazing, both with low-E coating.

Table 1
Thermal properties and symbols of considered cases

TYPE	**SYMBOL**	**THERMAL TRANSMITTANCE** ***U*** **[W/m^{2}K]**	
		INT. SKIN	**EXT. SKIN**
double skin	*U1*	2,8	5,5
	U2	1,4	5,5
	U3	1,4	2,8
single skin	*UY*	-	1,4
	UX	-	0,7

Table 2
Optical properties and symbols of considered cases

SYMBOL	**TRANSMISSION** τ **[-]**	
	INTERNAL SKIN	**EXTERNAL SKIN**
$\tau 1$	0,7	0,7
$\tau 2$	0,7	0,6
$\tau 3$	0,7	0,5
$\tau 4$	0,7	0,4
$\tau 5$	0,7	0,3
$\tau 6$	0,7	0,2
$\tau 7$	0,2	0,2

For single glass facades, analyses of transmission coefficient were carried out for cases $\tau 1$ - $\tau 6$ where τ was taken into consideration as for external skin.

Operation

Based on the classification of office buildings the second category of the building were assumed, which is applicable to new and existing buildings. On this basis the indoor temperature range was 20°C ÷ 26°C.

The total ventilation rate of the room has been adopted as recommended for the open space and low-polluted building. During the occupancy it reached the value of 0,058 [m^3/s] and during the rest of the time it decreased to 0,005 [m^3/s].

The minimum floor area per person in the assumed office is 15 m^2, and therefore in every zone the presence of 3 people have been adopted, from Monday to Friday, 8:00-16:00.

Heat gains were specified as 220 W per person. 100 W were produced by people staying in zone (half of which was sensible heat and half latent). The rest 120 W were emitted by equipment. It was assumed that during occupancy time, due to the large glazing area, solar radiation will by sufficient light source, and therefore the heat gains from lighting were set as zero.

Boundary conditions

The first part of analysis is devoted to determine the optimal solution under standard weather conditions. Basic set of climate data was assumed as standard WYEC2 (Weather Year for Energy Calculation, Version 2).

It was assumed that building was located in the urban environment of Central Europe. The analyses ware carried out taking into account winter and summer seasons. It was established that cooling season includes three months and starts in June. Heating season was assumed as lasting from October to May. Remaining two months – May and September – were considered as intermediate in temperate climate and were not analyzed.

OPTIMAL SOLUTIONS – RESULTS

Maximum frequency of zero loads

The results presented in this section were obtained for standard WYEC2. Firstly, according to the workflow presented in Figure 1, analysis was carried out for heating season. Different combinations of thermal transmittance were investigated. Results for specific orientation of glazed facade are shown in Figure 4 to Figure 7.

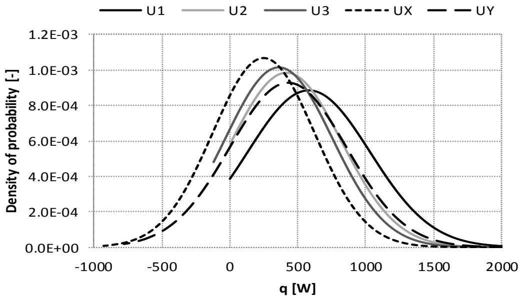

Figure 4 Normal distributions of heating loads for different U value for north orientated facade

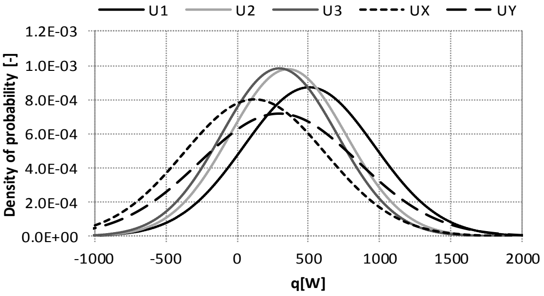

Figure 5 Normal distributions of heating loads for different U value for east orientated facade

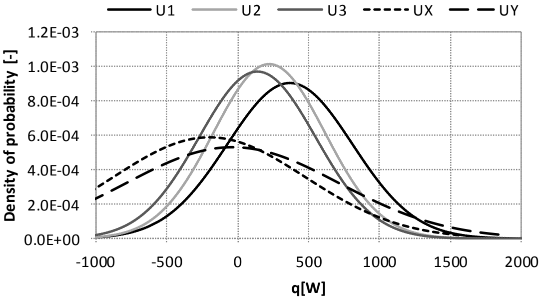

Figure 6 Normal distributions of heating loads for different U value for south orientated facade

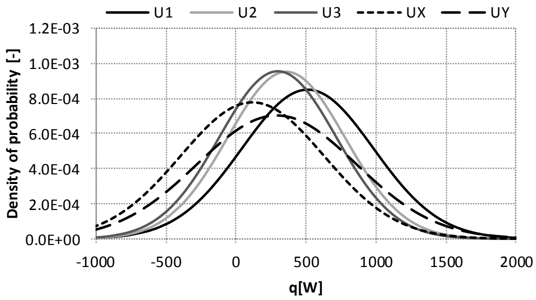

Figure 7 Normal distributions of heating loads for different U value for west orientated facade

Based on the normal distributions of heating loads, maximum frequency of zero loads was observed for case *U3* for south and *UX* for all others orientations.

Secondly, performance of the facade with different transmission, during cooling season was analyzed.

For each orientation of the facade the best results were obtained for minimum value of transmission (for single glazed facades – *τ6* and for double – *τ7*; Figure 8 to Figure 11*)*. Low value of *τ* assure reduction of heat gains and as result cooling loads.

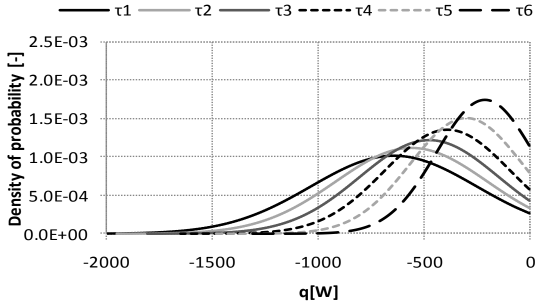

Figure 8 Normal distributions of cooling loads for different τ (case UX) for north orientated facade

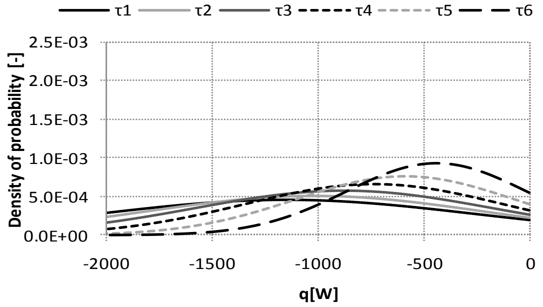

Figure 9 Normal distributions of cooling loads for different τ (case UX) for east orientated facade

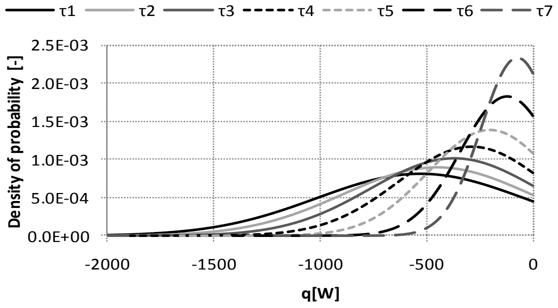

Figure 10 Normal distributions of cooling loads for different τ (case U3) for south orientated facade

As shown in Figure 10, additional glass skin and wide air space in chosen south orientated double skin facade can sufficiently reduce solar energy gains. Chosen south oriented double skin facade demonstrate the best performance.

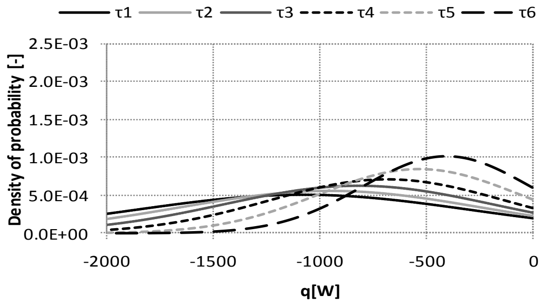

Figure 11 Normal distributions of cooling loads for different τ (case UX) for west orientated facade

In the last step, two most efficient combinations of thermal insulation with optimal value of transmission were compared (Table 3). The results confirmed the first selection of *U* value for all orientations of the facade.

Table 3
Cases considered in the last step of analysis

	τ	**U**
N	τ6	UX & U3
E	τ6	UX & U3
S	τ7	U3 & U2
W	τ6	UX & U3

Minimum value of standard deviation

That part of analysis was carried out analogously to the previous one, but in each selection stage minimum value of standard deviation indicated optimal solution. Tables 4÷6 present three optimisation steps and include the values of standard deviation where bolded ones were considered as the best and taken to further analysis.

Table 4
Values of standard deviation for different U

	N	**E**	**S**	**W**
U1	450.72	457.17	441.76	469.45
U2	405.23	407.57	**393.88**	419.13
U3	393.13	**405.64**	411.52	**417.88**
UX	**373.74**	497.53	678.54	513.10
UY	429.87	555.18	751.90	567.69

Table 5
Values of standard deviation for different τ

	N_UX	**E_U3**	**S_U2**	**W_U3**
τ1	392.66	506.47	471.96	455.31
τ2	360.60	458.28	426.19	410.86
τ3	328.82	408.07	377.41	364.36
τ4	297.12	356.20	324.29	314.85
τ5	264.58	298.12	263.81	259.48
τ6	**229.38**	229.42	190.53	194.75
τ7	-	**180.95**	**137.74**	**148.99**

Table 6
Values of standard deviation for optimal solution

	CASE	STANDARD DEVIATION
N	**UX_T6**	**378.21**
	U3_T6	392.34
E	**U3_T7**	**390.57**
	U2_T7	396.48
S	U2_T7	386.53
	U3_T7	**380.40**
W	**U3_T7**	**397.37**
	U2_T7	401.05

Minimum total heating/cooling energy delivered to the zone

Third optimisation criterion was minimum heating and cooling energy delivered to the zone.

Whole year analysis, in first selection step, shown that optimal solution for all orientations was DSF *U3*.

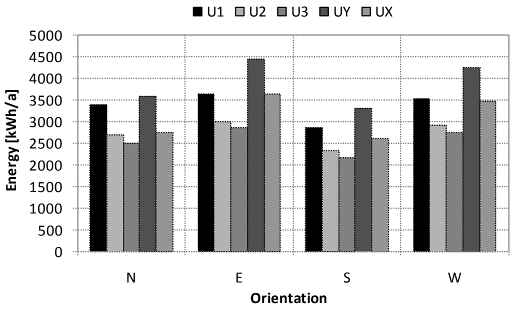

Figure 12 Energy delivered to zone for heating and cooling for different values of thermal transmittance

Whole year analysis of facades with different transmission revealed that the lowest value of τ do not guarantees the best performance of facade (for south and north orientation). Base on the results in Figure 13, better results were obtained for $\tau 5$.

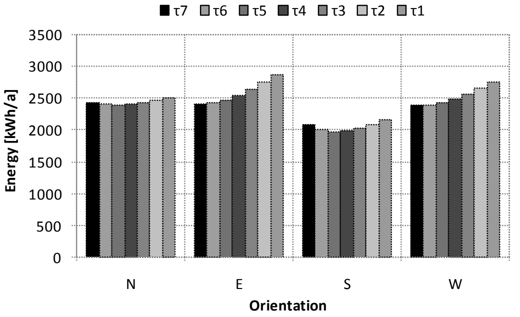

Figure 13 Energy delivered to zone for heating and cooling for different values of transmission

EFFECT OF WEATHER CONDITIONS

Climate analysis

In the first part of analysis, basic set of climate data was standard WYEC2 (Weather Year for Energy Calculation, Version2). Then data set was modified by using various weighs of indexes for temperature, wind speed and solar radiation. Every modified WYEC2 file was made by choosing singular months from minimum 30 years of measurements for the same location. The choice of a particular month was determined by the parameter with assigned the highest weight of index.

In the first modified climate set of data the decisive parameters were maximal wind speed and intensity of solar radiation. For second type of WYEC2 utmost importance was intensity of solar radiation and for third one type – wind speed.

Table 7
Weighs of indexes for different WYEC2 data sets

	WYEC2	WYEC2_1	WYEC2_2	WYEC2_3
$t_{a(max)}$	5	15	15	15
$t_{a(min)}$	5	15	15	15
$t_{a(mid)}$	30	10	10	10
$t_{r(max)}$	2.5	1	1	1
$t_{r(min)}$	2.5	1	1	1
$t_{r(mid)}$	5	1	1	1
$v_{w(max)}$	5	15	1	25
$v_{w(mid)}$	5	5	1	25
I_{th}	40	37	55	7

The effect of choosing different months is shown in Table 8-10. The highest differences were observed for ambient temperature, while for solar radiation and wind speed the differences are negligible. It was found that all chosen winter months are the same for WYEC2_1 and WYEC2_3.

Table 8
Medium ambient temperatures [˚C] (HS means heating season and CS - cooling season)

	WYEC2	WYEC2_1	WYEC2_2	WYEC2_3
HS	5,51	2,62	0,61	2,62
CS	17,15	17,04	15,99	17,44

Table 9
Solar global radiation on horizontal surface [kWh/m^{2}a] (HS means heating season and CS - cooling season)

	WYEC2	WYEC2_1	WYEC2_2	WYEC2_3
HS	334,5	340,6	350,3	340,6
CS	423,6	475,5	466,0	496,1

Table 10
Medium wind speed [m/s] (HS means heating season and CS - cooling season)

		WYEC2	WYEC2_1	WYEC2_2	WYEC2_3
N	HS	1.98	2.82	2.92	2.82
	CS	0.91	2.55	2.33	2.56
E	HS	3.81	4.16	3.79	4.16
	CS	2.54	2.91	2.64	2.30
S	HS	4.12	3.89	3.90	3.89
	CS	2.36	3.16	2.77	3.12
W	HS	4.64	4.49	4.36	4.49
	CS	3.43	3.72	3.72	3.93

RESULTS FOR DIFFERENT WYEC

Maximum frequency of zero loads

For each WYEC2 data set and specific orientation of the façade, the same case was assumed as the best solution, and it was *U3_τ7* for south and *UX_τ6* for all others orientations.

For every orientation of the facade, WYEC2 data set gave the highest frequency of zero loads while WYEC2_2 provided the lowest value. Because of selection of winter season for the last part of analysis, results for rest two data sets were the same. Normal distributions of heating loads of the best solutions for all orientations of the facade had the same shape and approximate values as for north orientated facade, (Figure 14).

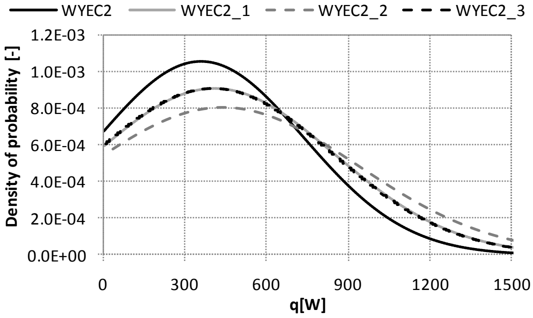

Figure 14 Normal distributions of heating loads of best solutions for north orientated facade

Minimum value of standard deviation

For each WYEC2 data set and specific orientation of the façade, the same case was assumed as the best solution, and it was as follows:

- north – *UX_τ6*
- east, south and west – *U3_τ7*

Despite of the selection of the same cases for a specific orientation, values of standard deviation for each of them were different. The differences between values obtained for WYEC2 and WYEC2_2 reached almost 25% (Table 11).

Table 11
Values of standard deviations for best solutions for different WYEC2 data sets

ORIENTATION	N	E	S	W
WYEC2	378.21	390.57	380.40	397.37
WYEC2_1	441.23	451.14	435.06	465.37
WYEC2_2	497.05	510.35	492.78	519.10
WYEC2_3	441.23	451.16	435.06	465.33

Minimum total heating/cooling energy delivered to the zone

In whole year analysis, for east and west orientated facade the same case was assumed as the best solution for each WYEC2 data set. For north and south orientation of the facade slight differences occurred, as shown in Table 12.

Table 12
Best solutions for whole year analysis and different WYEC2 data sets

ORIENTATION	N	E	S	W
WYEC2	*U3_τ5*	*U3_τ7*	*U3_τ5*	*U3_τ7*
WYEC2_1	*U3_τ5*	*U3_τ7*	*U3_τ4*	*U3_τ7*
WYEC2_2	*U3_τ4*	*U3_τ7*	*U3_τ4*	*U3_τ7*
WYEC2_3	*U3_τ5*	*U3_τ7*	*U3_τ4*	*U3_τ7*

For all orientations the highest value of energy delivered to the zone for the heating were obtained for WYEC2_2 data set, and the lowest for WYEC2 (except of south orientation). The differences beetwen extreeme values for east and west orientation reached even 15% (fig. 15).

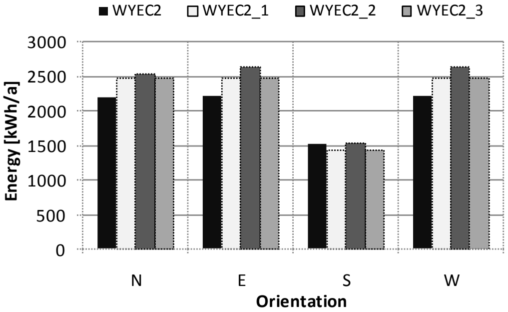

Figure 15 Heating energy delivered to the zone

By proper selection of thermo-optical properties of glazing, the energy demands for cooling were highly limited (Figure 16). For north, east and west orientation the value of energy delivered to the zone for cooling is insignificantly small in comparison to energy demands for heating.

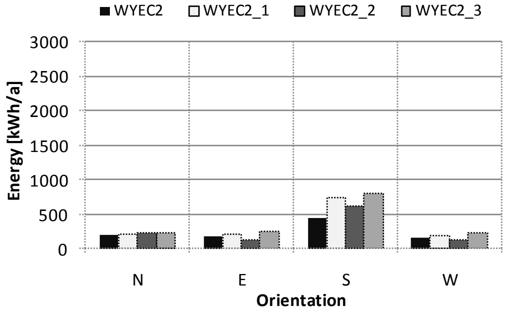

Figure 16 Cooling energy delivered to the zone

CONCLUSIONS

During the winter season, due to small angle of solar radiation, the choice of DSF as optimal solution for south orientated façade is quite obvious. For another orientation of the façade analyses shown that SSF provide better performance during heating season but in summer can be a reason of strong overheating. In case of highly glazed areas of the façade, additional glass skin allows to dynamically control heat gains.

Whole year analyses shown that two recommended solutions for all orientations of the façade are DSF. The third one is SSF, but characterized by the lowest value of thermal transmittance (*UX*). Therefore, it can be noted that energy balance could be provided by air cavity more efficiently than by improving insulation.

Despite of the same choice of optimal solutions for different WYEC2 data sets, the values of heating/cooling loads and energy delivered to the zone are significantly different. That differences can be considered as effect of varied values of such parameters as temperature, solar radiation and wind speed in specific direction.

The differences in values of mentioned parameters reflect the differences in cooling and heating energy demands. It can be noted that in summer season the decisive parameter is wind speed. The higher value results in more effective cooling and subsequently lower energy demands. During the winter season temperature and solar radiation have the biggest influence on energy performance of the façade. The highest values of both parameters assure lowest requirements for energy systems.

The lowest value of solar global radiation occurs for WYEC2 data set which resulted in choosing slightly lower value of transmission than for modified WYEC2 data sets (for south directed façade). Similar phenomenon can be noted for WYEC2_2 and north orientation. As an effect of lower temperature, slightly higher value of transmission was classified as optimal.

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REFERENCES

Bartak M., Dunovska T., Hensen J., 2001, Design support simulations for a double-skin facade. Proceedings of the 1st International Conference on Renewable Energy in Buildings "Sustainable Buildings and Solar Energy 2001", pp. 126-129, 15-16 November, Prague: Brno University of Technology / Czech Academy of Sciences.

Bliuc I., Lepadatu D., Baran I., 2009. Potential adaptation of buildings to climate. Role of glazed areas. Energy Efficiency and New Approaches, Istanbul TU, 577-583.

Cetiner I., Ozkan E., 2005. An approach for the evaluation of energy and cost efficiency of glass facades, Energy and Buildings, 37, 673-684.

Clarke J.A., Energy Simulation in building design, 2011.

Corgnati S. P., Perino M., Serra V., 2007. Experimental assessment of the performance of an active transparent facade during actual operating conditions, Solar energy, vol. 81, 993-1013

Crawley D.B., 1997, Which weather data should you use for energy simulation of commercial budilings? ASHRAE Transaction, Atlanta: ASHRAE, 104 (Pt 2).

Crawley D.B., 2008, Estimating the impacts of climate change and urbanization on building performance, Journal of Building Performance Simulation, vol. 1, no. 2, 91-115.

EnergyPlus Testing with ANSI/ASHRAE Standard 140-2001 (BESTEST), U.S. Department of Energy, 2003.

Fang Y., Hyde T. J., Hewitt N., 2010, Predicted thermal performance of triple vacuum glazing, Solar Energy, 84, s. 2132–2139.

Heim D., Janicki M., 2012. Double criterion optimisation of transparent facades accounting solar thermal processes, Proc. of 5th Building Physics Conference, Kyoto.

Hensen J. L. M, Lamberts R., 2011, Building performance simulation for design and operation, Spon Press.

Manz H., Menti U-P., 2012, Energy performance of glazings in European climates, Renewable Energy 37, 226-232.

Papaefthimiou S., Syrrakou E., Yianoulis P., 2009, An alternative approach for the energy and environmental rating of advanced glazing: An electrochromic window case study, Energy and Buildings, 41, s. 17–26.

Park K.E., Kang G.H., Kim H.I., Yu G.J., Kim J.T., 2010, Analysis of thermal and electrical performance of semi-transparent photovoltaic (PV) module, Energy 35 2681–2687

Saelens D., Carmeliet J., Hens H., 2003, Energy Performance Assessment of Multiple-Skin Facades, HVAC&R Research, vol. 9 (2), 167-185.

Serra V., Zanghirella Fabio., Perino M., 2007. Experimental evaluation of climate facade: Energy efficiency and thermal comfort performance, Energy and Buildings, vol. 42, 50-62.

Shameri M.A., Alghoul M.A., Sopian K., Fauzi M., M. Zain, O. Elayeb, 2011, Perspectives of double skin façade systems in buildings and energy saving, Renewable and Sustainable Energy Reviews, Vol. 15 (3), s. 1468–1475.