

THERMAL COMFORT IN HIGHLY GLAZED BUILDINGS DETERMINED FOR WEATHER YEARS ON ACCOUNT OF SOLAR RADIATION

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ABSTRACT

The presented work is devoted to the analysis of thermal comfort indexes in highly glazed buildings under different weather conditions. All cases considered here differ in thermo-optical properties (such as thermal resistance, transmission), geometry, construction and orientation. Building performance simulation models (thermal and air flow) were defined using simulation software ESP-r. According to the workflow, proposed by authors, the optimal solution for glazing façade system was found for each of four main directions: N, E, S and W. In the proposed method three criteria were used: PMV and PPD indexes during heating and cooling seasons and average PPD index for the whole year. All obtained results were analysed statistically. The basic weather database was worked out according to the WYEC2 standard procedure, based on the data of European location characterized by moderate climatic conditions.

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

The general final conclusions are that:

- optimal solution obtained on the basis of PPD and PMV indexes (for heating and cooling period), is different from the solution obtained on the basis of annually averaged value of PPD,
- final optimal solution depends on the assumed meteorological database (WYEC2 with different indexes), even then the input data (measured meteorological parameters of thirty years) are the same.

INTRODUCTION

The problems of thermal comfort in highly glazed buildings are well investigated and described (Hwang & Shu 2011, Lyons et al. 2000). Louvres systems and other shading devices are recommended to architects to protect against overheating during summer and to provide the required amount of daylight (Heim &

Kieszkowski 2006). During winter, the largely glazed external surfaces become a source of heat lost. On the other hand, architects like transparent building components because of the aesthetic and practical point of view (Arbab & Finley 2010). Office workers sitting behind uncover glass facade are usually strongly exposed to solar radiation and having an effect of radiation asymmetry. Therefore, a new concept of facade design is still desirable. One of the questionable idea is a concept of Double Skin Facade (DSF) (Poirazis 2006). However, in regards to the thermal comfort, in general, double skin façade (DSF) buildings have slight advantages in relation to single skin façade (SSF) buildings (Huckemann et al. 2010). On the other hand, the effect of individual, external climatic conditions, including specific location and climate change, should be considered in the optimization process (Crawley 2008).

THERMAL COMFORT IN A ROOM BEHIND HIGHLY GLAZED FACADE

Surface temperature and solar radiation

Glass curtain wall exposed to solar radiation and built up zone with control temperature is a very complex thermal system. The intensity of thermo-physical processes directly in a glass and on boundary layers depends on weather conditions and indoor parameters determined by heating/cooling control system. Particularly, the following two weather parameters should be taken into account: solar radiation and air temperature. Solar radiation decides of the intensity of photo-thermal conversion in a construction of the facade and the adjacent zone. High intensity solar radiation is unfavourable, as it increases the temperature of internal surfaces, which then causes a rise of the mean radiant temperature. Air temperature determines the heat exchange with human body and affects the internal surface temperature. Therefore, both parameters and thermo-physical processes indirectly create thermal comfort in a building.

Modelling and simulation

Analysis of indoor parameters and human comfort indexes was carried out using a dynamic model of heat and mass transfer with ESP-r (Clarke 2011).

ESP-r is an integrated energy modelling tool for thermal, visual, and acoustic performance simulation of buildings and the energy systems (Citherlet & Hand 2002).

Thermal comfort evaluation

Basic factors affecting the thermal comfort can be classified into environmental and personal (Cena & Clarke 1980). Environmental factors include: air temperature, mean radiant temperature, air velocity and relative humidity (Hensen & Lamberts 2011). Personal factors are the level of human activity (metabolic rate) and the thermal insulation of clothing (Djongyang et al. 2010).

Nowadays, two methods of determining thermal comfort coexist: the rational approach and the adaptive approach. The rational approach is based on the Fanger's theory of heat balance and thermoregulation (Fanger 1970), while the adaptive approach is based on research carried out among the people in the building (Nicol & Humphreys 2002).

In this paper, thermal comfort assessment will be carried out for heat balance approach through the indicators devised by Fanger PMV and PPD (Olesen & Parsons 2002). The main goal of the first part of the paper was a numerical analysis of thermal comfort in an office building with highly glazed façade, taking into account different thermo-optical properties for standard weather databases WYEC2. The aim of the second part of the study was to estimate an effect of modified weather databases on thermal comfort indexes – PMV and PPD in an office building with highly glazed facade.

OPTIMIZATION PROCEDURE

For the purpose of the presented study, individual algorithm was developed and described. Thermal comfort parameters assumed for optimization are described below.

Parameters of optimization

The first indicator considered in the paper is PMV (Predicted Mean Vote). PMV describes the predicted average rating of thermal comfort. The second means of assessing the thermal comfort is Fanger's PPD index (Predicted Percentage of Dissatisfied). It determines the participation of dissatisfied with the conditions in the room, expressed in percentage.

For the purpose of multi-criteria evaluation of thermal comfort, different thermal and optical properties of glazed facade were considered. Thermal comfort was analysed statistically, using a normal distribution of determined values. The following three criteria were established to find out the best solution:

- *criterion I* – the highest probability of the occurrence of neutral thermal sensation, which means the maximum density of probability for PMV index equal “0”, max. PMV(0),

- *criterion II* – the lowest variation in the perception of discomfort, which means the minimum standard deviation for a normal distribution of PPD index, min. σ (PPD),
- *criterion III* – the minimum number of people dissatisfied, namely the lowest average value of PPD index, min. PPD_{av}.

Workflow

The analysis algorithm was carried out for two workflows. First of them was developed for individual seasons and the second for the whole year.

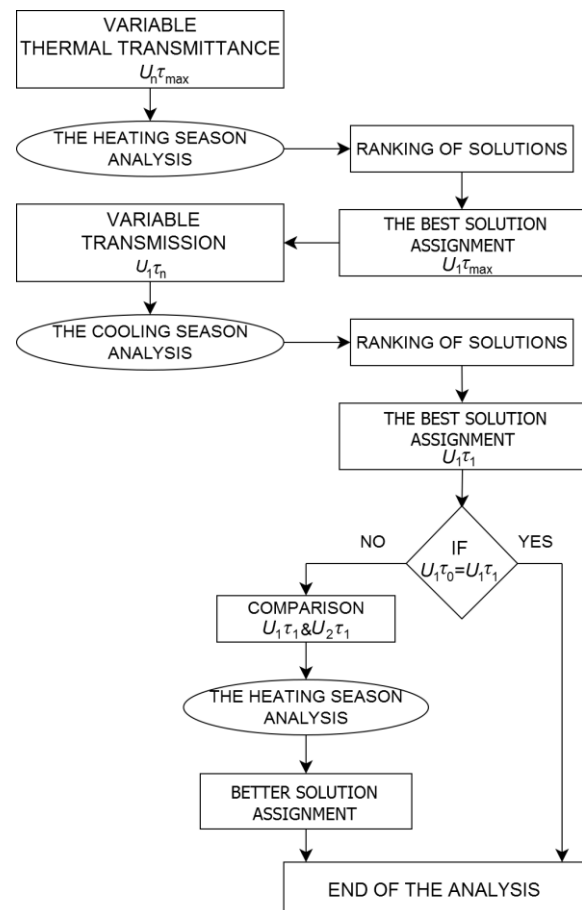


Figure 1 Workflow for individual seasons

The workflow presented in Figure 1 consists of three stages which are individually considered for heating and cooling seasons. At the first stage, various thermal transmittance values were analysed in the heating season. Based on the obtained results, the first ranking of solutions was carried out. The best solution was determined and marked as $U_1\tau_0$. In the next step, different transmission during cooling season was analysed. Just as at the earlier stage of the workflow, ranking of solutions was carried out by choosing the best one ($U_1\tau_1$). Subsequent stage was the comparison of the best solutions for the first and the second step of analysis. If they were identified as the same ($U_1\tau_0 = U_1\tau_1$), it would mean the end of analysis. Otherwise, the third stage of analysis should be performed for the heating season only. At that

stage, the first and second solution were compared in respect of thermal transmittance, assuming optical parameters selected in the second stage of analysis (e.g. $U_1\tau_1$ & $U_2\tau_1$). Final solution is determined on the basis of the last part of analysis. The procedure described above should be performed for both the *criterion I* and the *criterion II*.

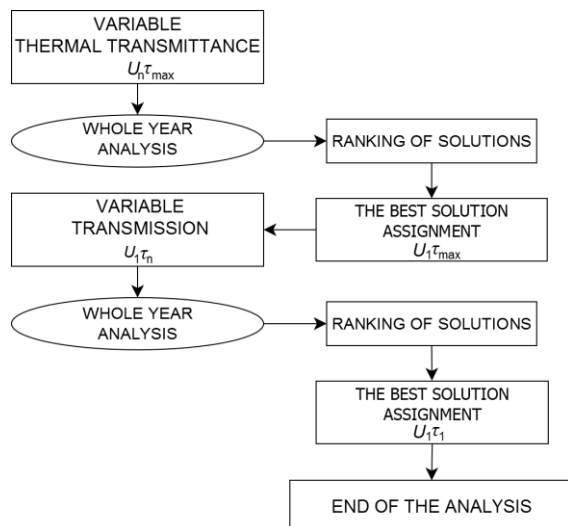


Figure 2 Workflow for the whole year

In an analogous way, the analysis was performed for the *criterion III*. As opposed to previous workflow, the first and second step was carried out for the whole year. Moreover, the end of analysis occurs after the second stage. Workflow for the *criterion III* is presented in Figure 2.

PROBLEM DEFINITION

Boundary conditions and thermal comfort

Two types of highly glazed buildings equipped with single and double skin facades were analysed and compared, taking into account thermal comfort parameters.

Due to this classification, five different values of thermal transmittance were considered in the first stage of the analysis. Three cases for double skin facade were denoted U1, U2, U3. For single facade it was UY and UX, respectively for double and triple glazing windows. Values of thermal transmittance assigned to individual cases are shown in Table 1.

Table 1
Values of thermal transmittance

PARTITION	THERMAL TRANSMITTANCE				
	DOUBLE SKIN FACADE			SINGLE SKIN FACADE	
	U1	U2	U3	UX	UY
External	5.5	5.5	2.8	0.7	1.4
Internal	2.8	1.4	1.4		

Different transmission values were considered in the second step of the analysis, from $\tau 1$ to $\tau 7$. Seven cases were analysed for double skin facade (from $\tau 1$ to $\tau 7$) and six for single skin facade (from $\tau 1$ to $\tau 6$). The exact values of transmission coefficients are given in Table 2.

Table 2
Analysed transmission

PARTITION	TRANSMISSION						
	$\tau 1$	$\tau 2$	$\tau 3$	$\tau 4$	$\tau 5$	$\tau 6$	$\tau 7$
External	0.7	0.6	0.5	0.4	0.3	0.2	0.2
Internal	0.7	0.7	0.7	0.7	0.7	0.7	0.2

The parameters required to determine the thermal comfort indexes adopted in the criteria for an office building, category II are presented in Table 3.

Table 3
Parameters of thermal comfort

Parameters	The heating season	The cooling season
Metabolic rate, [met]	1.2	1.2
Thermal insulation, [clo]	1.0	0.5
Air velocity, [m/s]	0.16	0.19

Climate analysis

Data of meteorological reference year WYEC2 “Weather Year for Energy Calculations, Version 2” was used for all simulations. In the first part of the work, the standard procedure (two workflows) was carried out for standard WYEC2, hereinafter referred to as WYEC2_0. Next, the same algorithm was performed for the modified WYEC2_1, WYEC2_2, and WYEC2_3. Modified weather data have different weights assigned to the various weather parameters, like global solar radiation or air velocity.

Due to thermal comfort, the most important of these parameters is solar global radiation. The comparison of solar global radiation for standard and modified WYEC2 is presented in Figure 4.

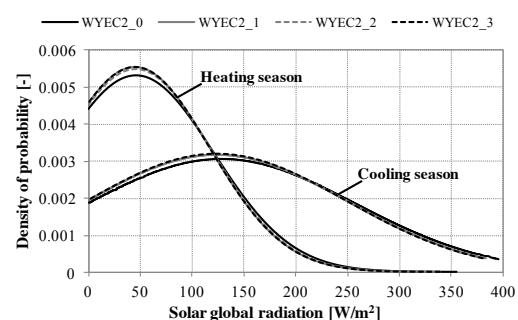


Figure 4 The normal distribution of global solar radiation for various weather data

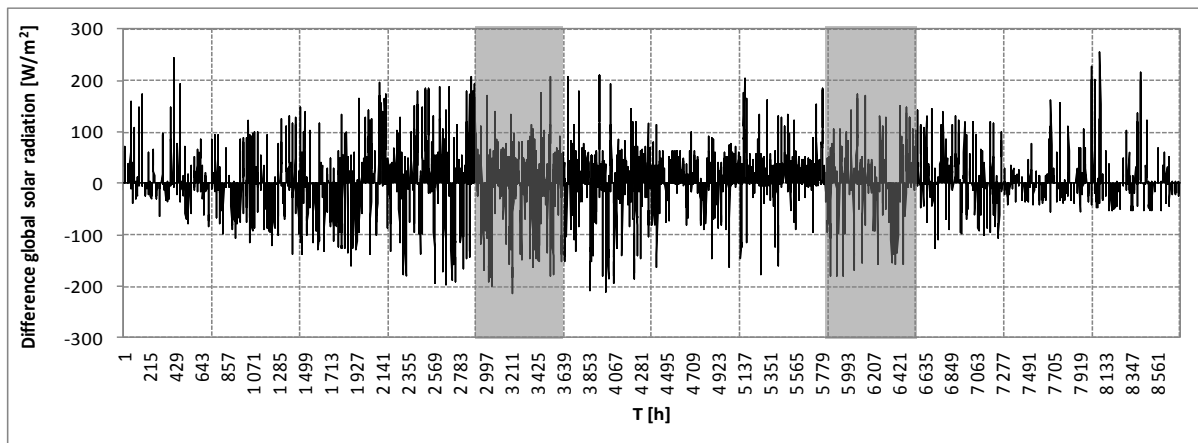


Figure 3 The difference global solar radiation for WYEC2_0 and WYEC2_1

Results displayed in Figure 4 show that global solar radiation for all modified weather data, both for the heating as well as for cooling season, is almost the same and very similar to standard WYEC2_0. Besides, monthly ratio presented in Table 4 shows that difference between these values is insignificant, from 0.83 to 1.11.

Table 4

Ratio of the global solar radiation between modified and standard WYEC2 for particular months

MONTH	WYEC2_1/ WYEC2_0	WYEC2_2/ WYEC2_0	WYEC2_3/ WYEC2_0
I	0.83	0.87	0.83
II	1.11	1.07	1.11
III	1.09	1.09	1.09
IV	0.96	0.96	0.96
VI	1.03	0.99	1.00
VII	1.00	1.00	1.01
VIII	0.90	0.91	0.90
X	0.92	1.01	0.92
XI	0.97	0.97	0.97
XII	0.88	0.88	0.88

However, more detailed analyses, with the hourly time step (Figure 3), show the substantial differences between the selected WYEC2_0 & WYEC2_1, reaching up to 250 W/m². Similar differences were also noticed for other types of weather data files.

CASE STUDY

The paper presents an analysis of the indoor thermal comfort for a single zone of an office building with glazing facade system. It was assumed that the test room is a landscape office classified into category II in consideration of estimation of temperature range and ventilation rate.

Due to the results obtained for May and September, it was assumed that this two months are not taken into account in the analysis. The heating season starts from 1st of October and ends on 30th of April, while the cooling season is from 1st of June to 31th of August. Further, analysis of PMV and PPD indexes was limited only to the period of the office occupancy, from Monday to Friday, 8.00 ÷ 16.00.

Geometry

Analysis was conducted for a vertical section of eight-storey building, located in the climatic zone of Central Europe. Glass façade starts on the second floor, and in the case of double skin façade, it finishes one meter above the building. Analysed landscape office, located on the fourth floor, has the following measurements, 8.0 × 6.0 × 2.7 m (width × depth × height), and adjacent facade zone 8.0 × 1.0 × 2.7 m respectively.

Operation

For the purpose of the analysis, it was assumed that double skin facade is naturally ventilated. Two cases of the air inlet and outlet opening were considered – different for the heating (fully closed) and cooling season (80% of opening for both inlet and outlet). Air flow in ESP- r can be model, using the nodal network method. The connection to the external environment was defined by two external nodes located at the appropriate heights above the ground, corresponding to the height of the inlet and outlet.

Authors assumed two ventilation air flow schemes due to the office occupancy. First scheme related to the presence of employees and the second applied to the absence of people. The total amount of air flow required during occupancy is $q_{tot1} = 0.0576 \text{ m}^3/\text{s}$. It was assumed that during the absence of the people total air flow decreased to the amount of $q_{tot2} = 0.0048 \text{ m}^3/\text{s}$.

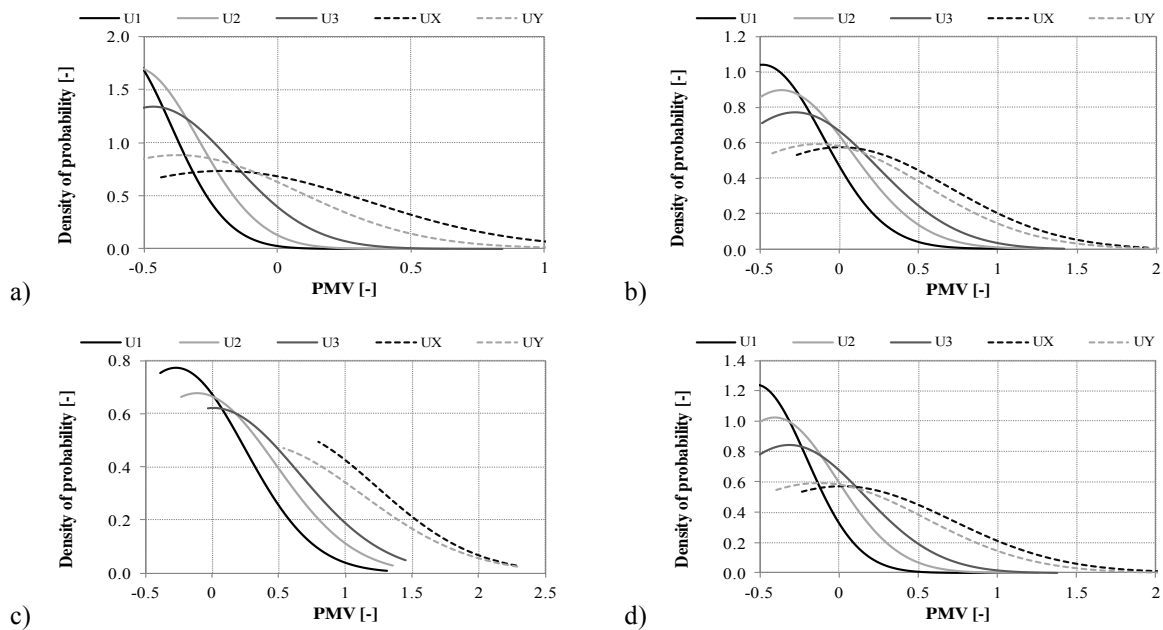


Figure 5 The normal distribution of PMV index for criterion I due to thermal transmittance for a) north, b) east, c) south and d) west oriented facade

Additionally, it was assumed that heat gains occurs only during the occupancy time. Total heat gains from one person is 100 W and additionally 120 W per one computer set. Under the assumption that for one person there was one computer and that three people worked in the office, the total internal heat gains equalled 660 W. On the other hand, during the absence of people, all internal heat gains were set to zero.

RESULTS FOR STANDARD WYEC2_0

According to the optimization procedure, around 600 simulations were performed for all cases considered in the analysis. All the results obtained are presented in the form of statistical analysis.

Results for criterion I and criterion II

Results for both, *criterion I* and *criterion II* were determined by the same workflow for individual seasons. The first stage of the analysis was to optimize the solution in terms of thermal insulation of the facade. U-value affects the amount of heat loss, which in the heating season is important to the thermal conditions in the analysed zone.

Solutions for *criterion I* were developed in consideration of the maximum density of probability for PMV index equal "0", max. PMV(0).

Normal distributions for all cardinal directions in terms of *criterion I* were presented in Figure 5.

Results for *criterion II* were determined due to the minimum standard deviation for a normal distribution of PPD index, min. σ (PPD).

Solutions arising due to *criterion II* for all orientations are shown in Table 5. The best solutions for each facade are indicated in bold.

Table 5
Values of standard deviation for a normal distribution of PPD index for criterion II due to analysis of thermal transmittance

	U1	U2	U3	UX	UY
N	4.17	3.77	3.78	4.70	4.37
E	4.72	4.61	5.11	9.38	8.62
S	5.60	6.42	8.00	14.15	16.73
W	4.61	4.34	4.46	9.65	8.97

The best solutions selected due to *criterion I* and *criterion II* are presented in Table 6

Table 6
The best solutions due to thermal transmittance

	N	E	S	W
<i>Criterion I</i>	UX	U3	U1	U3
<i>Criterion II</i>	U2	U2	U1	U2

Analysis of the best solutions taking into account thermal transmittance leads to the conclusion that thermal conditions for a building with double skin facade are more comfortable than for buildings with single skin facade.

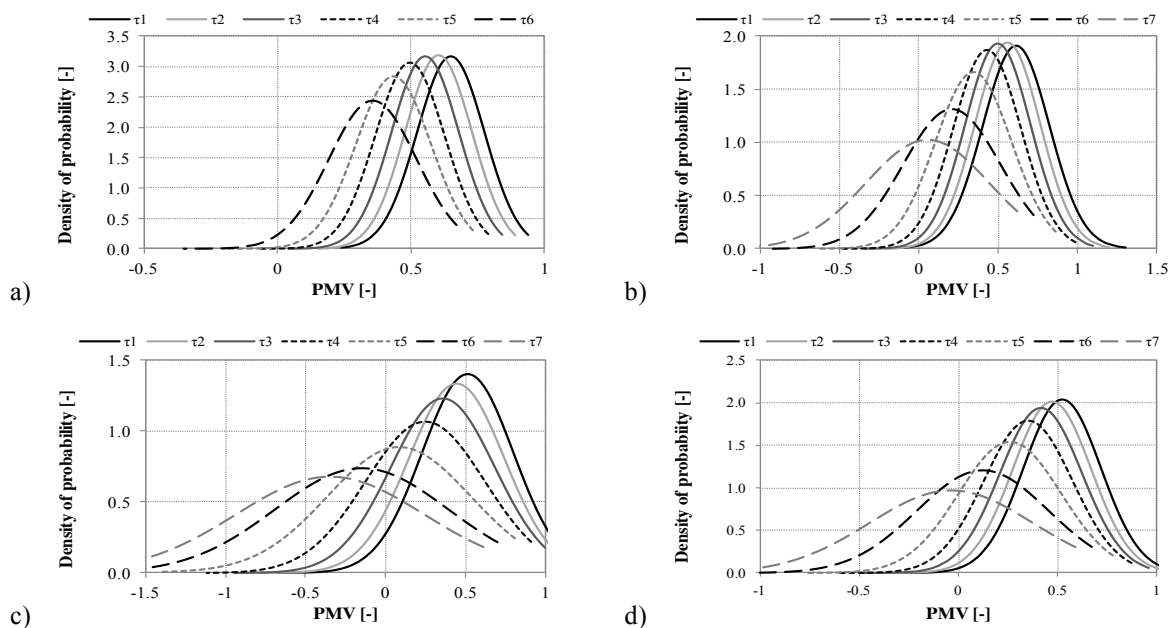


Figure 6 The normal distribution of PMV index for criterion I due to transmission for a) north, b) east, c) south and d) west oriented facade

In the second stage of optimization, seven or six (in the case of a single facade) different transmission τ values were analysed. This parameter has a significant effect on the solar heat gains and temperature (air and radiant) in the analysed room.

Normal distributions for all cardinal directions in terms of *criterion I* are presented in Figure 6.

Solutions obtained due to *criterion II* for all orientations are shown in Table 7. The best solutions for each facade are indicated in bold.

Table 7
Values of standard deviation for a normal distribution of PPD index for criterion II due to analysis of transmission

	τ_1	τ_2	τ_3	τ_4	τ_5	τ_6	τ_7
N	2.49	2.26	2.08	2.51	5.14	10.39	14.24
E	5.36	4.66	3.97	3.30	2.65	3.54	7.73
S	5.61	4.90	4.25	4.00	5.57	10.30	14.10
W	4.10	3.59	3.07	2.62	2.59	5.18	9.81

The best solutions selected due to *criterion I* and *criterion II* are shown in Table 8.

Table 8
The best solutions due to transmission

	N	E	S	W
<i>Criterion I</i>	UX τ_6	U3 τ_6	U1 τ_5	U3 τ_6
<i>Criterion II</i>	U2 τ_3	U2 τ_5	U1 τ_4	U2 τ_5

The best solutions in consideration of transmission were noticed for the medium value of τ (τ_3 - τ_6).

The third step of the analysis was to verify the correctness of previous results. For this purpose, comparison of the first and second solution, due to thermal transmittance, was conducted. Solar thermal transmittance values were assumed as the best from results of the second stage ($U_1\tau_1$ and $U_2\tau_1$).

The final solutions selected for *criterion I*, *criterion II*, and both: solar and thermal transmittance are presented in Table 9.

Table 9
Final best solutions for criterion I and criterion II

	N	E	S	W
<i>Criterion I</i>	UX τ_6	U3 τ_6	U2 τ_5	U3 τ_6
<i>Criterion II</i> min. σ (PPD)	3.47	3.51	4.03	3.41

After the third step of the analysis, only the best solutions for southern facade both for *criterion I* and *criterion II* had changed due to thermal transmittance from U1 to U2.

Results for criterion III

Results for *criterion III* were determined by the workflow for the whole year, taking onto account the lowest average value of PPD index (min. PPD_{av}). Optimization for criterion III was performed in an analogous way to the analysis of previous criteria. Firstly, the best solution due to thermal transmittance

for the whole year was developed. The results for this part of analysis are shown in Table 10.

Table 10
Minimum average value of PPD index for criterion III due to thermal transmittance

	U1	U2	U3	UX	UY
N	12.10	11.13	10.82	12.83	13.02
E	12.91	12.37	12.71	17.41	17.81
S	12.19	12.58	13.54	21.92	22.40
W	12.24	11.49	11.69	17.10	17.53

In the second step of optimization procedure, various transmission values for the whole year were analysed. Solutions determined for this part of analysis established the final solutions due to criterion III. The results for analysis of transmission are presented in Table 11.

Table 11
Minimum average value of PPD index for criterion III due to transmission

	τ_1	τ_2	τ_3	τ_4	τ_5	τ_6	τ_7
N	10.82	10.77	10.83	10.97	11.28	12.03	12.97
E	12.37	11.91	11.57	11.39	11.38	11.70	12.44
S	12.19	11.63	11.32	11.33	11.81	13.06	14.38
W	11.49	11.25	11.15	11.18	11.36	11.90	12.83

The final solutions selected for criterion III are shown in Table 12.

Table 12
The best solutions for criterion III

	N	E	S	W
Criterion III	U3 τ_2	U2 τ_5	U1 τ_3	U2 τ_3

All the best solutions in consideration of criterion III were determined for double skin facade and medium value of transmission.

RESULTS FOR DIFFERENT WEATHER DATA

In this section the comparison between the best solutions, obtained for various weather data is presented and discussed.

The best solutions, due to the criterion I and individual facade orientation, for modified weather data were the same (Table 13). Moreover, the normal distribution of them were very similar. The best solutions for standard WYEC2_0, with the exception of northern facade, were different than the best solutions for modified weather data.

Table 13
The best solutions for criterion I

	WYEC2_0	WYEC2_1	WYEC2_2	WYEC2_3
N	UX τ_6	UX τ_6	UX τ_6	UX τ_6
E	U3 τ_6	UY τ_6	UY τ_6	UY τ_6
S	U2 τ_5	U2 τ_6	U2 τ_6	U2 τ_6
W	U3 τ_6	UY τ_6	UY τ_6	UY τ_6

Further, the normal distribution of WYEC2_0 differed from others for south oriented facade (Figure 7). Similar differences were noticed for others also north oriented facade.

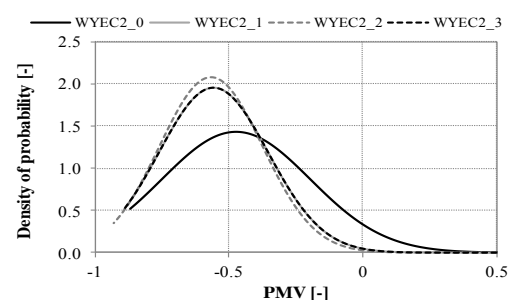


Figure 7 The normal distribution of PMV index for criterion I south oriented facade

More distinctions were noticed because of criterion II (Table 14). First of all, the best solutions for standard and modified WYEC2 were different, except for the similarity between WYEC2_0 and WYEC2_2 for the southern and western facade. Furthermore, only the results for WYEC2_1 and WYEC2_3 were the same, but it was caused by identical weather data for the heating season. The remaining best solutions for modified WYEC2 were different, except for the eastern facade. The greatest differences up to 11% were noticed for the western facade.

Table 14
The best solutions for criterion II due to the value of standard deviation of PPD index

	WYEC2_0	WYEC2_1	WYEC2_2	WYEC2_3
N	U2 τ_3	U2 τ_4	U3 τ_3	U2 τ_4
	3.47	3.44	3.79	3.44
E	U2 τ_5	U3 τ_6	U3 τ_6	U3 τ_6
	3.51	3.36	3.60	3.36
S	U2 τ_4	U2 τ_5	U2 τ_4	U2 τ_5
	4.03	3.79	4.13	3.79
W	U2 τ_5	U3 τ_5	U2 τ_5	U3 τ_5
	3.41	3.66	3.85	3.66

The differences in the selection of the best solution were also for criterion III. However, distinctions in

results were inconsiderable, the maximum up to 8% for the southern facade (Table 15).

Table 15

The best solutions for criterion III due to the value of average of PPD index

	WYEC2_0	WYEC2_1	WYEC2_2	WYEC2_3
N	U3 τ 2	U3 τ 1	U3 τ 1	U3 τ 1
	10.77	11.00	11.05	11.03
E	U2 τ 5	U2 τ 5	U2 τ 4	U2 τ 5
	11.38	11.57	11.61	11.65
S	U1 τ 3	U2 τ 5	U1 τ 3	U2 τ 5
	11.32	10.46	11.15	10.56
W	U2 τ 3	U2 τ 3	U2 τ 3	U2 τ 4
	11.15	11.34	11.39	11.44

CONCLUSION

Thermal comfort evaluation presented in this paper was performed due to three different criteria and various weather data. First of all, the results showed that the best solutions for individual criteria are different for the same building location (the same source data) but different WYEC files. Therefore, the choice of optimal criterion procedure significantly affects the selection of the optimal solution.

On the other hand, for zones with controlled indoor parameters (HVAC system), the effect of external weather conditions is unsubstantial, and thus uncomfortable conditions are avoided.

Analysis for standard WYEC2_0 leads to the conclusion that thermal conditions in a building with double skin facade are more comfortable than in a building with single skin facade.

Comparison of the optimal cases for different WYEC2 within the same criterion shows a lack of correlation. All the best solutions for *criterion I* were the same, but normal distributions for standard and modified WYEC2 were different. On the other hand, the optimal cases for *criterion II* and *criterion III* were diverse, while results of them were comparable.

Selection of final optimal solutions is uncertain and depends on the assumed meteorological database and the selection criteria.

Finally it can be concluded that the proposed method is very sensitive and difficult to be explicitly proposed for thermal comfort assessment in a building design stage.

ACKNOWLEDGEMENTS

Research work financed from the state budget funds in 2011 - 2013 as a research project (2059/B/T02/2011/40).

REFERENCES

- Arbab M., Finley J. J., 2010, Glass in Architecture, Int. J. of Applied Glass Science, 1 [1] 118–129.
- Cena K., Clark J. A. 1980, Bioengineering, thermal physiology and comfort, Wrocław TU Press.
- Citherlet S., Hand J., 2002, Assessing energy, lighting, room acoustics, occupant comfort and environmental impacts performance of building with a single simulation program, Building and Environment 37, 845-856.
- Clarke J.A., 2001, Energy Simulation in Building Design (2nd edition), Butterworth-Heinemann.
- 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.
- Djongyang N., Tchinda R., Njomo D., Thermal comfort: A review paper, 2010, Renewable and Sustainable Energy Reviews 14: 2626-2640.
- Fanger P. O.: Thermal comfort-analysis and applications in environmental engineering, Danish Technical Press, Copenhagen 1970.
- Heim D., Kieszkowski K., Shading devices designed to achieve the desired quality of internal daylight environment, PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 September 2006.
- Hensen J. L. M, Lamberts R., 2011, Building performance simulation for design and operation, Spon Press.
- Huckemann V., Kuchen E., Leao M., Leão E., 2010, Empirical thermal comfort evaluation of single and double skin façades, Building and Environment 45, 976-982.
- Hwang R.-L., Shu S.-Y., 2011, Building envelope regulations on thermal comfort in glass facade buildings and energy-saving potential for PMV-based comfort control, Building and Environment 46, 824-834.
- Lyons P., Arasteh D., Huizenga C., 2000, Window Performance for Human Thermal Comfort, ASHRAE Winter Meeting, Dallas, February 5-9.
- Nicol J. F., Humphreys M.A.: Adaptive thermal comfort and sustainable thermal standards for buildings, Energy and Buildings, vol. 34, 563-372, 2002.
- Olesen B.W., Parsons K.C.: Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730, Energy and Buildings, vol. 34, 537-548, 2002.
- Poirazis H., 2006, Double Skin Facades - A literature review, A report of IEA SHC Task 34 ECBCS Annex 43