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An analysis of influences of blinds and solar radiation on microclimate in office rooms during summer days: a pilot study

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Abstract. Windows are the only part of a building that can directly penetrate the solar radiation into the occupied space and thus the shading devices are needed to control the solar penetration. In the office buildings, they usually use external blinds and internal blinds to reduce heat gains during summer caused by sunlight as well as solar radiation. Therefore, these blinds are main part to maintain thermal comfort for office workers. The aim of this paper is to present results of measurements in four big office rooms in different situations of blinds application. Then, the influence of the internal and external blinds on the internal microclimate conditions inside the large offices during the hot summer days with high solar radiation will be evaluate. The offices floor area is from 43.3 m^2 to 59.5 m^2 and height 2.8 m. The experiments in this research were focused on measurement and evaluation of globe temperature, indoor air temperature and relative humidity at level of working place during several hot summer days. Comparison of the results of short-term measurements in a room with open blinds and closed blinds has shown the influence of the blinds on the reduction of indoor temperature. More significant was the effect of external aluminium blinds. Solar energies passing through the windows into the interior were 3,476 W without blind and 305 W in case of aluminium venetian external blinds. When the maximum outside temperature was 29.9 °C and office workers used blinds with natural ventilation, the maximum air temperatures in four rooms were from 27.2 °C to 28.5 °C, which exceeded maximum recommended temperature (28 °C). The external aluminium venetian blinds and internal fabric vertical blinds did not maintain thermal comfort inside the offices during all summer days, but it can help in reduction of energy consumption for air-conditioning.

Key words: air-temperature, glazed window, globe temperature, measurement.

INTRODUCTION

Building energy consumption is closely related to the lighting environment, according to daylighting. Daylighting is an important factor in determining indoor visual comfort, and affects user satisfaction and productivity (Edmonds & Greenup, 2006; Hirning et al., 2014). In addition, daylighting from windows can bring both positive and negative experience: access to view and daylight, but also glare and thermal discomfort (Boubekri & Boyer, 1992; Leather et al., 1998; Aries et al., 2010).

Glazed windows are the critical component of building envelope that influences highly on the building energy demand. In the summer when skylight is voluminous and the sun transverses in all directions, windows with properly designed shading introduce effectively exterior daylight to illuminate an interior space jointly with light from electric lamps including protecting building occupants from glare situation (Hirning et al., 2014).

People nowadays expect good natural lighting in workplaces especially as glazed facades have become more popular. However, among all components of the building envelope, these surfaces demonstrate the weakest thermal performance (Al Touma et al., 2016), at least five times weaker than the walls according to conservative building codes (The Saudi Building Code, Energy Conservation, 2007). In hot climates, their thermo-physical properties increase the space loads significantly, which outweighs its benefits even during cold seasons, and raise the occupants' sensation of thermal and visual discomforts and radiation asymmetry due to the exposure.

Some researchers have been conducted to study the impact of large surfaces that is useful for using natural lighting on the workshops (Cao & Kic, 2018). Those surfaces have a great influences to indoor temperature in the summer also to the heat balance in the winter.

The effects of adding shading devices, such as blinds, screens and shutters, to glazed surfaces and implementing control strategies have been widely studied. For instance, the effect of roller shutter placement on windows along with the implementation of shading and lighting control strategies were investigated (Gosselin & Chen, 2008).

The distribution of solar radiation as a function of the wavelength is called the solar spectrum, which consists of a continuous emission with some superimposed line structures. The Sun's total radiation output is approximately equivalent to that of a blackbody at 5,776 K. The solar spectrum is usually divided into three main parts: ultraviolet sunlight (2% of total solar radiation), visible solar radiation (47% of total solar radiation) and infrared solar radiation (51% of solar radiation).

When this total sunlight impact on the glazed window, it is divided according to the technical parameters of the windows, namely: reflection, absorption and transmission (Qiang, 2006; Mishchensko et al., 2015).

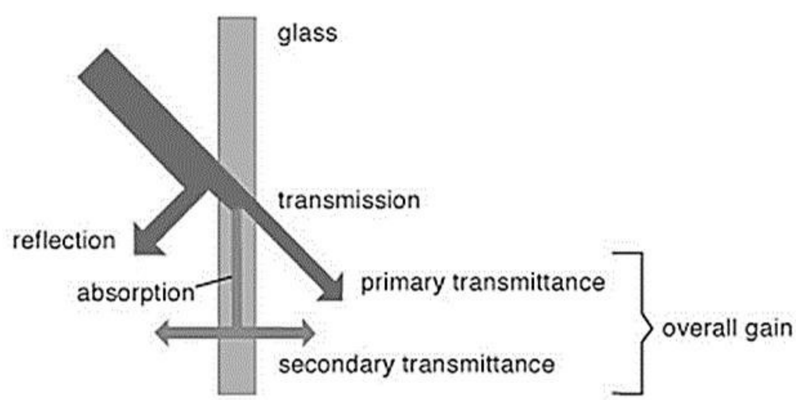

Figure 1. Sunlight impact on the glazed window (Alwetaishi, 2019).

The influence of the sunlight impact on the glazed window is indicated on the Fig. 1. The shine reflected by the window (reflection) is returned to the external area and it does not effect on the heating. The radiation that is absorbed by the window (absorption) increases its temperature. The radiation that is transmitted through window into an interior (transmission) heats up surface behind it. The proportion between all three components is determined by the angle of incidence and by the type of glazing.

According to the position in a building, the sun shading device can be classified as one of three types: internal, external and inter-pane (Fig. 2).

Internal sun shading devices (curtains, venetian blinds, vertical louvre blinds, roller blind etc.) have only a limited effect on reducing the heat load. They are usually adjustable and allow to the occupants in the rooms to regulate the amount of direct light entering their space. This type has mostly the form of horizontal or vertical blinds attached above the windows.

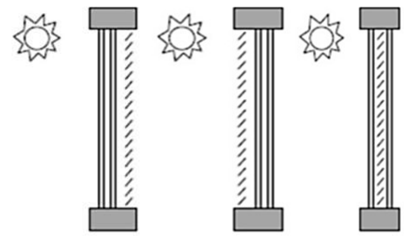

Figure 2. Sun shading devices: inside (left), outside (centre) and mid-pane (right).

External sun shading devices (vertical, horizontal and egg-crate) are considered better than internal. This type is more thermally efficient as it controls the amount of radiation entering the building externally (Kumar, 2016).

Internal and external blinds are used in different type of buildings and rooms, e.g. family houses, shops, offices, restaurants etc. where is necessary to reduce the summer heat load and cerate the suitable microclimate for people. The use of blinds is one of the form of so called passive system of air-conditioning, which could reduce the consumption of energy for cooling of the air.

The main objective of this study is to evaluate the influence of the internal and external blinds on the internal microclimate conditions inside the large offices during the hot summer days with high solar radiation.

Table 1. Work class according to the average total energy output of people (M)

Work class	Work type	M, W m^{-2}
I	Seated work with minimal whole body movement activity, office administrative work, control activity in control rooms, work with PC, laboratory work, compilation or sorting small light object etc.	≤ 80

The suitable conditions which are recommended for office workers with computer in the office rooms are presented in the Government decree no. 361/2007 Coll. (data summarized in the Table 1). The recommended temperature should be from 20°C to 28°C and recommended relative humidity should be from 30% to 70% (data summarized in the Table 2).

Table 2. Microclimate requirement (operating temperature t, relative humidity RH and airflow velocity v_a) according to work classes and total energy output of people (M)

Work	M	t_{min}	t_{max}	v_a	RH
class	W.m^{-2}	°C	°C	m.s^{-1}	%
I	≤ 80	20	28	0.1 to 0.2	30 to 70

The results of this research will show and evaluate the thermal comfort for office workers in four big office rooms in different situations of blinds application.

MATERIALS AND METHODS

For this research has been selected a building, which has large windows equipped with internal and external blinds. This allows to study the effect of blinds on reducing the heat load in the summer. Four large rooms on the top floor of the building were selected for the measurements (Fig. 3), as the windows are not shaded by trees or other structures. Six office workers with personal computers work in each room. No room is equipped with air conditioning. General related construction information of four rooms are shown in the Table 3.

Table 3. Main construction parameters of the four measured rooms

Rooms	Floor area	Glazed area	Type of blind
-	m^2	m^2	-
R1	59.5	19.1	External
R2	43.3	6.8	External
R3	58.8	18.9	Internal
R4	54.2	7.1	Internal

The suitable period for this research and measurements was since June 25th to July 04th 2018, during the hot summer days.

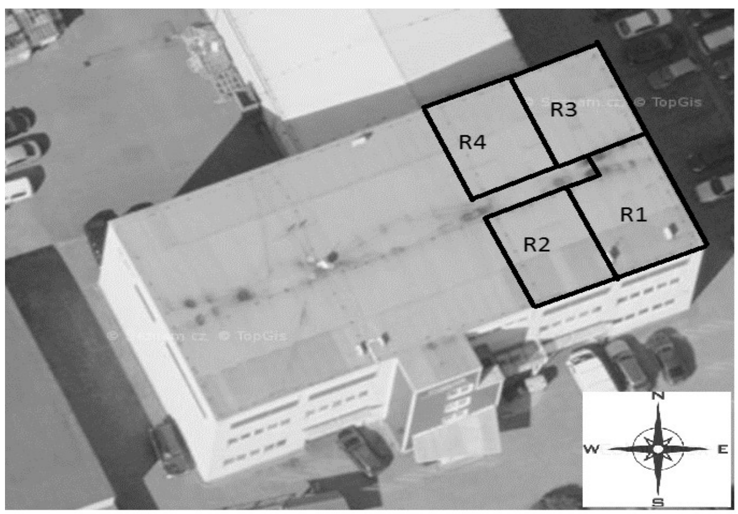

Figure 3. Orientation of the relative position of the building and four rooms (R1, R2, R3, R4), where N is the north; S is the south; W is west; E is east.

Room 1 (R1) and room 3 (R3) have two walls with glazed windows, room 2 (R2) and room 4 (R4) have only one wall with glazed windows. Four rooms have the same height (2.8 m) but have different internal area. R1 and R2 have aluminium venetian blinds which are installed externally, R1 and R2 have fabric vertical blinds which are installed internally. This room layout allows to measure one room on the same side of the building with shaded windows and the other room unshaded with the same intensity of external sunshine. This enables to assess the effect of blinds on internal conditions.

The first measurements (long-time measurements) were carried out continuously during the working days (from Monday to Friday, working hours since 7 a.m. till 5 p.m.). The indoor conditions were influenced by the opening the windows and regulation of blinds by the persons inside the offices. This arrangement of measurement enable to evaluate the effect of blinds in the real office operation.

The second (short-time measurements) were carried out during the daytime of the weekend (since 8 a.m. till 5 p.m.) when the rooms were empty without persons and without ventilation (closed windows). It enables to measure more directly and exactly the influence of the blinds on the indoor conditions.

The information about the measuring conditions of four rooms are in Table 4.

Table 4. Measuring conditions during the long-time and short-time measurements

Long-time measurements				
Rooms	Instruments	Period	Type of blinds	Use of blinds
R1, R2	Comet System ZTH65	Continuously Monday to Friday	External	Individual by people
R3, R4	Comet System ZTH65	Continuously Monday to Friday	Internal	Individual by people
Short-time measurements				
R1	Almemo 2690	Saturday	External	Opened
R2	Almemo 2590	Saturday	External	Closed
R3	Almemo 2690	Sunday	Internal	Opened
R4	Almemo 2590	Sunday	Internal	Closed

During the working days, office workers used blinds and natural ventilation. Air temperatures and relative humidity were measured by data loggers Comet System ZTH65 inside the offices with registration at intervals of 15 minutes during one week (long-time measurement). Parameters of ZTH65 are: temperature operative range –30 to + 70 °C with accuracy ± 0.4 °C and operative range of relative humidity 5–95% with accuracy ± 2.5%.

At the weekend, R1 and R2 were continuously measured on Saturday, R3 and R4 were measured on Sunday by globe temperature which includes the combined effect of radiation, air temperature and air velocity (measured by globe thermometer FPA 805 GTS with operative range from –50 to +200 °C with accuracy ± 0.1 °C and diameter of 0.15 m) together with temperature and humidity of surrounding air measured by sensor FHA 646–21 including temperature sensor NTC type N with operative range from –30 to +100 °C with accuracy ± 0.1 °C, and air humidity by capacitive sensor with operative range from 5 to 98% with accuracy ± 2%. All these data were stored at intervals of one minute to measuring instrument ALMEMO 2590 and ALMEMO 2690 during approximately nine hours (short-time measurement).

Effect of combinations of temperature and relative humidity is included in the THI (Sleger & Neuberger, 2006; Vladut, 2011). According to (Zejdova et al., 2014) the THI is determined by the equation (1). Calculation of the BGHI is based on the results from short-time measurements with the use of black globe temperature instead off dry bulb temperature, according to the Eq. (2).

$$THI = 0.8 \cdot t_i + \frac{(t_i - 14.4) \cdot RH_i}{100} + 46.4 \qquad (1)$$

where THI – temperature-humidity index, -; t_i – internal temperature of air, °C; RH_i – internal relative humidity of air, %.

$$BGHI = 0.8 \cdot t_g + \frac{(t_i - 14.4) \cdot RH_i}{100} + 46.4 \qquad (2)$$

where *BGHI* – black globe-humidity index, -; t_g – globe temperature, °C.

For evaluation of THI are usually used the following limit values. If THI ≤ 65 it means comfort state; if THI is from 66 to 79 it means alert state, prolonged exposure occurs fatigue; and if THI ≥ 80 it means discomfort, if THI ≥ 84 it is dangerous, heat stress is highly probable if the activity continues. BGHI is widely used index to describe the heat stress, and it is also a key indicator of the environmental conditions of stress, as it includes not only air temperature, but also the influence of radiation measured by globe thermometer.

There was also measured and evaluated illumination in the four rooms by using daylight factor. The different translucent area of windows resulted in different daylight factors, which were measured by lux meter TECPEL 536. The daylight factor is visual and light condition in interior. It shows the quantitative criterion of luminous state of the environment. The daylight can be calculated according to the Eq. (3).

$$e = \frac{E_m}{E_H} \cdot 100 \qquad (3)$$

where e – daylight factor, %; E_m – illumination of the given plane in the interior, lx; E_H – simultaneous unshadowed external horizontal illuminance, lx.

Total solar energy transmittance with protection against sunlight is calculated according to the equation:

$$g_{total} = F_c \cdot g \qquad (4)$$

where g_{total} – total solar energy transmittance with protection against sunlight; F_c – reduction factor (according to DIN 4108). The value of this coefficient is between 0 and 1 (the value is 1 when is not protection against sunlight); g – solar energy transmission factor of window that is determined by the manufacturer of window.

The obtained results of air temperature and relative humidity as well as the daylight measurements were processed by Excel software and verified by statistical software Statistica 12 *(ANOVA* and *TUKEY HSD Test*) to recognise if the differences are significant. Different superscript letters (*a, b, c*) in common are significantly different from each other in the columns of the tables *(ANOVA; Tukey HSD Test; P ≤ 0.05)*, e.g. if there are the same superscript letters in the columns (office R1, R2, R3 and R4) it means the differences between the values in rooms are not statistically significant at the significance level of *0.05*.

RESULTS AND DISCUSSION

The main objective of this article is a presentation of measured results of main microclimate parameters in office rooms and comparison of obtained results with values recommended in relevant standards. Based on the measurement results the influence of blinds to the main microclimate is evaluated.

The results of long-time measurement of temperature and relative humidity of the air in four office rooms are presented in Table 5.

Table 5. Average values and standard deviation of the air temperature t, relative humidity RH and temperature-humidity index THI in four office rooms and outside in meteorological station during the long-time measurements. Different letters (*a, b, c*) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test*; *P≤ 0.05*) between the conditions in the rooms

Place of measurement	t	RH	THI
-	°C ± SD	% ± SD	-
External	18.9 ± 3.3	69.6 ± 14.2	64.1 ± 4.3
R1	24.8 ± 1.1^{a}	45.5 ± 5.1^{a}	70.9 ± 1.2^{a}
R2	$25.0 \pm 0.9^{a, b}$	$45.2 \pm 4{,}8^{a}$	$71.2 \pm 1.0^{a, b}$
R3	25.4 ± 1.1^{c}	44.2 ± 5.4^{a}	71.5 ± 1.2^{b}
R4	$25.2 \pm 1.0^{b, c}$	44.3 ± 5.3^{a}	71.3 ± 1.0^{b}

SD – Standard deviation.

Working hours in days are usually from 7 a.m. till 5 p.m., which is the time when the microclimate was evaluated. This period includes maximum air temperatures and minimum relative humidity. According to the Government decree no. 361/2007 Coll. for work with computer in the office room, the recommended temperature is from 20 °C to 28 °C and recommended relative humidity is from 30% to 70%. The indoor conditions are influenced by the activity of people inside (different position of blinds, different ventilation etc.), therefore, the comparison and statistical evaluation of microclimate common for all four rooms.

The best conditions were in room R1, but there were not significantly different air temperatures in rooms R1 and R2 with external blinds, which were lower than in the rooms with internal blinds R3 and R4. The difference between the temperatures in rooms R3 and R4 was not significant. There was even not significant difference between the temperatures in rooms R2 and R4. It can be explain by different activity of people inside.

Internal relative humidity of air was in the recommended range, significantly lower than external as the internal temperature was higher. There were not significant differences between the rooms. The measured results show that the relative humidity is in the range of recommended values, however, the air temperatures are sometimes higher than recommendation. It means that this way do not maintain thermal comfort inside the rooms for all office workers during their work in the office, they need to use air conditioning to reduce air temperature.

Regarding the influences of using blinds, maximum air temperature in the room R1 (28.0 °C) and R2 (27.2 °C) were not exceed maximal recommended temperature but and in the room R3 (28.5 °C) and R4 (28.3 °C) were exceed maximal recommended temperature. The results show that, the use of external venetian blinds was useful in this building, it contributed to reduce air temperature.

The temperature-humidity index THI is from 70.9 to 71.3, it means alert state, prolonged exposure occurs fatigue. There were better conditions inside the rooms with external blinds (R1 and R2), the difference of THI in comparison to rooms with internal blinds was not big, nevertheless significant between room R1 and others.

The course for representative of the air temperature and relative humidity of air in four office rooms and outside during 24 hours (from Monday morning to Tuesday morning) of working day is in the Figs 4 and 5.

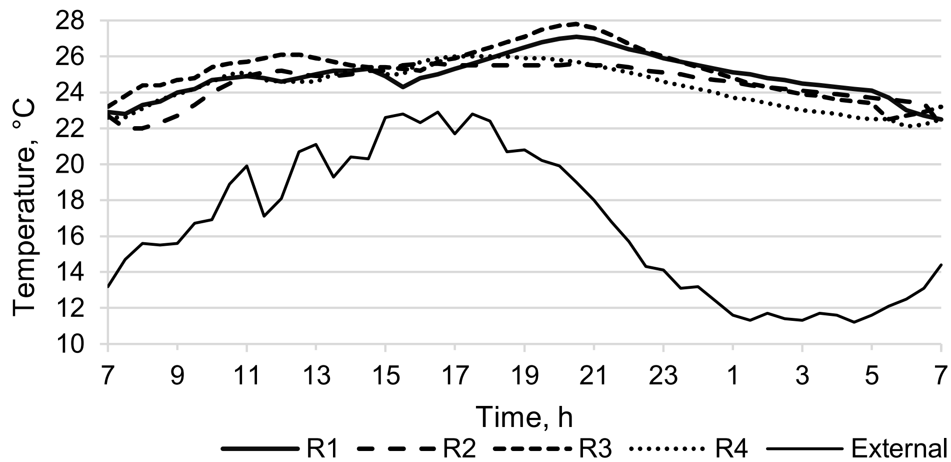

Figure 4. The course for representative of the air temperature outside and inside the rooms R1, R2, R3 and R4 during 24 hours of working day (on Monday).

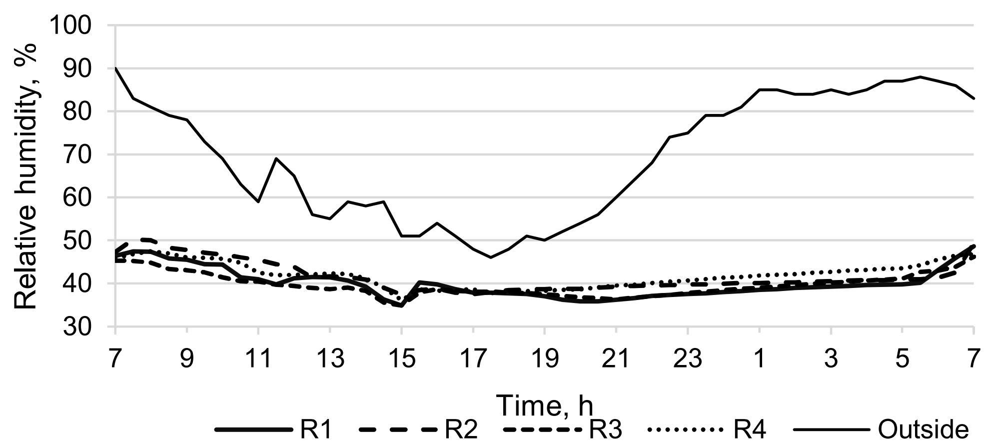

Figure 5. The course for representative of the air relative humidity outside and inside the rooms R1, R2, R3 and R4 during 24 hours of working day (on Monday).

The courses of air temperature and relative humidity in four rooms during day were repeated similarly every day from Monday to Friday. It show that the temperature in room R3 was almost the highest during day, the temperature in room R2 was the lowest. However the difference was not high in comparison with others. It means that the external venetian blinds decrease air temperature more than using fabric vertical blinds, but the difference and efficiency was not much during working periods when the natural ventilation is used. The highest temperature in four rooms was in period time from 7 p.m. to 9 p.m. The reason is thermal accumulation in the building walls during the sun radiation, and as these rooms were not ventilated because of the closed windows. Recommended maximum relative humidity 70% was not exceeded in all rooms.

In the short-time measurements, air temperature and relative humidity were measured to evaluate influences of radiation when rooms were empty, closed and ventilation was not active. The blinds of room R1 and R3 were opened to receive natural light. Average values and standard deviation of the external air temperature, globe temperature, internal air temperature, relative humidity, temperature-humidity index and black globe-humidity index during the short-time measurements are presented in Table 6. The statistics is used for separated comparison of indoor conditions of rooms equipped by the same type of blinds (external or internal) which are opened in one room and closed in the second one.

Table 6. Average values and standard deviation of globe temperature t_g, air temperature t, relative humidity RH, temperature-humidity index THI and black globe-humidity index BGHI in four office rooms and outside in meteorological station during the short-time measurements on Saturday and on Sunday with corresponding situation of blinds. Different letters (*a, b*) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test*; *P≤ 0.05*) between the conditions in the rooms

Place of measurement	Situation of blinds	t_g °C ± SD	t °C ± SD	RH % ± SD	THI % ± SD	BGHI % ± SD
Saturday	External	-	19.8 ± 1.6	43.1 ± 5.4	64.4 ± 1.8	-
R1	Opened	28.5 ± 1.0^{a}	28.2 ± 0.6^{a}	35.4 ± 1.4^{a}	73.8 ± 0.7^{a}	74.1 ± 1.2^{a}
R2	Closed	26.0 ± 0.4^{b}	25.8 ± 0.4^{b}	48.1 ± 1.2^{b}	72.5 ± 0.3^{b}	72.7 ± 0.4^{b}
Sunday	External	-	19.1 ± 1.6	40.9 ± 4.1	63.5 ± 1.7	-
R3	Opened	27.4 ± 0.6^{a}	27.3 ± 0.6^{a}	35.5 ± 1.0^{a}	72.8 ± 0.6^{a}	72.9 ± 0.6^{a}
R4	Closed	26.0 ± 0.7^{b}	25.8 ± 0.7^{b}	41.6 ± 1.0^{b}	71.7 ± 0.7^{b}	71.9 ± 0.7^{a}

SD – Standard deviation.

Window view with external aluminium venetian blind when the room R1 was opened (in left photo) and the room R2 was closed (in right photo) is shown in Fig. 6. Similarly, Fig. 7 is a photograph of the internal fabric vertical blind when the room R3 was opened (in the left photo) and the room R4 was closed (in the right photo).

Figure 6. Situation of external aluminium venetian blind when the room R1 was opened (in left photo) and the room R2 was closed (in right photo).

Figure 7. Situation of internal fabric vertical blind when the room R3 was opened (in left photo) and the room R4 was closed (in right photo).

The short time measurements give better idea about the influence of blinds. From the measured results it is evident the negative effect of radiation, which increased the globe temperatures in all rooms. When the external blinds were not used, air temperature in room was higher (about 2.5 °C) in comparison with using blinds. Moreover, maximum air temperature in this case exceed maximum recommended temperature (28 °C) and this negative effect makes thermal discomfort for office workers. We can use this results to calculate power or energy for air conditioning to maintain better thermal comfort inside the room. The differences between the air temperature, globe temperature, relative humidity, THI and BGHI in rooms with opened and closed blinds are in all cases statistically significant (Table 6).

The higher air temperatures resulted in higher THI, which was from 71.7 to 73.8, it means alert state, prolonged exposure occurs fatigue and this effect of solar radiation is even more obvious from the BGHI which was from 71.9 to 74.1.

The use of external or internal blinds contributes to reduce the impact of solar radiation on the indoor thermal comfort and reduces the inside temperature. However, the artificial lighting must be used. The comparison of average measured illuminance and daylight factors in the office rooms R1 and R3 are presented in Table 7.

Table 7. Results of measurement of the illuminance and calculated daylight factor e in two office rooms R1, R3 during the short time with the area of glazed windows. The same letter (*a*) in the superscript is the sign that there is not high significant difference (*ANOVA; Tukey HSD Test; P≤ 0.05*) between the daylight factors in the rooms

Place of measurement	Area ofwindows	Average measured illuminance	Daylight factor e
	m^2	lx ± SD	% ± SD
R1	19.1	3,188 ± 3,684	9.67 ± 11.16[a]
R3	18.9	1,632 ± 1,590	4.53 ± 4.41[a]

The average daylight factor e = 9.67% in the room R1 was bigger than e = 4.53% in the R3. The difference between the daylight factors was evaluated statistically and surprisingly the difference was not significant at the significance level of 0.05. It can be explained by the large standard deviations of the measured values of illuminance. According to the visual activity class IV in both office rooms minimum demanded daylight factor is 1.5%. The room R1 has average daylight factor e bigger which is caused by the orientation of this room (see the Fig. 3).

We calculated solar energy through the window into the interior in period time of short measurement following equation (2). We also used values global solar radiation, reduction factor F_c of blinds and solar energy transmission factor of glass (g = 0.65). All values and obtained results are showed in Table 8.

Table 8. Solar energy through the window into four rooms in time period of short measurement.

Room	Type of blinds	F_c	g_{total}	Global radiation	Solar energy through into the interior
		-	-	W m^{-2}	W
R1	Without blind	1.0	0.65	280	3,476
R2	Aluminium venetian external	0.25	0.16	280	304
R3	Without blind	1.0	0.65	235	2,887
R4	Fabric vertical internal	0.5	0.33	235	550

When the room was not covered by blinds, the solar energy through the window into the interior was very high (in room R1 and R3) in comparison to room that was covered by blinds (room R2 and R4). This solar energy makes increase air temperature in the rooms. Therefore, the temperature in the room R1 and R3 is higher than in the room R2 and R4. The use of aluminium venetian external is more effective than fabric vertical internal. Therefore it can be said once more that the use of blinds for glazed windows helps to improve indoor thermal comfort of the internal microclimate.

CONCLUSIONS

During working days, relative humidity in all measured rooms were in the range of recommended value. When index THI was used to evaluate effect of combinations of temperature and relative humidity, internal climate conditions in four rooms were not in comfort state but in alert state, prolonged exposure can occur fatigue. The reduction of inside air temperature is needed.

The external aluminium venetian blinds maintained thermal comfort inside the rooms (R1 and R2) for office workers during their work in the office in summer, but internal fabric vertical blinds did not, air conditioning is needed to reduce the air temperature.

Concerning the influences of blinds during the working periods, the use of external venetian blinds only slightly contributes to reduce air temperature in comparison with internal blinds. Without ventilation and without external blinds the air temperature was higher (about 2.5 °C) in room in comparison with the use of blinds. Obtained results of measurement inside the tested rooms can be useful for calculation of power for air conditioning to maintain better thermal comfort inside the room.

The position and orientation of building and rooms are important as they influence the radiation and light from the sunlight and thus effect indoor microclimatic conditions. Blinds can help to reduce slightly the inside air temperature and reduce the consumption of energy for cooling, but there is reduced also natural daylight therefore it is necessary to use the artificial illumination.

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