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Research paper

Analysis of lighting on exterior scaffoldings at different times of day

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Abstract: Lighting of the workplaces has a large impact on safety, proper vision comfort and visual efficiency. The aim of this article is to present an analysis of the lighting of the workplaces of people working on scaffoldings. The researches were carried out on 23 frame-type facade scaffoldings. The scaffoldings were examined from March to October 2017. Due to the specificity of works performed on scaffoldings, the researches were carried out in accordance with an individually adapted research program. The study analyzed the illuminance at particular points and variability in the lighting uniformity in a given workspace. Analysis of the obtained results showed a large variability in illuminance in workplaces of people working on scaffoldings. The measured illuminance levels in the workspaces on the one hand were higher than the minimum illuminance levels defined by the construction site standards, but on the other hand, illuminance levels that may dazzle the employees were also recorded. The luminous intensity depended on the season, time of day, location of the scaffolding, as well as the presence of a protective net installed on the scaffolding, which reduced the occurrence of values that could lead to situations in which the worker could be dazzled. The protective net installed on the scaffolding also reduces the differences in lighting in the scaffolding workspace, improving the lighting conditions of the workplaces.

Keywords: construction sites workers, illuminance, lighting uniformity, scaffoldings

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1. Introduction

People working on the construction site should be able to execute entrusted tasks in the most comfortable conditions possible which ensure the appropriate level of safety, which is significantly affected by the appropriate lighting in the workplaces. The construction site is one of the places where the risk of accidents, especially fatal ones, cannot be ignored. Only in Poland, in 2018, 5202 accidents at work were recorded, in which 5247 people were injured, and 48 of them died [1, 2]. Falls from heights account for most accidents on construction sites [3]. Most often, an accident occurs as a result of a series of events. There are many causes of an accident, for example, organizational, human or technical reasons [4–7]. In the work [8], on the basis of the analysis of accident protocols involving construction scaffolding, submitted by the National Labor Inspectorate, 1132 causes of accidents were identified, among which organizational causes constituted 48%, human – 27.4% and technical – 24.6%. On the other hand, an analysis of 206 fatal accidents in Malaysia and the USA showed that the main cause of falls from height was the lack of effective management [9]. However, in the work [10], as a result of the analysis of falls from height on the construction site, it was found that the most common cause was the lack of guard rails.

Human errors arise as a result of both inappropriate human behavior and psychophysical state [7]. The employee's psychological ill-health may be caused by, among others, work in an inconvenient (burdensome) environment – too high noise level, inadequate lighting or too high or low air temperature.

The sun is an unlimited source of energy that is transferred to the earth's surface by radiation. Part of the energy of solar radiation reaches the globe and amounts to approximately 1.9×10^{17} W [11]. The vast majority of solar radiation is in the wavelength range of 0.3–1.5 µm, and the visible radiation is in the range between 0.38 and 0.78 µm [11]. Poland is located in the temperate climate zone between 49° and 54.5° N. The solar radiation energy flux density here is approx. 1 kWh/m^2 year. The annual sum of sunshine duration, e.g. for Warsaw, in 2017 was 1 350.7 hours, in 2018 – 1 749.7 hours and in 2019 – 1 651.2 hours [12]. The angle of incidence of sunlight on the vertical surface (slope of the surface to the horizon 90°) can be calculated from the formula [13]:

$$\cos\theta = -\sin\delta \cdot \cos\varphi \cdot \sin\varphi \cdot \cos\alpha + \cos\delta \cdot \sin\varphi \cdot \cos\alpha \cdot \cos\omega + \cos\delta \cdot \sin\alpha \cdot \sin\omega \tag{1.1}$$

where: φ – latitude, α – solar azimuth, ω – hour angle, δ – solar declination – the angle of incidence of sunlight on equatorial plane calculated from the formula [5]:

$$\delta = 23.45 \sin\left(360\frac{284+n}{365}\right) \tag{1.2}$$

where: n – next day of the year e.g. for January 1, $n = 1$.

In the literature, can be found on lighting outdoor spaces with artificial light or in combination with natural light, however, there are few works on lighting with daylight. Among analyzed were, among many, lighting of construction sites [14, 15], streets [16–20], pedestrian and bicycle paths [21], basketball courts [22] and factory outdoor lighting [23].

In the study there is also an analysis of 187 accidents involving construction scaffoldings in the years 2010–2017 in the following voivodeships: Dolnośląskie, Lubelskie, Łódzkie, Mazowieckie and Wielkopolskie, based on accident reports provided by the National Labor Inspectorate. A small number of protocols contain information on the climatic conditions that prevailed at the time of the accident on the construction site. As far as lighting is concerned, there is no such information.

On the other hand, when analyzing the Statistical Accident Card [24] in the harmful event entry – the effects of radiation, noise, light and pressure are marked with one code. Therefore, it is not possible to indicate whether the accident occurred as a result of inadequate lighting.

This may prove that the impact of the external environment, including natural or even artificial lighting, on the probability of an accident to happen is underestimated. Workers do not notice the dangers connected with the climate. At a time of global warming and an increase in the number of sunny days, it is becoming more and more important to consider climate parameters in the assessment of the causes of accidents. The purpose of this article is to draw attention to the possibility of an accident occurring as a result of unfavorable lighting conditions. During the research, the scaffolding was lit only with daylight, therefore in this article lighting of workplaces with artificial light was not analyzed.

2. Regulations

Proper lighting of workplaces should ensure safety, proper visual comfort, visual efficiency, and allow to properly execute the entrusted tasks in difficult conditions also over an extended period of time. The basic parameters describing the lighting of workplaces include: luminance distribution, illuminance, glare, light directivity, color rendering, the color of light and flickering [25]. When considering daylight-lit workplaces, there are several worth attention. Correct luminance distribution affects the correct visual acuity, contrast sensitivity and efficiency of the ocular functions as well as comfort in the field of vision. It is also important to prevent sudden changes in luminance.

The PN-EN 12464-2:2014-05 standard specifies the minimum values of operational illuminance in the space where the task is executed, which for construction sites should be greater than, e.g.: 50 lx for the zone of construction, transport, storage and additional tasks, 100 lx for workplaces where elements of structures are assembled or light reinforcement works are done, 200 lux for workplaces where connecting elements are made. It should also be remembered to provide the appropriate illuminance in the surrounding spaces, which should be related to the illuminance of the space where the task is executed. The illuminance in the surrounding space may be lower than in the space where the task is executed, but not lower than the values specified in the standard, e.g. for the workspace where structural elements are assembled, the minimum illuminance should be not less than 20 lux. Significant changes in the intensity in the surrounding space may cause some visual stress. Illumination in the workspace and the space around the workspace should also be as uniform as possible. The standard specifies the requirements for the uniformity of lighting, which depend on the type of work performed. In case of construction sites and works in the construction zone, or during the assembly of structural elements, the uniformity of lighting in the space where the work is done should not be lower than. 0.4, while in case of making connecting elements, not lower than 0.5. Another parameter that should be taken into account is an attempt to avoid dazzling, which may result from the presence of bright surfaces in the field of vision, as well as the reflection of light from shiny surfaces. Dazzling resulting from the presence of bright surfaces may be perceived as unpleasant or disturbing dazzle.

3. Methods

3.1. Researches on scaffoldings

The tests were carried out on 23 frame-type, facade scaffoldings outside the buildings. The scaffoldings were located in 6 voivodships: Mazowieckie, Wielkopolskie, Pomorskie, Opolskie, Kujawsko-Pomorskie, and Małopolskie. List of scaffoldings along with the month in which the tests were carried out (Month), width (Width), maximum height (Height), the surface of the scaffolding facade (Area), the number of tested spaces located on the scaffoldings (Na) and the number of illuminance measurements (N_{Ep}) during the week are in Table 1. In addition, the table includes the presence of the net on the scaffolding (Net) and the position of the scaffolding in relation to the cardinal points (Direction). The scaffoldings were tested from March to October 2017. Due to the specificity of works performed on scaffoldings, the tests were carried out in accordance with an individually adapted research program. Measurements on each scaffolding were carried out for five days of the week at three times of day and were adapted to the work of the majority of workers on the construction sites. The first measurement was taken from 8 a.m., the second from 11 a.m. and the third from 2 p.m. Each day and at each time of day the measurements were taken in a minimum of three and maximum of twelve scaffolding workspaces. The number of measured spaces depended on the width and height of the scaffolding and availability. In the vertical direction, the tests were performed on 1, 2 or 3 levels of decks. The number of tested spaces in the horizontal direction was from 1 to 4, in the vertical direction from 2 to 3 [26]. The scaffolding diagram with the location of the tested spaces is shown in Fig. 1 on the example of the W13 structure.

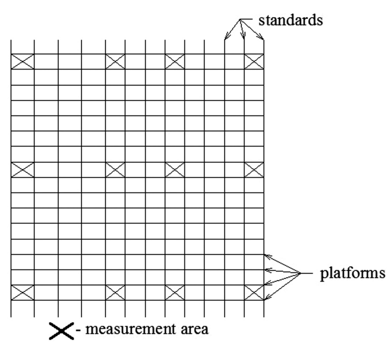


Fig. 1. Scaffolding diagram with measurement areas location

Table 1. List of scaffolding structure

No.	Month [–]	Width [m]	Height [m]	Area [m^2]	Na [–]	NEp [–]	Netting [–]	Direction [–]
W11	March	13	12	160	9	459	no	SE
W12	March	13	13	174	9	455	no	NW
W13	April	33	36	1178	12	581	no	S
W14	April	17	43	733	9	271	no	S
W15	April	12	8	100	4	139	yes	N
W16	May	36	20	635	12	310	no	NE
W17	May	8	18	174	6	216	no	SE
W18	May	24	54	1218	9	504	no	NE
W19	June	10	22	232	6	142	no	SW
W20	July	22	10	223	6	239	no	N
W21	July	29	10	283	7	275	yes	S
W22	July–August	2	18	28	6	306	yes	NE
P12	March	35	37	1148	8	384	no	
P13	April	46	17	724	12	660	no	N, W
P14	April	16	52	640	9	264	no	
P15	May	33	13	434	12	686	no	SW
P16	May	12	14	167	6	336	no	SE
P17	July	12	14	171	6	326	no	NW
P18	July	9	15	136	6	334	no	WS
P19	July	31	33	949	12	656	yes	N
P20	July	3	32	99	3	152	no	W
P21	October	9	15	136	6	236	no	SE
P22	October	12	13	129	5	212	no	SE

In each test area, illuminance was measured for four points located on the scaffold standards. Two points were located at a height of 0.5 m from the scaffold platform, and two points at a height of 1.5 m counting from the scaffold platform. At each test point, the illuminance was measured for about 1 minute with testing done every 1 second. For a total of 23 scaffoldings, the illuminance was measured at 8143 points. The parameters of the external environment: air temperature, relative humidity, atmospheric pressure, wind speed and direction, sound level and dustiness, were also measured in each space [27–31].

3.2. Measuring instruments

Measurements were taken with the use of the KIMO AMI 310 multifunction instrument to which probes were connected. The MCC climatic conditions module recording air temperature, relative humidity, atmospheric pressure and SLU probes, used for measuring illuminance, were permanently connected to the device. The measuring range of the SLU photometric probe ranged from 0 lx to 150000 lx with an accuracy of ±2 lx. Resolution 0.1 lx for measurements from 0 to 999.9 lx, 1 lx for measurements from 1000 to 9999 lx, 10 lx for measurements from 10000 to 99990 lx and 100 lx for measurements from 100 000 to 150 000 lx.

3.3. Illuminance and luminance variability

The average illuminance at each test point was determined according to the formula:

$$E_p = \frac{1}{n}\sum_{s=1}^{n} E_s \tag{3.1}$$

where: E_s – values from measurements at each second, each point, each time of day, each day, on the scaffolding standard, n – number of measurements at each point, each time of day, each day.

The illuminance at each second, each point, each time of day, every day, on the scaffolding standard (E) was determined according to the formula [32]:

$$E_s = \frac{\mathrm{d}\phi}{\mathrm{d}A} \tag{3.2}$$

where: ϕ – luminous flux per unit area [lm], A – surface area of the photometric probe [m^2].

Based on the average value of illuminance at particular points in the scaffolding space, luminance variability in the space between the scaffolding standards was also calculated according to the formula:

$$V_{op} = \frac{E_{p\,\min}}{\sum_{p=1}^{4} E_p} \tag{3.3}$$

where: $E_{p\,\min}$ – minimum light intensity at a point in each of the tested scaffolding spaces.

4. Results

Figures 2, 3 show an example of the results of measurements from the W13 scaffolding. The scaffolding was located in Warsaw at the southern facade of the building. It did not have a protective net. The research was conducted from April 3 to 7 (5 working days from

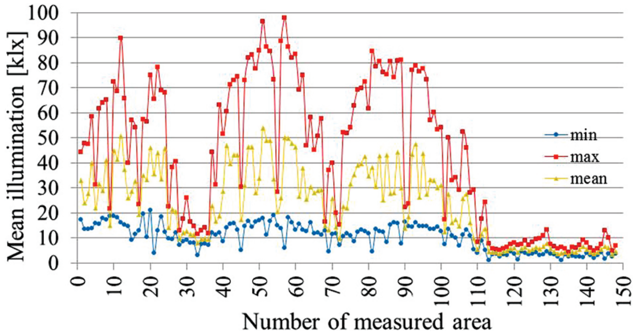


Fig. 2. Illuminance in each examined space

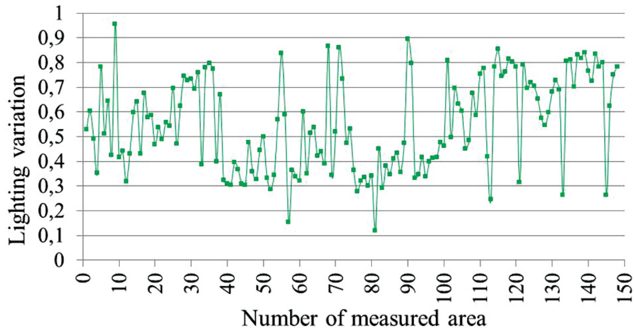


Fig. 3. Luminance variability in each examined space

Monday to Friday). The number of spaces where measurements were taken each day and at each time of day was 12 (4 fields on 3 levels of work platforms).

Each day measurements started around 8 a.m., 11 a.m. and 3 p.m. The total number of measurements was 581. The minimum, maximum and average values of illuminance in each tested workspace are shown in Fig. 2. The luminance variability in each space is presented in Fig. 3. By analyzing the obtained results, it is possible to notice significant differences in illuminance both between individual workspaces and also between the times of day when the measurements were taken. The lowest value of 1.02 klx was recorded on the fifth day on the third tested deck in the series of tests starting at 11 o'clock. The highest value of 97.84 klx was recorded on the second day on the third tested deck in the series of tests starting at 11 o'clock. Major differences were also observed in the case of variability of lighting. The smallest variation in illumination at the level of 0.97 occurred on the first day on the third tested deck in the series of tests starting at 11 o'clock. The highest variation in illumination, at the level of 0.12, occurred on the third day on the second tested deck in the series of tests starting at 9 o'clock. An example of the mean illuminance distribution and the lighting uniformity for the W13 scaffolding is shown for the third day in Fig. 4. The results for measurements starting at 8 a.m., 11 a.m., and 2 p.m. are presented separately.

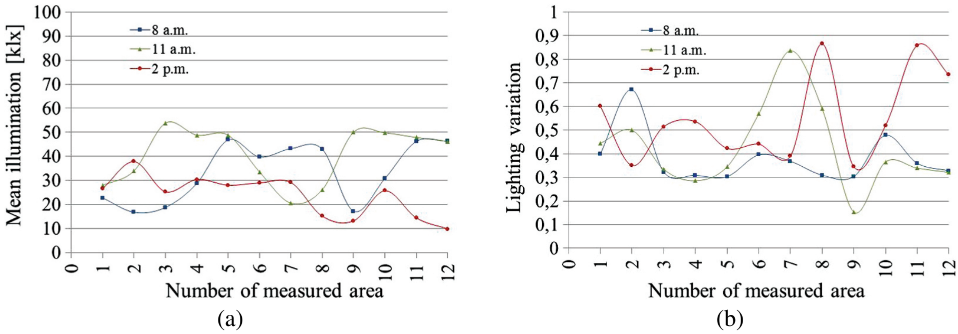


Fig. 4. a) Mean illumination, b) Variability of lighting on the second day for the W13 scaffolding, for measurements starting from 8 a.m., 11 a.m., and 2 p.m.

Analyzing the results obtained it is possible to observe large differences in mean illumination both between the different areas and also between the times of day when the measurements were performed. The minimum values were registered during measurements starting at 2 p.m. The maximum values were registered during measurements starting at 8 a.m. in areas 9–12, which is the sixteenth scaffold platform. Differences are also present in lighting variation. The minimum variability of lighting occurred during measurements starting at 11 a.m. and 2 p.m., while the maximum variability of lighting occurred during measurements starting at 8 a.m.

Table 2 shows the minimum and maximum values of illuminance and variability of lighting separately for all 23 scaffoldings during the whole week of testing.

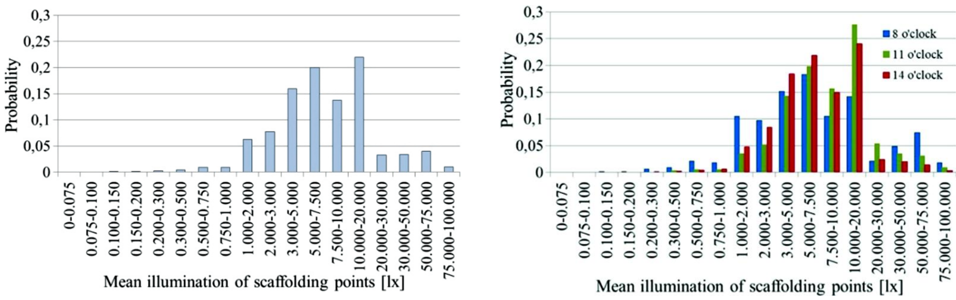
The extreme values for all scaffoldings are in bold. Additionally, the mean values calculated for the entire test week are presented. Taking into account the results based on in-situ data on illuminance, a minimum value of 0.107 klx was observed for the scaffolding tested in March during measurements, which started at 8 a.m. on the fifth day on the first platform. The scaffolding was on the southeast side of the building. The scaffolding was located in Garwolin and did not have a safety net installed. The highest value of 123.84 klx was recorded on the scaffolding in October during measurements, which started at 11 a.m. on the fourth day on the seventh platform. The scaffolding was located on the southeast side of the building. The scaffolding was located in Ostrzeszów and did not have a protective net installed.

Figure 5a shows the probability distributions of a given average illuminance for individual points for all 23 scaffoldings. The lighting intensity ranges were determined in accordance with the PN-EN 12464-2:2014-05 [25] standard. The maximum probability of an average illuminance of 0.24 occurs in the range of 10–20 klx. It is disturbing that the average illuminance is registered at the level of 30 to 100 klx, in which the sun can cause dazzling. The total probability in these ranges is 0.08. Out of 8143 points measured, in 770 measured illuminance (Es) was in the range from 30 to 100 klx, which is 9.4%. In order to determine the differences in illumination between particular times of day, the results for the measurements starting at 8, 11 and 2 o'clock are presented separately (Fig. 5b).

Table 2. Illuminance and variability of lighting based on in-situ data

No.	Illuminance			Variability of lighting		
	Min. [klx]	Mean [klx]	Max. [klx]	Min.	Mean	Max.
W11	0.107	11.813	99.389	0.24	0.71	1.00
W12	0.224	5.043	44.363	0.44	0.81	0.99
W13	1.017	23.677	97.836	0.12	0.55	0.96
W14	0.187	9.310	86.652	0.08	0.50	0.94
W15	0.239	3.995	11.170	0.54	0.77	0.94
W16	0.563	19.969	96.309	0.11	0.53	0.96
W17	0.958	14.250	91.869	0.12	0.72	0.96
W18	0.432	7.717	25.402	0.54	0.80	0.98
W19	1.658	13.086	78.365	0.33	0.74	0.94
W20	0.521	7.786	31.282	0.41	0.79	0.98
W21	1.543	16.855	65.287	0.29	0.56	0.89
W22	1.346	9.256	41.053	0.51	0.81	0.98
P12	0.674	5.621	26.944	0.41	0.75	0.97
P13	0.291	4.573	68.028	0.17	0.69	0.95
P14	0.233	11.866	70.149	0.12	0.70	0.98
P15	0.800	18.138	91.685	0.17	0.69	0.98
P16	1.361	11.990	38.728	0.47	0.77	0.98
P17	2.942	22.086	97.172	0.13	0.59	0.98
P18	1.511	17.184	101.016	0.24	0.69	0.97
P19	0.399	6.028	83.042	0.34	0.76	0.99
P20	0.934	19.159	107.585	0.22	0.68	0.92
P21	0.144	4.752	79.399	0.23	0.67	0.94
P22	0.708	5.275	123.840	0.01	0.45	0.93

By comparing the histograms for measurements starting at different times of day, differences can be notices. In case of measurements starting from 8 o'clock, higher values, compared to other times of day, occur in the ranges from 0 to 3 klx, when the light intensity is comfortable for people who work. Higher values are also present in the ranges from 30 to 100 klx. The total probability in these ranges is at the level of 0.14. Lighting in this range can dazzle the workers, especially since the sun at 8 o'clock is low in relation to the horizon. A worker turning to pick up a material or equipment may be dazzled by low-lying sun. For measurements starting from 11 o'clock, higher values than at other times of day occur



(a) (b)

Fig. 5. Mean illuminance distribution histograms for: a) all scaffoldings, b) measurements starting at 8 a.m, 11 a.m. and 2 p.m.

in the ranges from 10 to 30 klx, and for measurements starting from 2 p.m. in the ranges from 3 to 7.5 klx. The total probability in the range from 30 to 100 klx for measurements starting at 11 a.m. is at the level of 0.07, and for measurements starting at 2 p.m. at the level of 0.04.

Figure 6 shows the probability distributions of the average illuminance separately for scaffoldings with and without the protective net installed. It should be noted that the probability distribution with the installed net was obtained from the measurements from 3 scaffoldings, and without the net from 20 scaffoldings, however, some differences can be noticed.

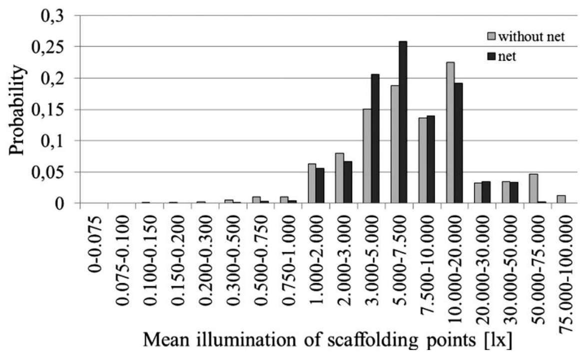
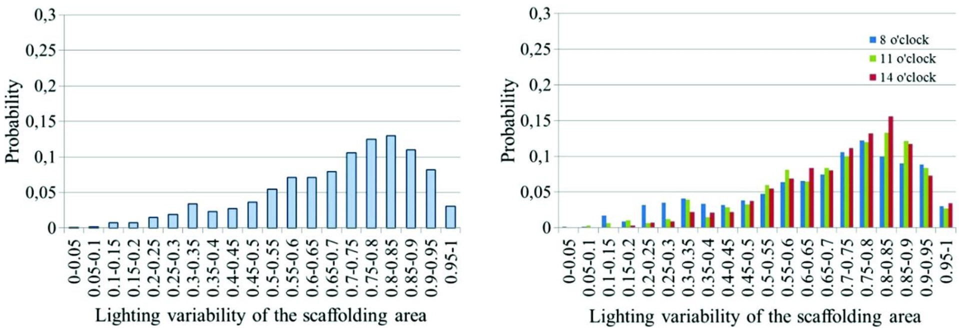


Fig. 6. Mean illuminance distribution histograms for scaffolding with a protective net installed and without it

When analyzing the obtained probability distributions, the maximum value of illuminance occurs in the range from 10 to 20 klx for scaffoldings without a net, and in the range from 5 to 7.5 klx for scaffoldings with a net installed. For the scaffoldings with the installed net, no values lower than 100 lx were recorded (such values are not recommended according to the standard [6] for workplaces on construction sites) but a reduction in unfavorable values in the range from 30 to 100 klx was recorded. The total probability is at the level of 0.04. On the other hand, on scaffoldings without a protective net installed, the total probability equals 0.09.

Based on the average value of illuminance at points of the scaffolding workspace, the variability of the illumination in the space between the scaffolding standards was also calculated. Figure 7a shows a histogram of the variability of the ambient lighting of individual workspaces of all 23 scaffoldings. The maximum probability of lighting variability at the level of 0.13 occurs in the range 0.8–0.85. The occurrence of lighting variability at a level inconsistent with the recommendations from 0 to 0.5 when works on the construction site are performed is disturbing. The total probability in these ranges is at the level of 0.17. To determine the differences in the lighting variability of the workspace between particular times of day, the results for the measurements starting at 8 a.m, 11 a.m. and 2 p.m are presented separately (Fig. 7b).



(a) (b)

Fig. 7. Lighting variability distribution histograms for: a) all scaffoldings, b) measurements starting at 8 a.m, 11 a.m. and 2 p.m.

By comparing the histograms for measurements starting at different times of day, differences can be noticed. For measurements starting at 8 a.m., the maximum values of lighting variability compared to other times of day occur for the ranges from 0 to 0.5. The total probability in these ranges is at the level of 0.24. These values are inconsistent with the requirements for tasks executed on construction sites. For measurements starting at 11 a.m., the maximum values of lighting variability compared to other times of day are in the ranges from 0.5 to 0.6, 0.65–0.7 and for the ranges from 0.85 to 0.95. For measurements starting at 2 p.m., the maximum values are in the range from 0.6 to 0.65, from 0.7 to 0.85 and in the range from 0.95 to 1. The total probability in the range from 0.1 to 0.5 for measurements starting at 11 a.m. is at the level of 0.15, and for measurements starting at 2 p.m. at the level of 0.12.

Figure 8 shows separately the distribution of the lighting variability for the scaffoldings with and without the net installed. When analyzing the obtained probability distributions, the maximum value of lighting variability occurs for scaffoldings without a net in the ranges from 0 to 0.65 and from 0.90 to 1, while for scaffoldings with the net installed in the ranges from 0.65 to 0.9. The total probability in the range from 0.1 to 0.5 without the installed protective net is at the level of 0.19, while on scaffoldings with the installed net it equals 0.08. The protective net on the scaffolding reduces the differences in lighting in the scaffolding workspace.

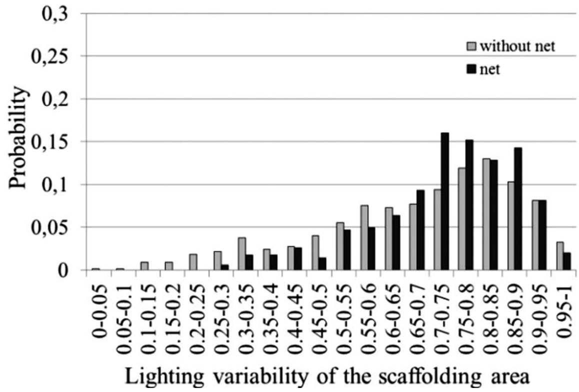


Fig. 8. Lighting variability distribution histograms for scaffoldings with a protective net installed and without it

5. Conclusions

Work on scaffoldings requires a lot of physical effort and is a kind of job in which an accident can occur. Therefore, the employer should provide employees with the best possible working conditions. The employer has no influence on the climatic conditions, but he can organize the work process in such a way as to minimize the adverse impact of weather conditions on the employee. Summarizing the obtained results, it is possible to notice a large variability of the lighting intensity in workplaces of people working on scaffoldings. The measured illuminance levels in the workspaces where tasks are executed are higher than the minimum levels specified in the standard for construction sites. On the one hand, daylight is the best type of light, but it must be remembered that the sun is also the most powerful source of light, which might dazzle. The standard does not define the upper limit, however, the lighting intensity at the level of several tens of thousands of lux may dazzle employees. In the tests, the maximum illuminance was 123,840 lux. Illuminance depends on the weather conditions, time of year, time of day, location of the scaffolding, as well as the presence of a protective net installed on the scaffolding. The lowest total probability in the ranges from 30 to 100 klx occurred for the measurements starting at 2 p.m. and equaled 0.04, while the highest, for the measurements starting at 8 a.m. equaled 0.14. Unfavorable lighting conditions at 8 a.m. occurred 378% more often than at 2 p.m. Also, the variability of illumination in the range from 0.1 to 0.5 was the highest for measurements starting at 8 o'clock and amounted to 0.24 and occurred 198% more often than at 2 p.m.

In turn, the protective net reduced the occurrence of values that could dazzle the worker by 257‰, and the unfavorable variability in the scaffolding space lighting by 234‰.

The presence of a protective net installed on scaffoldings has a positive effect on the lighting conditions of workplaces. In further research, the effect of other types of scaffoldings covers can be investigated.

Changing lighting conditions put an additional burden on the people working on scaffoldings, and as a consequence may contribute to the emergence of situations that could lead to an accident. A changing climate with an increasing number of sunny days may additionally increase the risk of an accident occurring for people working on construction sites. Unfavorable lighting conditions in workplaces reduce visual comfort and worsen the mood, which result in reduced safety of people working on scaffoldings. Therefore, studies of the illuminance in the workplaces on scaffoldings should be continued in the future.

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Analiza oświetlenia słonecznego na rusztowaniach zewnętrznych w różnych porach dnia

Słowa kluczowe: oświetlenie, zmienność oświetlenia, rusztowania, pracownicy budowlani

Streszczenie:

Oświetlenie miejsc pracy ma duży wpływ na bezpieczeństwo, właściwy komfort widzenia, czy wydolność wzrokową. Celem artykułu jest przedstawienie analizy oświetlenia miejsc pracy osób pracujących na rusztowaniach.

Badania przeprowadzono na 23 ramowych, elewacyjnych rusztowaniach budowlanych stojących przy ścianach zewnętrznych budynków. Rusztowania zlokalizowane były w 6 województwach: mazowieckim, wielkopolskim, pomorskim, opolskim, kujawsko-pomorskim, i małopolskim. Rusztowania badane były w terminie od marca do października 2017 roku. Ze względu na specyfikę prac wykonywanych na rusztowaniach budowlanych, badania przeprowadzono zgodnie z indywidualnie dostosowanym programem badawczym. Pomiary na każdym rusztowaniu wykonywane były przez pięć dni tygodnia w trzech porach dnia dostosowanych do pracy większości pracowników na budowach, pierwsza od godziny 8, druga od godziny 11 i trzecia od godziny 14. W każdym dniu i w każdej porze dnia badania przeprowadzono minimum w trzech i maksimum w dwunastu polach rusztowania. Liczba pól pomiarowych zależała od szerokości i wysokości rusztowania oraz od dostępności. Pomiary zostały wykonane przy użyciu urządzenia wielofunkcyjnego KIMO AMI 310, do którego podłączone były: na stałe moduł atmosferyczny MCC rejestrujący temperaturę powietrza, wilgotność względną, ciśnienie atmosferyczne oraz sondy SLU do pomiaru natężenia oświetlenia.

W pracy analizowano natężenie oświetlenia w poszczególnych punktach oraz zmienność oświetlenia pola. Analiza wyników wykazała dużą zmienność natężenia oświetlenia miejsc pracy osób pracujących na rusztowaniach.

Dla pomiarów rozpoczynających się od godziny 8 większe wartości w porównaniu do innych pór dnia występują w przedziałach od 0 do 3 klx a więc wtedy, kiedy natężenie oświetlenia jest komfortowe dla osób wykonujących pracę. Większe wartości występują również w przedziałach od 30 do 100 klx. Oświetlenie w tym przedziale wartości może spowodować u osób pracujących oślepienie, zwłaszcza, że słońce o godzinie 8 jest w niskim położeniu w stosunku do linii horyzontu. Pracownik odwracający się po materiał bądź urządzenie może zostać oślepiony przez nisko położone słońce. Dla pomiarów rozpoczynających się od godziny 11 większe wartości w porównaniu do innych pór dnia występują w przedziałach od 10 do 30 klx, a dla pomiarów rozpoczynających się od godziny 14 w przedziałach od 3 do 7.5 klx.

Analizując zmienność oświetlenia dla pomiarów rozpoczynających się od godziny 8 maksymalne wartości w porównaniu do innych pór dnia występują dla przedział ów od 0 do 0.5. Są to wartości niezgodne z wymaganiami dla czynności wykonywanych na placach budów. Dla pomiarów rozpoczynających się od godziny 11 maksymalne wartości zmienności oświetlenia w porównaniu do innych pór dnia występują w przedziałach od 0.5 do 0.6, 0.65–0.7 oraz dla przedziałów od 0.85 do

0.95. Dla pomiarów rozpoczynających się od godziny 14 maksymalne wartości występują w przedział ach od 0.6 do 0.65, od 0.7 do 0.85 oraz w przedziale od 0.95 do 1.

Podsumowując zmierzone natężenia oświetlenia na polu zadania są wyższe od minimalnych natężeń zawartych w normie dla placów budowy. Z jednej strony światło dzienne jest najlepszym rodzajem światła, jednak trzeba pamiętać że słońce jest również najsilniejszym źródłem mogącym powodować oślepienie.

Norma nie określa górnej granicy, jednak natężenie oświetlenia na poziomie kilkudziesięciu tysięcy luksów może powodować oślepienie pracowników. W badaniach maksymalne natężenie oświetlenia wyniosło 123840 luxów. Natężenie oświetlenia zależy od warunków atmosferycznych, pory roku, pory dnia, położenia rusztowania, jak również od obecności siatki ochronnej zamontowanej na rusztowaniu. Najmniejsze łączne prawdopodobieństwo w przedział ach od 30 do 100 klx występowało dla pomiarów rozpoczynających się od godziny 14 i wynosiło 0.04, natomiast największe dla pomiarów rozpoczynających się od godziny 8 i wynosiło 0.14. Niekorzystne warunki oświetleniowe o godz. 8 wystąpiły więc 378 % częściej niż o godzinie 14. Również zmienność oświetlenia w przedziałach od 0.1 do 0.5 był a największa dla pomiarów rozpoczynających się od godziny 8 i wynosiła 0.24 i wystąpiła 198% częściej niż o godzinie 14. Z kolei siatka ochronna zmniejszyła występowanie wartości mogących powodować oślepienie pracownika o 257%, a niekorzystną zmienność w polu rusztowania oświetlenia o 234%. Obecność siatki ochronnej zamontowana na rusztowaniach korzystnie wpływa na warunki oświetlenia miejsc pracy. W dalszych badaniach można zbadać wpływ innego rodzaju osłon stosowanych na rusztowaniach.

Zmieniające się warunki oświetlenia stanowią dodatkowe obciążenie dla osób pracujących na rusztowaniach, w konsekwencji mogąc przyczyniać się do powstania sytuacji mogących prowadzić do wypadku. Zmieniający się klimat z coraz większą liczbą dni słonecznych może dodatkowo powodować wzrost zagrożenia dla osób pracujących na budowach. Niekorzystne warunki oświetlenia miejsc pracy obniżają komfort widzenia, pogarszają samopoczucie prowadząc do zmniejszenia bezpieczeństwa osób pracujących na rusztowaniach. W związku z tym, badania natężenia oświetlenia miejsc pracy na rusztowaniach, powinny być w przyszłości rozwijane.

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