Forecasting of Scaffolding Work Comfort Parameters Based on Data from Meteorological Stations

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***Abstract*—**Work at height, such as construction works on scaffoldings, is associated with a considerable risk. Scaffolding workers are usually exposed to changing weather conditions what can additionally increase the risk of dangerous situations. Therefore, it is very important to foresee the risk of adverse conditions to which the worker may be exposed. The data from meteorological stations may be used to asses this risk. However, the dependency between weather conditions on a scaffolding and in the vicinity of meteorological station, should be determined. The paper presents an analysis of two selected environmental parameters which have influence on the behavior of workers – air temperature and wind speed. Measurements of these parameters were made between April and November of 2016 on ten scaffoldings located in different parts of Poland. They were compared with the results taken from the meteorological stations located closest to the studied scaffolding. The results gathered from the construction sites and meteorological stations were not the same, but statistical analyses have shown that they were correlated.

***Keywords*—**Scaffoldings, health and safety at work, temperature, wind speed.

I. Introduction

SCAFFOLDINGS have many applications. The main task of scaffolding is to provide optimal working conditions for employees working at height or in places which are hard to reach. These are, for example, construction works involving, erecting buildings, cladding works, or renovation works. The situations which may occur during these works, may lead to the development of potentially accidental events, accidents or even construction disasters. Furthermore, people working on scaffoldings are continuously subjected to varying environmental factors such as high and low temperature or strong wind, that additionally influence workers. Researches show that as a result of global warming, extreme weather conditions will occur more and more often [1]. Working at low or high temperatures can lead to poor mood, reduced concentration or the onset of disease symptoms [2] and even death. In Canada, as a result of working in high temperature in 16 regions of Quebec, in the years from 1998 to 2010, 253 people fell ill, and 6 died. Construction workers made 10.7% of the number of people who were ill [3].

In North Carolina, there were 161 deaths related to high temperature in the period from January 1st, 1977 to December 31st, 2001. There were 10 construction workers among the deceased [4]. Furthermore, in Hong Kong, 17.4% of construction workers experienced various symptoms as a result of high temperatures (research was conducted among 207 construction workers). Most of these symptoms were dizziness (18 cases), fatigue (10 cases), fever (8 cases), vomiting (8 cases), fainting (7 cases), headache (6 cases), discomfort (5 cases), breathing difficulty (4 cases), and isolated cases of thirst, dehydration, rash, sweating, hot and dry skin, loss of consciousness and heat stroke [5]. Another important parameter which has strong influence on comfort is wind. Strong wind, especially at low temperature or poor air movement at high temperature and high humidity can cause changes in human heat balance [6].

There are many different wind comfort criteria. They may depend on various parameters, such as climate zone, type of building or human activity [7]. Strong wind can also have a mechanical effect on the human body and can cause dangerous imbalances. Another aspect is the air flow which affects the air quality [8].

Flows around buildings are difficult to predict. Despite the fact that many scientists have attempted to predict airflow and dispersion of pollutants [8], it is still the area of science to explore.

The assessment of the risk of unfavorable conditions to which the employee may be exposed is an important problem. Such analysis can be made on the basis of measurements of temperature, wind speed, pressure, sun exposure and etc., carried out continuously in meteorological stations. However, the adaptation of these results to the study of the working environment at scaffoldings requires to determine the relationship between the results of measurements at meteorological stations and the results of measurements made at scaffoldings. This is the main purpose of this work.

II. Research Methods

A. Results from IMGW

To determine the relationship between the conditions at the scaffolding and in the vicinity of meteorological stations, the results of measurements made by Institute of Meteorology and Water Management (IMGW) and own measurements of environmental parameters at scaffoldings were used. The values of air temperature and wind velocity measured in the vicinity of people working on scaffoldings and values obtained from IMGW meteorological stations were compiled.

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The IMGW stations closest to each scaffolding site were chosen. Meteorological data were taken for the same days and hours (times of the day) in which the scaffolding was examined. All scaffoldings except W01 and L07 were located in the same city as the meteorological stations. For the scaffolding W01, the results of own measurements were compared with the results from the meteorological station located in Warsaw, whereas for L07 they were compared with the results from the station located in Lublin. A list of scaffoldings with the date of the measurement, the scaffolding location and its distance from the meteorological station are given in Table I.

TABLE I
LIST OF SCAFFOLDINGS

Scaffolding	Measurement date	Scaffolding location	Distance from the METEO station [km]
W01	25–29 April	Piaseczno	10.9
D01	30 May–4 June	Wrocław	8.4
D03	6–10 June	Wrocław	12.0
E01	6–10 June	Łódź	4.9
D04	4–8 July	Wrocław	2.1
L04	6–12 July	Lublin	11.5
W06	25–29 July	Warszawa	2.1
E05	1–6 August	Łódź	3.8
L07	8–12 August	Łęczna	35.4
W08	5–9 August	Warszawa	7.9

B. In-situ Measurements of Scaffoldings

The measurements and their results described in this paper were a part of the bigger research on façade frame scaffoldings. This research was conducted by five teams consisting of employees from: Faculty of Civil Engineering and Architecture (Lublin University of Technology), Faculty of Management (Lublin University of Technology), Faculty of Civil Engineering, Architecture and Environmental Engineering (Lodz University of Technology) and Faculty of Civil Engineering (Wroclaw University of Science and Technology) [9]. The authors of this paper were members of three of these teams.

The scope of the whole research was very extensive and included measurements of: environmental parameters, such as – air temperature, relative humidity, atmospheric pressure, illuminance, wind speed, sound level, dustiness [10], [11], technical parameters – deviations from the ideal geometry of the scaffolding (imperfections), technical condition of the elements, forces in the anchoring, forces in the stand of scaffolding frame, frequency of vibrations, wind acting on the scaffolding structure, soil bearing capacity, operational loads [12], [13], and physiological parameters of the workers [14].

The selected environmental parameters were used in this work, i.e. air temperature and wind speed. The results described in this paper are based on 10 scaffoldings located at construction sites in various places in Poland and used in different periods from April to November of 2016. For each scaffolding, measurements were carried out for one working week.

Three rounds of tests were performed on each day: the first from 8 a.m., the second from 11 a.m., the third from 2 p.m. Each measurement round lasted about one hour. The number and the location of measurement points on the level of one work platform depended on the number of scaffolding sections and on the availability. If a scaffolding had only 1 horizontal section – there was 1 measurement point, if 2 to 4 sections – there were two measurement points (at first and last scaffolding section), if 5 to 8 sections – there were three measurement points (at first, last and middle scaffolding sections), and for 9 or more scaffolding sections – there were four measurement points (at first, last and two middle scaffolding sections). The number of tested levels depended on the scaffolding height and ranged from: 1 tested level – for scaffolding with 1 to 2 levels of decks, 2 tested levels (lowest and highest scaffolding level) – for scaffolding with 3 to 5 levels of decks, 3 tested levels (lowest, highest and middle scaffolding level) – for scaffolding with 6 or more levels of decks. A list of scaffoldings, considered in this paper, with their characteristics and number of measurement points is provided in Table II.

TABLE II
SCAFFOLDINGS CHARACTERISTICS AND NUMBER OF MEASUREMENT POINTS

Scaffolding	Façade area [m^2]	Height [m]	Number of measurement points
W01	174.12	12.10	6
D01	450.32	3.24÷19.04	12
D03	633.57	18.18	12
E01	882.59	18.31÷22.31	12
D04	796.40	26.31	12
L04	198.00	13.35	9
W06	363.17	5.10÷20.12	9
E05	248.81	13.50	6
L07	139.22	15.10	4
W08	201.60	15.09	9

The scaffoldings: W01, E01, L07 and W08 were installed at the north-west façades of the buildings, scaffolding D01 – at the north-east façade of the building, scaffoldings D03, D04 and L04 – at the south-west façades of the buildings, scaffoldings W06 and E05 – at the south-east façades of the buildings. All of the above-mentioned scaffoldings were assembled on the basis of the manufacturer's catalogs. Different systems of scaffoldings were used, for W01, D01 and D04 it was Blitz scaffolding system, for D03 – RUX Super 65 scaffolding system, for E01 – RR-0.8 scaffolding system, W06 - Plettac Sl scaffolding system, E05 – BAL-073 scaffolding system.

The scaffoldings: D03, E01, E05 and W06 where fully cladded. Scaffoldings W01 and W08 had only partial cladding, scaffolding D04 was cladded above the fifth level, whereas scaffoldings D01, L04, L07 had no cladding.

C. Measuring Equipment

The environmental parameters were measured using KIMO multifunction instrument AMI 310 and the following probes (Fig. 1):

- climatic conditions module, measuring atmospheric

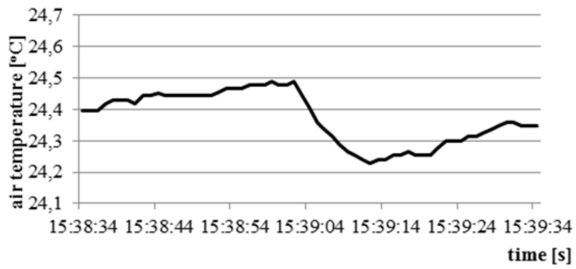
pressure, air temperature and relative humidity,
- telescopic vane probe (SHT 100) measuring wind speed.

In each measurement point, air temperature was measured at the height of the employee's face (about 1.5 m above the deck level). The duration of the measurement at each point was 4 minutes with a sampling period of 1 s.

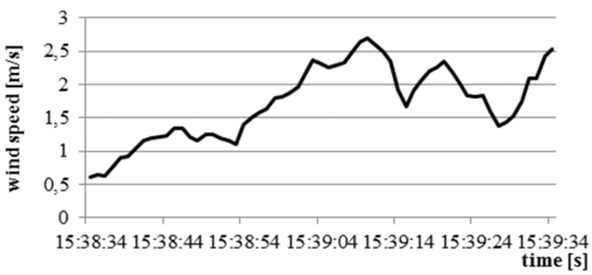
At the same time, wind speed was measured with the probe firstly directed perpendicularly to the scaffolding and next – along the scaffold façade (about 1.5 m above the deck level). Each measurement lasted for 1 minute, and data were recorded at each second.

Fig. 1 The measurements on the scaffolding

The graphs in Fig. 2 present sample values of air temperature and wind speed of 1-minute measurement made on scaffolding W01.



(a)



(b)

Fig. 2 Sample time histories of: (a) air temperature, (b) wind speed, measured at scaffolding W01

III. Measurements Results

Tables III and IV show the minimum, maximum, and average values of air temperature and wind speed measured at the scaffoldings during five test days. The minimum, maximum, and average values of wind speed are selected from the both measured directions.

The highest value of measured air temperature (41.4 °C), was observed at scaffolding W06 tested in July, whereas the lowest (9.6 °C) value was obtained at scaffolding W01 tested in April. The highest absolute value of measured wind speed (8.3 m/s) was observed at scaffolding E01 tested in June.

Measurements carried out at construction sites indicate that the air temperature varied depending on the time of day [11], [15] and height [16]. To compare the values measured at the scaffolding with the values from the meteorological station, the average temperature was calculated for each day and for each time of the day, from the 60 s measurement, according to:

$$T_k = \frac{1}{n}\sum_{p=1}^{n} T_p \tag{1}$$

where: T_p – the air temperature measured at every second, n = 61.

TABLE III
AIR TEMPERATURE

Scaffolding	Minimum temperature [°C]	Maximum temperature [°C]	Average temperature [°C]
W01	9.6	24.8	15.2
D01	19.4	41.2	26.7
D03	17.0	39.3	24.4
E01	14.3	30.1	20.8
D04	15.3	35.3	24.0
L04	12.8	33.0	24.5
W06	22.4	41.4	30.2
E05	19.7	35.0	25.2
L07	16.7	36.4	23.5
W08	17.7	32.1	24.7

TABLE IV
WIND SPEED

Scaffolding	Minimum wind speed [m/s]	Maximum wind speed [m/s]	Average wind speed [m/s]
W01	0	3.5	0.4
D01	0	7.5	0.5
D03	0	5	0.4
E01	0	8.3	0.7
D04	0	7.3	0.8
L04	0	6.4	0.6
W06	0	7.9	0.6
E05	0	3.5	0.2
L07	0	3.5	0.5
W08	0	1.3	0.1

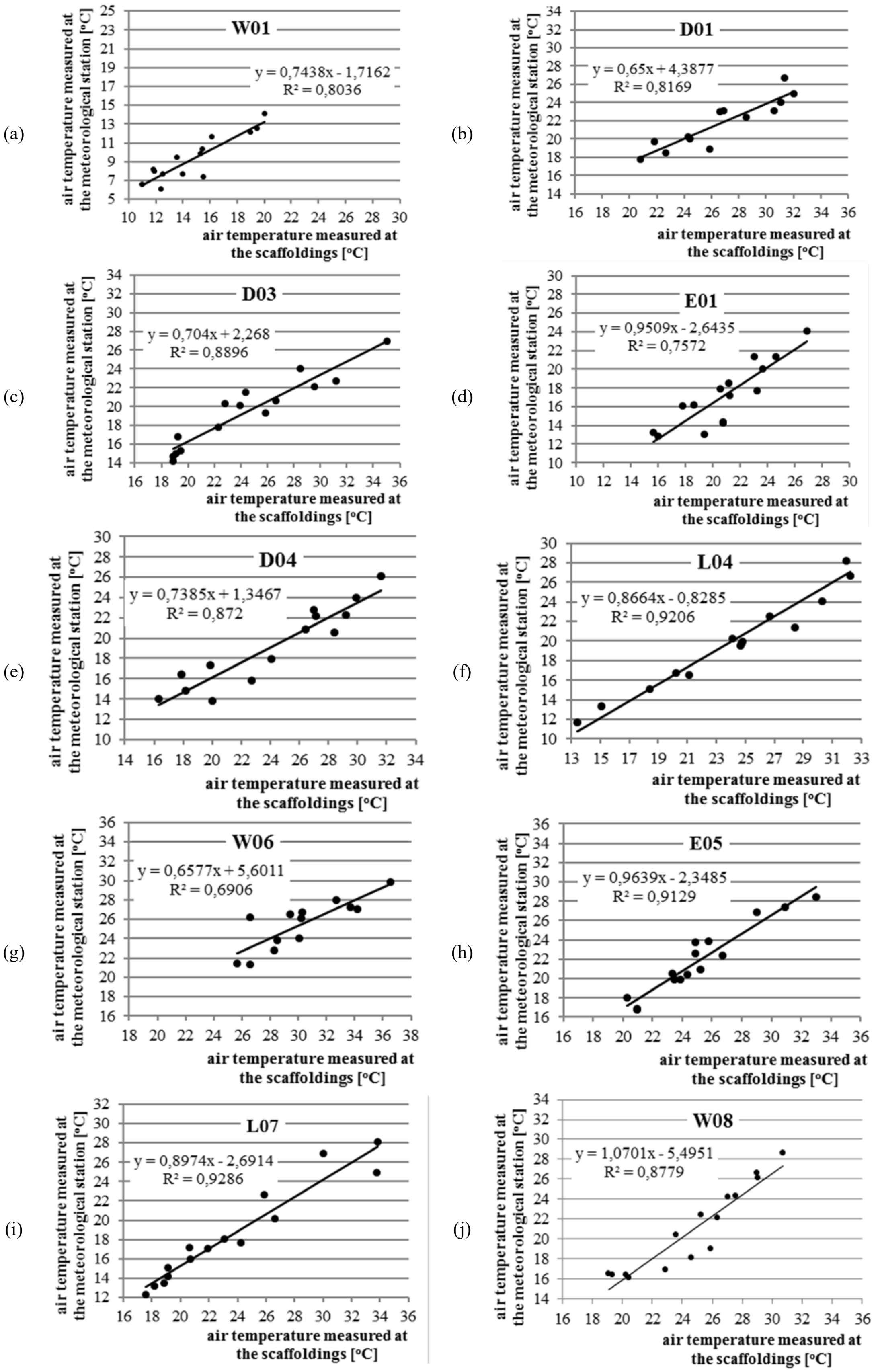


Fig. 3 The dependence of the values of the air temperature measured at the meteorological station and at scaffoldings: (a) W01, (b) D01, (c) D03, (d) E01, (e) D04, (f) L04, (g) W06, (h) E05, (i) L07, (j) W08

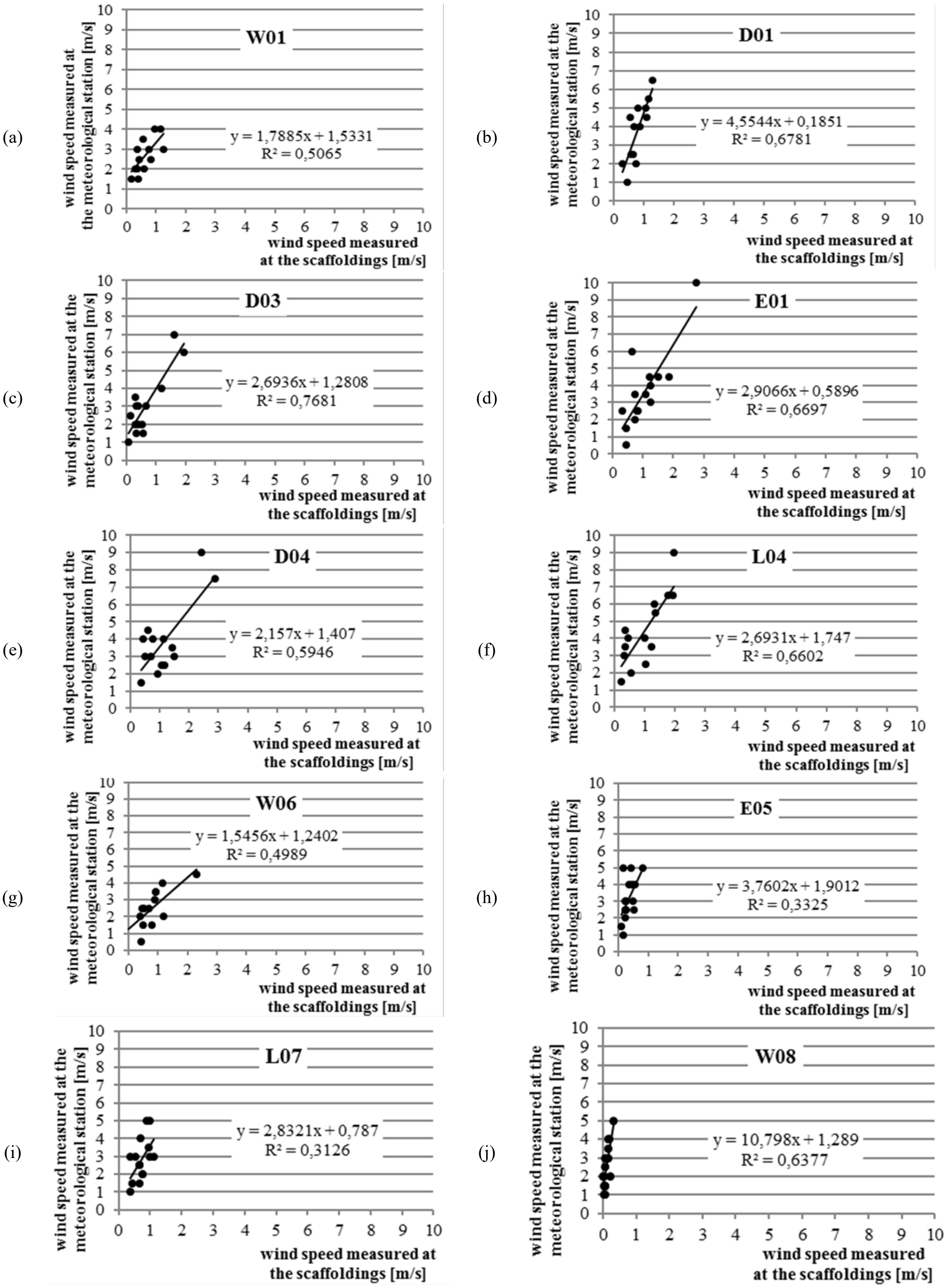


Fig. 4 The dependence of the values of the resultant wind speed measured at the meteorological station and at scaffoldings: (a) W01, (b) D01, (c) D03, (d) E01, (e) D04, (f) L04, (g) W06, (h) E05, (i) L07, (j) W08

Fig. 3 shows the relationship between the temperature measured at the scaffoldings and the temperature measured at the meteorological stations.

Analyzing the obtained results, the relationship between the temperature measured at the meteorological station and the temperature measured on the scaffoldings can be noticed. The values of air temperature obtained from in-situ scaffoldings measurements are greater than the values measured at the meteorological stations. This is caused by the fact that the air temperature in the city is always higher than the temperature outside the city (meteorological stations are usually located outside cities, in the open terrain) and also because of the building influence such as the reflection of solar radiation. The smallest angular coefficient of line approximating dependences between the average temperature at the scaffolding and the temperature measured at the meteorological station is observed for scaffoldings D01 and W06, where some measurements were performed at higher levels than measurements performed at meteorological stations. The higher angular coefficient occurs for scaffoldings L07, which is located outside large cities (there is no additional temperature difference coming out of the scaffolding location in the urban terrain). The scaffolding location relative to the directions of the world (orientation) or the presence of cladding did have much influence on the above results.

Fig. 4 shows the relation between the average wind speed measured at the scaffoldings and the wind speed measured at the meteorological stations. To compare the values measured in-situ with the values from the meteorological station, the wind speed was calculated for each measurement point at scaffolding, using formula:

$$v_w = \sqrt{v_{\rightarrow}^2 + v_{\uparrow}^2} \tag{2}$$

where: $v_{\rightarrow}$ – wind speed component in the direction parallel to the façade, $v_{\uparrow}$ – wind speed component in the direction perpendicular to the façade.

Then, the average wind speed was calculated for each day and for each time of day from the formula:

$$v_k = \frac{1}{n}\sum_{p=1}^{n} v_p \tag{3}$$

where: v_p – wind speed values measured at every second, n = 61.

Analyzing the obtained results of the wind speed measurements, as in the case of the temperature, one can notice the relationship between the wind speed measured at the meteorological station and the wind speed measured at the scaffoldings. However, the values of coefficient R^2 between points (with coordinates: measurement made at scaffoldings, measurement made at a meteorological station), and approximation line are smaller than the values obtained in the case of temperature. This may be caused by the fact that the meteorological stations were located in the open terrain, whereas scaffoldings were located in the urban terrain. The values obtained from measurements at scaffolding are lower, which is associated with disturbances of the air flow. The air flow in urban areas (cities) is usually highly disturbed and depends, among other things, on the location of buildings, the presence of trees, the ground roughness and wind direction. The results indicate that the mounted clads did not have a significant impact on the value of R^2 coefficient, but they had a clear impact on wind speed values at the scaffoldings. The angular coefficient of approximating line is much smaller for cladded scaffoldings than for these which were not cladded or only partially cladded. This means that the presence of the clad reduces the wind speed and can protect scaffolding users from unfavorable influence of wind. The highest value of the angular coefficient of approximating line (10.8) was observed for scaffolding W08. This value is much bigger than in case of other scaffoldings. But, it may be unreliable because the flow rate on the scaffolding was small, which could have caused a measurement error.

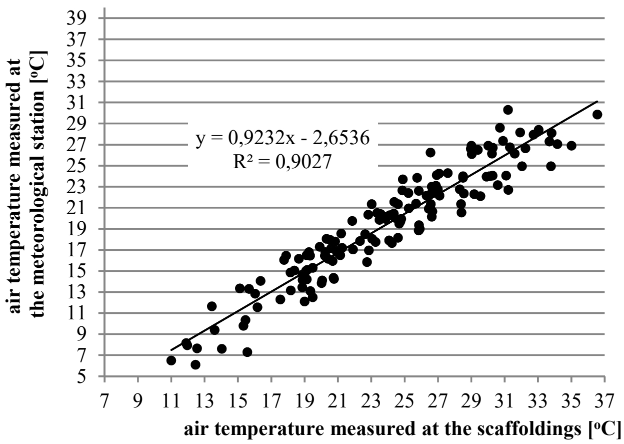


Fig. 5 The dependence of the values of the air temperature measured at the meteorological station and at scaffoldings

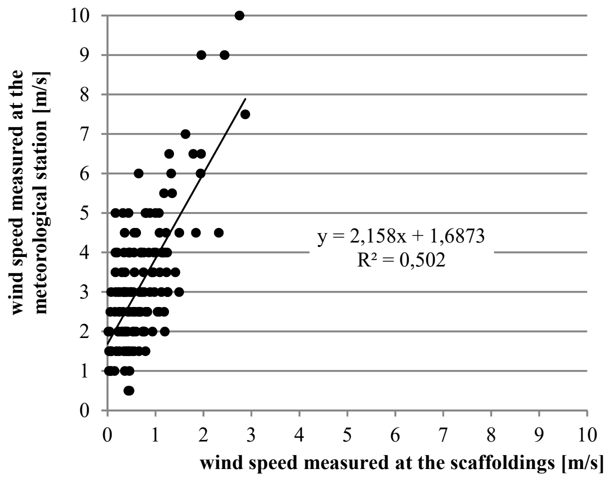


Fig. 6 The dependence of the values of the resultant wind speed measured at the meteorological station and at scaffoldings

Figs. 5 and 6 present dependence of the values of the air temperature and wind speed measured at the meteorological station and on scaffolding, respectively. As in the case of single scaffolding, the relation between in-situ measurements and metrological data is definitely more pronounced for the values of air temperature, than for the values of the wind speed.

IV. Conclusions

People working on scaffoldings often do work that requires a lot of physical effort and they do it at high altitudes. This is related with a high level of risk of accidents or potentially accidental events. The risk increases in the case of unfavorable conditions of the external environment: high or low temperature, and low flow rate or, on the contrary, high wind speed. Therefore, monitoring the parameters of the work environment is very important.

The research has shown that the obtained results of climatic parameters: air temperature and wind speed measured at scaffoldings and at the meteorological station are correlated. Stronger correlation occurs for the air temperature, weaker for the wind speed, due to the greater number of parameters affecting it.

The paper presents test results for 10 scaffoldings. Due to many factors affecting the parameters of the working environment at scaffolding (scaffolding height, solar radiation reflectance level, surroundings, location relative to the cardinal directions, year's season) this test, because of low number of considered cases, can only serve for indicating general dependencies. But, it cannot be a basis for qualitative evaluation of the relationship between the air temperature and the wind speed measurements at scaffolding and at meteorological stations. Therefore, studies of the working environment around people on scaffolding should be developed.

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