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Work comfort on scaffolding structures

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SUMMARY:
This paper analyses comfort/discomfort of people working on construction sites on building scaffolding, i.e. at heights where they are more exposed to adverse environmental conditions including air temperature, wind and humidity. The paper assesses the possibility of using two different sets of data gathered in full scale: (i) on a scaffolding structure close to working people and (ii) on the nearest meteorological station, to estimate the heat stress of people working on scaffolding structures at construction sites. The main purpose is to check if the use of public data from meteorological stations can provide reliable estimation of worker's comfort or discomfort. A simplified formula of Universal Thermal Climate Index (*UTCI**) is used in analyses. The values of *UTCI** calculated on the basis of two sets of input parameters are compared to each other and their correlation relationship is checked. The measurements and *UTCI** calculations are presented for 24 scaffolding structures located in Łódź and Lower Silesian provinces in Poland. The details of the research are presented in Szer et al. (2022).

Keywords: Universal Thermal Climate Index, heat stress, scaffolding, occupational safety, construction workers

1. INTRODUCTION

Every year, many accidents in the construction industry, including fatalities, occur. Accidents of human and of structural character are reported for several countries (e.g.: Shao et al., 2019). Human errors are the most common cause of accidents and appear mainly as a result of people's fatigue often associated with unfavourable environmental conditions.

There are many tools assessing comfort/discomfort of people in the external environment which are based on environmental data. *UTCI* (Błażejczyk et al., 2010) is one of them and is considered as one of the most universal indices. It can be used in all climatic zones and can describe the extreme thermal sensations. Recent examples of using *UTCI* were shown in e.g.: Fang et al. (2019), Manavvi and Rajasekar (2020), Zare et al. (2019). The research usually concerns comfort/discomfort of people during their outdoor activities, less often working. In the first case such activities have voluntary character, in the second case people are constrained by different labour standards and freedom in their activities often does not apply.

2. MATERIALS AND METHODS

2.1. UTCI and UTCI*

UTCI [°C] is defined as the equivalent air temperature at which, the basic physiological parameters of the body under reference conditions assume the same values as under real

conditions. The calculation of *UTCI* requires appropriate knowledge about particular parameters describing model and specialized software. It is often impossible to meet such requirements in construction site conditions. Therefore, a simplified formula, co-called *UTCI** [°C] was developed (Błażejczyk and Kunert, 2011):

$$UTCI^{*} = 3.21 + 0.872t + 0.2459T_{mrt} - 2.5078v_{10} - 0.0176RH \quad (1)$$

where: t is air temperature [°C], T_{mrt} is mean radiant temperature [°C], RH is relative air humidity [%] and v_{10} is wind speed at 10 m above the ground [m/s]. The assessment scale of the heat stress of the human organism according to *UTCI* and *UTCI** is as follows: extreme heat stress (> +46.0); very strong heat stress (+38.1 – +46.0); strong heat stress (+32.1 – +38.0); moderate heat stress (+26.1 – +32.0); thermo neutral zone (+9.1 – +26.0); slight cold stress (+0.1 – +9.0); moderate cold stress (-12.9 – 0.0); strong cold stress (-26.9 – -13.0); very strong cold stress (-39.9 – -27.0); extreme cold stress (< -40.0).

2.2. Environmental data

Environmental data was obtained from two sources:

1. Synoptic meteorological station. Data was obtained from Polish Institute of Meteorology and Water Management. The following data from the stations located closest to the construction site were used: (i) wind speed, (ii) air temperature, (iii) air relative humidity, and (iv) cloudiness. In addition, (v) exact geographic coordinates and (vi) measurement time corresponding to the time of construction site measurements were collected. These parameters made it possible to determine the remaining values necessary to calculate T_{mrt} and *UTCI**.

2. Construction site. The measurements were performed on frame façade scaffolding structures. The experiments were conducted in 2017, from January to November. The tests usually lasted 5 days and were carried out for all structures. Every day 3 series of measurements were made. One full series took 1-2 hours. During single full series, the tests were performed on 1, 2 or 3 levels of decks and in 1, 2, 3 or 4 points located on every tested deck. One of the assumptions of the measurements was the presence of workers on the scaffolding. The climatic parameters were measured with KIMO AMI310 multifunction device. The measurements were performed on 24 scaffolding structures located in two provinces in Poland: Łódź and Lower Silesian provinces. Detailed description of research can be found in e.g.: Szer et al. (2022).

3. RESULTS

Example results concerning environmental data are presented for the chosen scaffolding in Fig. 1. The scaffolding was tested at the end of June, during 5 working days, 3 times a day. The number of measurement points was 12. Some data was lost due to weather conditions, equipment problems or inattention of the device operator. Finally, the number of data for analyses was 172. Similar analyses were performed for all 24 scaffolding structures. The correlation dependencies between environmental data collected at scaffolding and meteorological station were calculated. Examples are presented in Fig. 2, collectively for all structures. Based on data and assuming some simplifications, the values of T_{mrt} were calculated. The input data for estimation of T_{mrt} were: (i) geographical coordinates, (ii) exact date of measurements, (iii) air temperature, (iv)

relative humidity, (v) cloudiness. The other required parameters were adopted at their standard values. Because the values of T_{mrt} were not obtained directly, their correlation with air temperature was calculated and respective functions were inserted in Eq. 1.

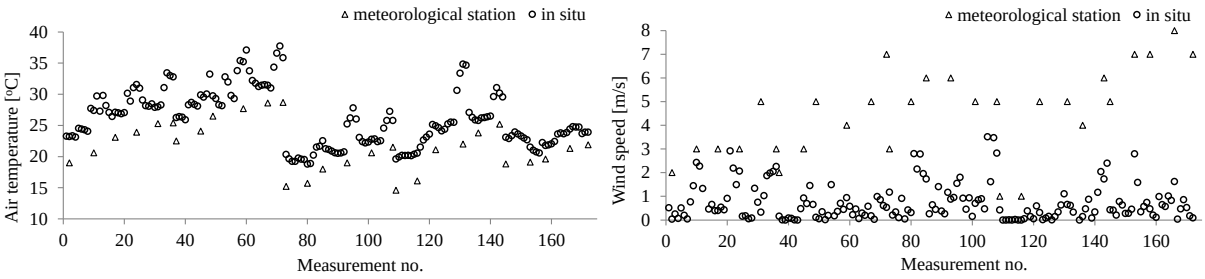

Figure 1. Environmental data for chosen scaffolding structure.

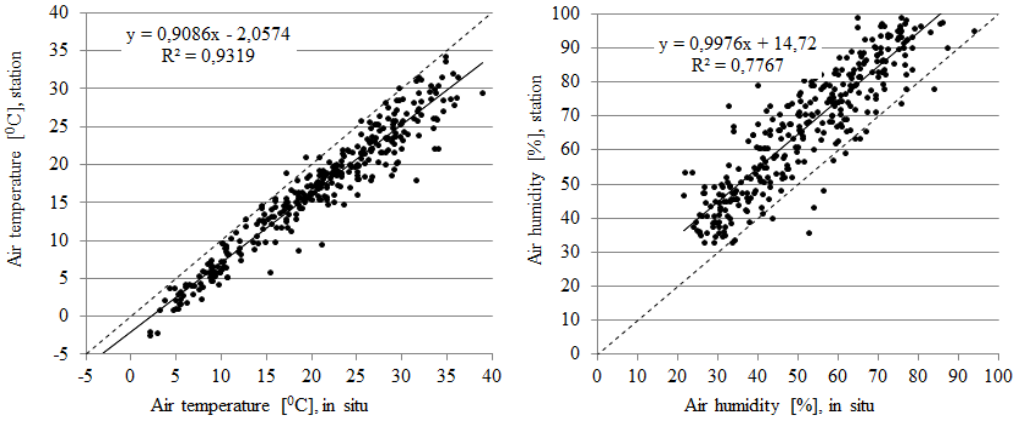

Figure 2. Correlation between data from scaffolding and meteorological station for 24 structures.

As final result the average value of *UTCI** was calculated, separately for each scaffolding, according to the formula:

$$UTCI^* = \frac{1}{n}\sum_{p=1}^{n} UTCI_p^* \quad (8)$$

where: $UTCI_p$* – values from measurements at every point, every time of the day, every day, in the surrounding of workers on the scaffolding, n – number of measurements on the given structure. The analogical calculations were repeated for data from meteorological stations. The level of heat stress of people working on particular structures is presented in Fig. 3. There are ranges of $UTCI_p$* and mean values of *UTCI**. It is clear that in many cases the heat stress of scaffolding workers is outside the comfort range. The differences between values of extreme $UTCI_p$* or mean *UTCI** calculated with different input data are quite significant. The values differ on average by 12.2°C (for means). When considering extreme values the differences are considerably larger.

Figure 4 shows the correlation relationship between values of *UTCI** calculated for structures located in Łódź and Lower Silesian provinces, respectively.

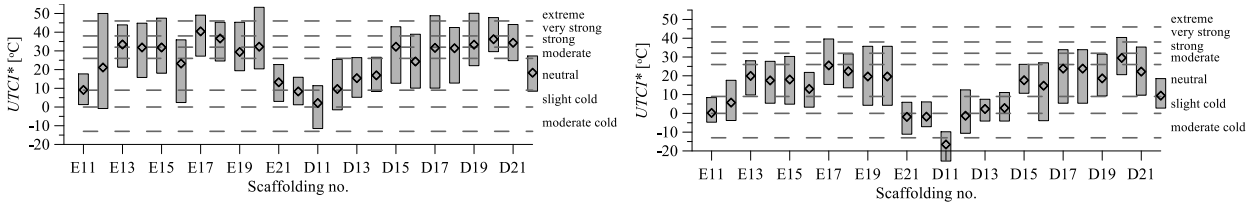

Figure 3. Heat stress of people working on scaffolding: based on data from scaffolding (left), based on data from meteorological station (right). Grey areas – the range of $UTCI_p$*, ◇ – mean *UTCI**.

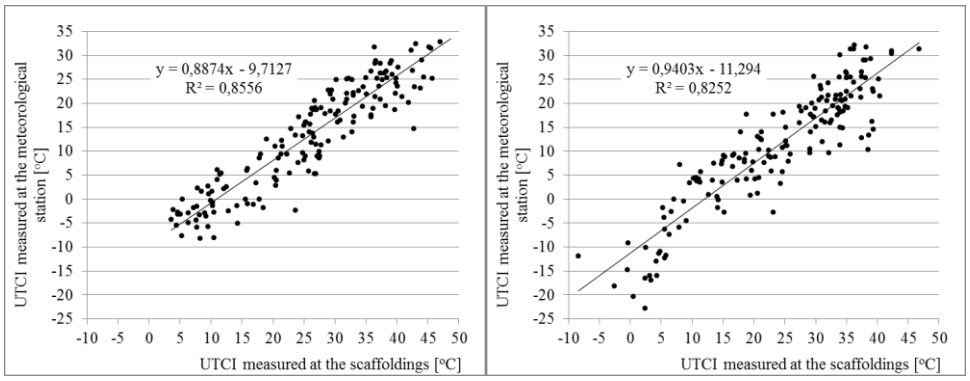

Figure 4. Correlation of *UTCI** for scaffolding structures in Łódź (left) and Lower Silesian (right) provinces.

4. CONCLUSIONS

Performing environmental measurements described in this work is usually impossible in construction site conditions. Therefore, it is worth considering the use of measurement data recorded at nearby meteorological stations to determine the heat stress of people working at construction site. The knowledge about the correlation relationship between both quantities provides the possibility of conducting calculations based on the data from the stations. The paper shows that based on the obtained dependencies and on the climatic forecasts prepared by appropriate office or service, one can anticipate the risk of unfavourable environmental conditions resulting in the occurrence of heat stress of construction workers.

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