Hazards induced by thermal conditions during work on scaffolding

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Abstract. The article presents the results of research on hazards induced by thermal conditions illustrated by the example of air temperature. Presented results concern ten construction scaffoldings located in Wroclaw, which were investigated from May 30 to October 14, 2016. The scaffolding area ranged from 146 m^2 to 1303 m^2. On three scaffoldings, the air temperature was above 40 ℃. The air temperature in 46 % of cases was in the unfavorable for employees temperature range. In addition, people working on scaffoldings are exposed in most cases to strong or severe thermal stimuli connected with large temperature differences during the working day. Unfavorable, dynamically changing climatic conditions pose a serious threat to people working outside. There is an increase in errors, and as a result the risk of situations that could lead to an accident increases.

1 Introduction

Construction workers working on construction scaffolds are exposed to a high risk of health and life threats. Accidents related to the use of scaffolding occur all over the world. They are subject to research in many countries. For example, in Norway in 2015, 15% of accidents in construction are falls from scaffolding [1]. In Spain, about 40% of serious accidents are caused by a fall from height, and about 30 % of them are falls from temporary devices on structures assembled for work at height [2]. In the United States in 2000, there were 734 fatal accidents at work due to a fall from height, 12% of these accidents concerned a fall from a scaffolding or a stage [3]. Studies have shown that in Poland young people between 20 and 29 years old are most frequent victims of such accidents [4]. Researchers are trying to determine the causes of accidents at construction sites [5] and to develop a methodology of actions that will reduce this risk [6], while paying attention to a large number of elements affecting work safety on scaffolding.

The risk of accidents is additionally increased by work in dynamically changing, often uncomfortable, external environment conditions. High or low temperatures can cause unfavorable changes in the body, even in case of workers accustomed to such weather conditions. High temperature affects the physical and mental state of man. When working in a hot microclimate, in order to maintain a constant body temperature, the body needs to quickly activate reactions and adaptation mechanisms to protect itself from overheating. With

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an unbalanced heat balance, the increase in body temperature by 1.0°C - 1.5°C can also cause an overload of almost all organs, in particular the circulatory system, and above 2.5°C circulatory disorders or even collapse [7]. High temperature increases irritation, causes indifference to phenomena occurring in the environment. The concentration decreases, the reaction time is longer and, as a result, there is an increase in errors at work [7]. Even above 32°C there is a drop in the efficiency of heavy work and above 35°C there is a risk of quick exhaustion of the employee's strength [8].

The continuous increase in greenhouse gases will cause more frequent, more intense and longer-lasting heat waves [9]. Changing climatic conditions can therefore be an increasing threat to people working on construction sites, especially on scaffoldings. As a consequence, the risk of situations that could lead to a hazardous event or an accident may increase. Environmental conditions should therefore play an increasingly important role in the accident risk assessment.

2 Thermal conditions

An approximate assessment of thermal conditions can be made on the basis of simple thermal indicators based on average or extreme air temperature values and the difference between the minimum and maximum values (daily fluctuations). For humans, the conditions in which there is very high or very low air temperature are onerous. For the temperature on a particular day [10]:

- between -10°C and -0.1°C – frosty day,
- between 0°C and 9.9°C – cold day,
- between 10.0°C and 14.9°C – chilly day,
- between 15.0°C and 19.9°C – warm day,
- between 20.0°C and 24.9°C – very warm day,
- between 25.0°C and 29.9°C – hot day,
- above 30.0°C – very hot day.

During evaluation of thermal conditions, it is possible to calculate the number of days when the temperature is above the given range. The degree of bio-thermal conditions burden increases with the number of very cold and frosty days as well as hot and very hot days.

To determine the stimulus of thermal conditions [10], also the diurnal temperature fluctuation is used - the difference between the minimum and maximum values, which significantly affects the human well-being. For a daily temperature change which are:

- lower than 4.0°C thermal stimulus is described as neutral,
- between 4.0°C and 7.9°C thermal stimuli are weakly felt,
- between 8.0°C and 11.9°C thermal stimuli are strongly felt,
- equal or higher than 12.0°C thermal stimuli are strong.

3 Research methods

3.1 Investigations of scaffoldings

The scaffolding research was conducted by five teams from the Faculty of Civil Engineering and Architecture at the Lublin University of Technology, Faculty of Management at the Lublin University of Technology, Faculty of Civil Engineering, Architecture and Environmental Engineering of the Lodz University of Technology and the Faculty of Civil and Water Engineering at the Wroclaw University of Technology. The scaffoldings were

located in various places in Poland. The study covered a total of 120 facade construction scaffoldings [10].

Measurements and their results presented in this article are part of the research in which information was collected about the scaffolding itself, its surroundings and scaffolding users. On the scaffoldings, among others, selected air climate parameters were examined: temperature, relative humidity, atmospheric pressure, wind speed and direction [12, 13] and lighting intensity, sound level [14], dustiness, and technical parameters: deviations from the ideal geometry of the scaffolding, technical condition of the elements, strength in the anchoring, forces in the stands, load-bearing capacity of the soil, frequency of natural vibrations, operation of wind on the scaffolding structure, operational loads [15, 16] and physiological parameters of employees [17].

The paper presents exemplary measurements and results of thermal parameters of air for selected scaffoldings located in Wroclaw. The scaffoldings on which the measurements were obtained were examined from May 30 to October 14, 2016. The scaffolding area ranged from 146 m² to 1303 m².

Three series of measurements were carried out each day. The first measurement was carried out from 8 a.m., the second from 11 a.m., the third from 3 p.m. Each sequence of measurements of air parameters lasted from one to about one and a half hour depending on the number of measurement spots. The selection of the number of spots on the work platform depended on the scaffolding width. For 1 scaffolding deck it was one measurement spot, for 9 and more scaffolding decks - four measurement spots (extreme and two middle scaffolding areas). The number of tested platforms depended on the scaffolding height and was respectively from one to three scaffolding levels (first, highest and half-height). In total, tests were carried out in six, eight, nine or twelve scaffolding spots. Table 1 presents a list of scaffoldings with the test date, width, height and number of measurement point.

Table 1. Scaffoldings contrasted.

Scaffold symbol	Date of the test	Width [m]	Height [m]	Number of measurement point
D01	30 May - 4 June	33.8	19.0	12
D02	30 May - 4 June	12.8	11.3	6
D03	06 June - 10 June	34.8	18.2	12
D04	04 July - 08 July	30.3	26.3	12
D05	11 July - 15 July	22.6	18.4	9
D06	08 August - 12 August	36.0	10.2	8
D07	16 August - 20 August	19.5	22.0	8
D08	12 September - 16 September	43.1	30.1	12
D09	19 September - 23 September	46.1	28.3	12
D10	10 October - 14 October	39.9	18.1	12

All scaffolds were tested during one working week.

An exemplary scaffolding with marked measurement spots is shown in Figure 1.

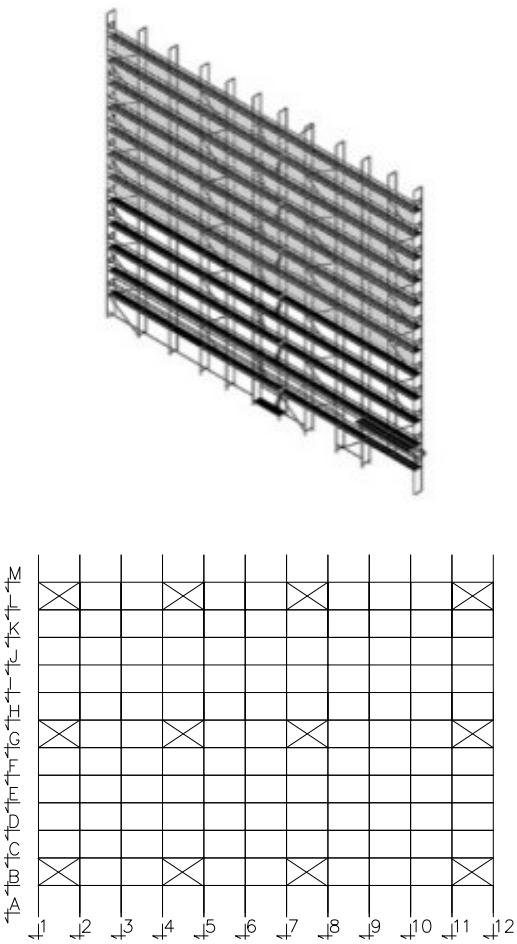


Fig. 1. Scaffolding scheme with marked measurement spots.

3.2 Measurement instruments

Measurements of climatic parameters were carried out using the multifunction AMI310 device with attached climate module registering the temperature. The measuring range of the probe used to measure the temperature ranged from -10°C to 45°C with sampling every 0.1°C. In each measurement area, the air temperature was measured at a height of approx. 1.5 m above platform level. The duration of the measurement in one spot was 4 minutes with a sampling period of 1 s.

4 Research results

Figure 2 presents examples of air temperature values that were measured on the D08 scaffold during 4 minutes on the fourth day of testing on the scaffolding, in the first measuring spot at around 8 a.m., 11 a.m. and 2 p.m.

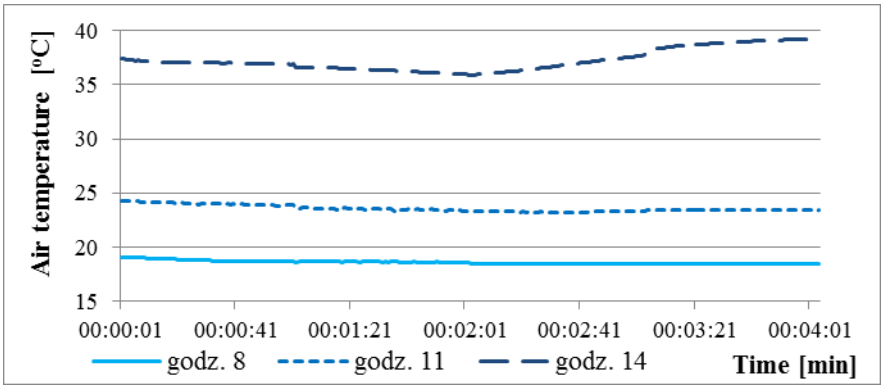


Fig. 2. Sample time history of air temperature measurements carried out on scaffolding.

Analysis of the obtained results shows that the temperature varied depending on the time of day. Table 2 lists the minimum and maximum air temperature values measured on ten scaffoldings. The minimum and maximum value are the lowest and the highest values recorded during tests conducted during one working week.

Table 2. Air temperature measured on the scaffolding.

Scaffold symbol	Air temperature	
	Minimal [°C]	Maximal [°C]
D01	19.4	**41.2**
D02	22.2	34.5
D03	17.0	39.3
D04	15.3	35.3
D05	16.9	**42.9**
D06	14.4	32.1
D07	20.3	34.9
D08	17.7	**42.5**
D09	12.3	29.0
D10	**5.3**	15.6

The maximum air temperature – 42.9°C value was observed on scaffolding D05 tested in July, while the lowest value for scaffold D10 tested in October was 5.3°C.
Due to the temperature change depending on the time of day and height, the measurements were divided by both time of day and scaffolding level.

The distribution of the probability of the occurrence of the T_w temperature range at the i time and at the scaffolding level j was determined for the scaffolding according to the following formula [13]:

$$P_{ij}(T_w) = \frac{S_{ij}(T_w)}{N_{ij}} \quad (1)$$

where N_{ij} - number of measurements at time i and at scaffold level j, S_{ij} - number of measurements at time i and on scaffolding level j with the temperature range T_w, calculated with the formula:

$$T_w = \frac{1}{n}\sum_{p=1}^{n} T_p \quad (2)$$

where: T_p - values from measurements at time i and on scaffolding level j, n - number of measurements at time i and on scaffold level j.
Then, the probability distribution of particular temperature values for the entire scaffold was determined according to the formula:

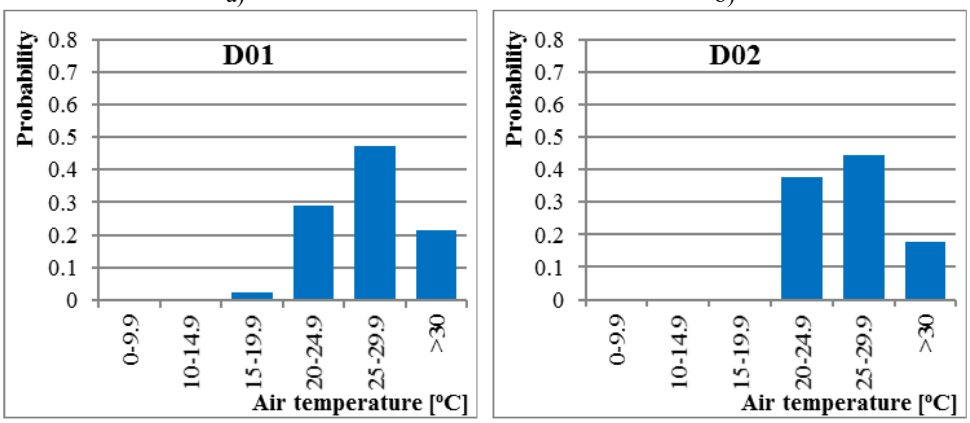
$$P(T_w) = \frac{1}{n_{level} n_{hour}} \sum_{j=1}^{n_{level}} \sum_{i=1}^{n_{hour}} P_{ij}\,(T_w) \quad (3)$$

where n_{level} – number of levels, n_{hour} – number of times during the day when measurements were obtained.

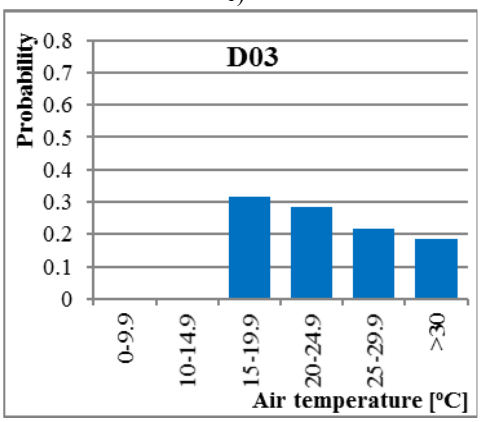
Figure 3 presents histograms of the probability distributions of occurrence of a given range of air temperatures for ten scaffoldings located in Wroclaw. The temperature ranges have been presented in a way which allows to determine the probability of occurrence of the above-mentioned thermal conditions.

On scaffoldings D09 and D10 that were tested at the end of September and at the beginning of October, there were the most favorable working conditions as far as temperature is concerned. On nine scaffoldings there were air temperatures between 25.0°C and 29.9°C, and over 30°C, which means that all onerous bio-thermal conditions were influencing scaffolders. During analysis of histograms some differences can be observed. The air temperature distribution on scaffold D10, measured in the period of the lowest temperatures, have the lowest number of divisions, and the maximum probability value of 0.75 is on the side of higher temperatures. In the case of the distribution on the scaffold D05 tested in the period when the maximum temperature was observed, the number of divisions is higher, the maximum probability value – 0.35 is also on the side of higher temperatures.

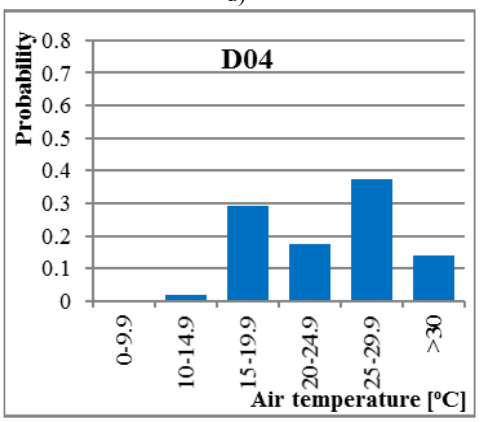
a) b)



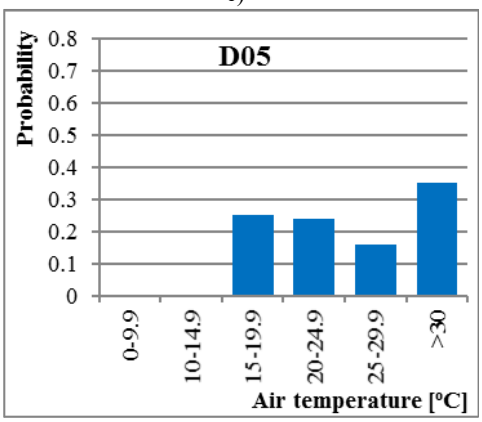
c)


D03
Probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-9.9
10-14.9
15-19.9
20-24.9
25-29.9
>30
Air temperature [ºC]

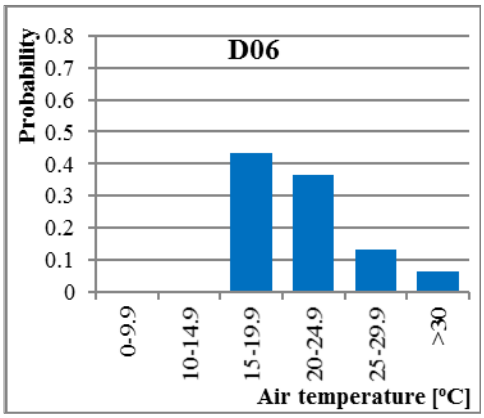
d)


D04
Probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-9.9
10-14.9
15-19.9
20-24.9
25-29.9
>30
Air temperature [ºC]

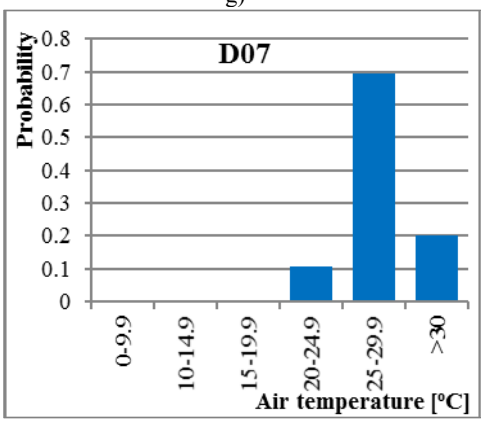
e)


D05
Probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-9.9
10-14.9
15-19.9
20-24.9
25-29.9
>30
Air temperature [ºC]

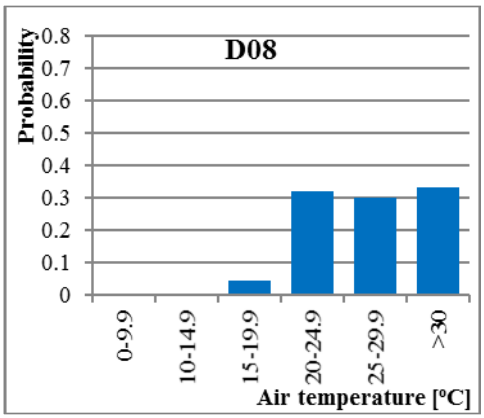
f)


D06
Probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-9.9
10-14.9
15-19.9
20-24.9
25-29.9
>30
Air temperature [ºC]

g)


D07
Probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-9.9
10-14.9
15-19.9
20-24.9
25-29.9
>30
Air temperature [ºC]

h)


D08
Probability
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-9.9
10-14.9
15-19.9
20-24.9
25-29.9
>30
Air temperature [ºC]

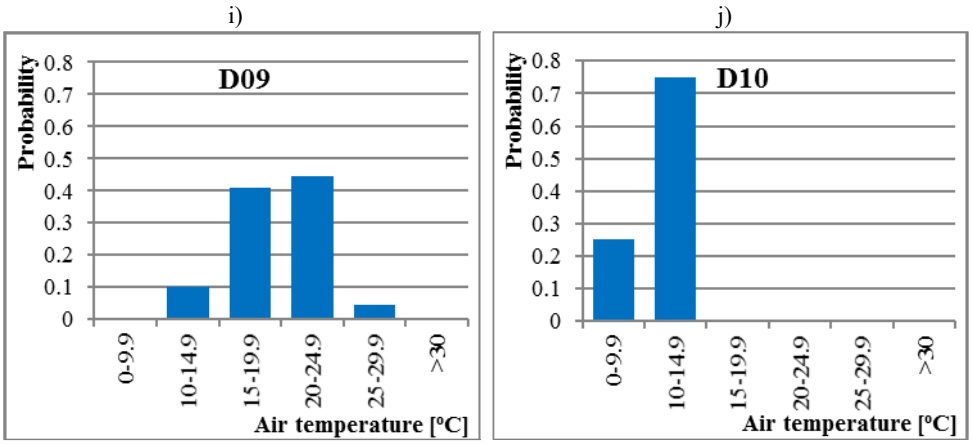


Fig. 3. Histogram of the probability distributions for scaffoldings: a) D01, b) D02, c) D03, d) D04, e) D05 f) D06, g) D07, h) D08 i) D09 j) D10.

Figure 4 presents the histogram of the probability distribution obtained for air temperature measurements on scaffolds D01 - D10.

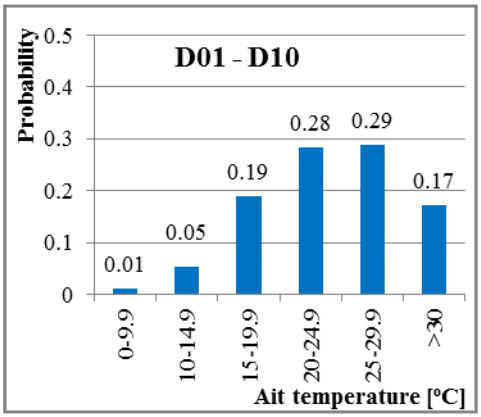


Fig. 4. Histogram of the probability distribution for scaffolds D01 – D10.

The results obtained indicate that the highest probability of 0.29 occurs at an unfavorable temperature range between 25.0°C and 29.9°C, when thermal conditions indicate that it is hot. Probability when it is hot and temperatures are above 30.0°C is 0.17. Employees are therefore exposed to high temperatures, which can increase the number of behaviors causing potentially hazardous situations. Figure 5 presents the histograms of the probability distributions of occurring difference in temperatures during one working day. Temperature differences were calculated for the minimum and maximum air temperature observed during one working day between 8 a.m. and 5 p.m. This is definitely a lower time difference than the one for which stimulus is defined.

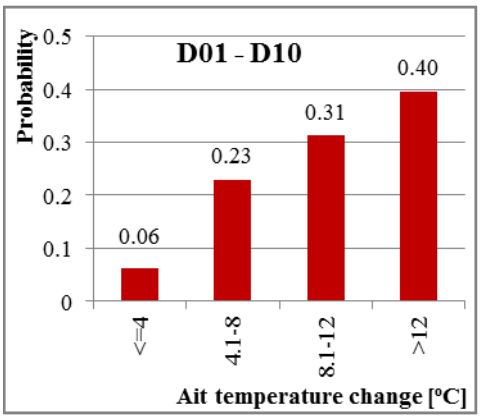


Fig 5. Histogram of distribution of air temperature change during one working day on scaffolds D01 – D10.

Analysis of the results makes it clear that in most cases the employees are affected by strong or acute thermal stimuli. The D01 - D10 scaffolds tests were carried out during 48 days. During this period, during 19 days there was over 12°C change in temperature, which constitutes 40% (probability value at the level of 0.4). Such temperature changes do not allow the worker to adapt to the surrounding temperature. In addition, the person working on the scaffolding often changes the workplace, including the level of the platform on which the work is done.

5 Conclusions

The performed analyses show that during construction works on the scaffolding there was an air temperature indicating the possibility of thermal disturbances that could influence men and cause danger during work on scaffolding. On three scaffolds D01, D05 and D08, the air temperature was above 40°C. The results also showed that the probability of unfavorable thermal conditions, i.e. air temperature higher than 25°C, is 0.47. In addition, employees are exposed in most cases to strong or severe thermal stimuli associated with large temperature differences during the working day. These are conditions in which physical effort should be temporarily reduced or limited. It is also necessary to temporarily use air-conditioned rooms, work in shaded places and stay hydrated.

Unfavorable, dynamically changing climatic conditions pose a serious threat to people working outside. They cause an increase in errors, and therefore the risk of situations that could lead to an accident increases.

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