A system for measuring environmental data in full-scale

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Abstract. The paper presents a system created for measuring wind speed and its direction in full-scale conditions. The system consists of devices used to measure environmental parameters in one point at a time and a complex weather station. On the basis of the results obtained from the first part of the system, the static effect of wind action on structures or climatic comfort can be approximated, while the second part of the system is used to determine the dynamic wind action on objects. The use of the designed system is illustrated by in-situ studies.

1. Introduction
There are three main ways to conduct research in wind engineering: 1. wind tunnel tests, 2. in-situ measurements, 3. CFD simulations. Nowadays, CFD is used more and more frequently to solve wind engineering problems, however, there is still a need to validate CFD results with wind tunnel data (eg. [1-2]) or even better with full-scale data (eg. [3]). Moreover, the use of CFD for wind engineering purposes often requires very huge computing power and produces several problems with scaling, and related to them issues with maintaining Reynolds number.

From the point of view of wind engineer and civil engineer there are not too many data about in-situ measurements of wind loading on different structures. There are a few buildings which throughout the years were measured in details and now the data collected on them are the base for wind tunnel tests and CFD simulations as well. Such structures are Commonwealth Advisory Aeronautical Council high-rise building, Texas Tech Building, and finally Silsoe Cube, all of them are thoroughly described in the literature. Recently, the more common monitoring of long span bridges, high-rise buildings etc. provides invaluable database of information. From the other hand, the urbanization of cities makes the flow more complex and estimation of the real wind action becomes almost impossible without extensive full-scale, model-scale or CFD investigations.

Various equipment designed for the measurements of wind speed, pressure, deflections of structures under wind loading is commonly used in full scale tests in wind engineering. Measurements usually concern the static and dynamic response of buildings to wind action (eg. [4-6]), chimneys (eg. [7-8]), and other structures. Many data come from measurements of the behavior of high-rise buildings during cyclones (eg. [9-10]) or investigations on the vertical wind profile in cities (eg. [11]) and spatial features of strong winds near ground (eg. [12-13]). Simple devices (such as KIMO) that are also a component of the measuring system described in this paper are less frequently used in wind engineering, and are mainly designed to investigate ventilation systems (eg. [14-17]).

This work presents application of a developed system designed for measuring climate parameters, mainly the parameters of the wind speed and its direction in a full-scale. The system consists of two parts: 1. two devices, each of them allows to measure the environmental parameters in one point in a space, 2. expanded weather station. The operation of the system is illustrated by examples.
2. Description of measuring devices

Basic information about environmental parameters are obtained with KIMO multifunction instrument AMI 310, held in hands or mounted in a given point of the structure. The described system uses two KIMO devices, each of them have the following probes: telescopic vane probe for wind speed measurements in one direction (Fig. 1a, Fig. 2) and other exchangeable modules, allowing measuring atmospheric pressure, humidity, temperature, and illuminance. The advantage of this device is its portability and the ability to set up in virtually any condition, as well as simultaneously recorded measurement data being saved directly on the device’s memory card. The main disadvantage is the relatively low resolution and low measurement accuracy. Usually such devices can be used for climatic comfort experiments, both inside and outside the building. In this paper an estimation of static wind action on the facade scaffolding is presented as the example. The detailed description of two different analyses, based on the data from the measurements performed with use of KIMO devices is presented in [18-19].

The second part of the measuring system – an extensive weather station – allows for simultaneous measurements of the wind speed and its direction in 6 points in the space (5x2D anemometers, and 1x3D anemometer – Fig. 1b,c), atmospheric pressure, temperature and humidity in one point and differential pressure in 16 points (Fig. 1d). The data are archived with the use of National Instruments equipment, which has been specially designed to manage these measurements (Fig. 1e). A description of the designed system, with the emphasis put on the cooperation of software and hardware is presented in [20] and the detailed description of sample measurements in [21]. Here, in this paper the short example which illustrates the capability of the system to estimate wind action on a scaffolding is enclosed.

![Figure 1. Components of the system.](image-url)
3. Examples of measurements

3.1. Static wind action

The use of the measuring system for estimation of the static wind action is based on KIMO data which are averaged over a given time, in the example below over 1-min. The operation of the system is illustrated by the example of its use on the façade scaffoldings (Fig. 2). Figure 3a shows the wind speed time history registered with the KIMO device around left top corner of the scaffolding showed in Fig. 2. The data were recorded during 1 minute every 1 second. Individual curves indicate two directions of the wind flow velocity, $v_1$, $v_2$, respectively perpendicular and parallel to the façade of the building. Moreover, there are $h$ – humidity and $T$ – temperature 60-sec. time histories in Fig. 3. To get an overview of overall wind action on the scaffolding, similar measurements were repeated in several points of the structure. The results based on one week course of measurements are presented in Fig. 4. There are statistical characteristics of the wind speed in both directions, and mean values of humidity and temperature for several repetitions of measurements (days and hours). The results concern point of measurements located at the left top corner of the scaffolding from Fig. 2.

More complex sample results based on the data measured on 50 scaffoldings in several points located at every object (from 4 to 12 locations) containing maximum and minimum values of the mean wind speed, standard deviation and gusts for $v_1$ (perpendicular component) are presented in Fig. 5. These data concern the whole one week course of measurements carried out on every structure and statistical values calculated from all points together. Measurements carried out at various locations on the scaffolding allow for estimation of the approximate value of the wind static load (more information in [18]). This approach is burdened with an error introduced by non-simultaneous measurements of the wind speed, what does not occur while using the second part of the system.

![Figure 2. Examples of measurements on scaffolding.](image)

![Figure 3. 60-sec measurements of climatic parameters: $v_1$ – ●, $v_2$ – □, $h$ – ○, $T$ – ◊.](image)
Figure 4. 60-sec statistical characteristics of climatic parameters: a) $v_1$, b) $v_2$, c) $h$ and $T$.

Figure 5. Characteristics of climatic parameters for 50 scaffolding structures.
3.2. Dynamic wind action

The second component of the measuring system eliminates weaknesses of the first one and can be used for determination of the dynamic wind action. The use of anemometers or pressure sensors allows gathering instantaneous data in high resolution, e.g., every 0.2 sec., which can illustrate the dynamic behavior of the flow or of the structure. The example of its use is illustrated by measurements also performed on scaffolding structures. Five 2D ultrasonic anemometers were hanged on consoles which were fixed to stands of the scaffolding. The 3D ultrasonic anemometer was mounted in a place where the flow is undisturbed by the object – on the roof of the building or fixed to the highest part of stands of the scaffolding. Such location of devices – in undisturbed flow (3D) and on the facade of the scaffolding (2D) – allows to estimate the real instantaneous as well as mean wind action on the structure. The data from 3D anemometer are used as the reference and provide information about the real direction of the flow on the structure and moreover, can be related to the nearest weather station. 2D measurements give the data that take into account the closest neighborhood of the building, presence of other buildings which can produce contraction of the flow or interference effect or edges that induce vortex shedding etc. A few examples of anemometers location on scaffolding structures are presented in Fig. 6.

The example of time history of wind speed and its direction measured in 3 points by 2D anemometers are presented in Fig. 7b–d. In this case anemometers were mounted to the scaffolding structure at the penultimate level of decks. The direction was defined against the facade of the scaffolding, where 0° means the flow perpendicular to the facade, so the value of approximately 100° (as in Fig. 7b–d) means that the wind acted from right. The duration of measurements was 1 hour, and the time step was 0.2 sec. Additionally, time histories of other climatic parameters (\( h \) – humidity, \( T \) – temperature) are shown in Fig 7a.
Figure 6. Examples of location of 3D and 2D anemometers on scaffoldings.

Another example presents the results of 10-min mean values of the wind speed and direction calculated on two scaffoldings (Fig. 8). The wind speed and its direction were measured on the facade with five 2D anemometers and on the roof of the building – with 3D device. In the above mentioned Fig. 8, the horizontal cross-section of the building and outer scaffolding standards are shown. The vectors are drawn in the appropriate scale and show the values and directions of the wind speed averaged over 10 minutes. Possible directions of the flow indicate complex distribution of the wind load on the scaffolding structure. In the first example, the placement of the scaffolding in the building wake can produce large forces at the edge (right corner) which can further lead to twisting of the structure. It should be underlined that such situation is not considered by any available design standards. The second example shows the situation in which the building façade had openings and the wind acting on the scaffolding could cause its detachment from the building façade. Detailed information about these results can be found in [21].
4. Conclusions
The described measuring system is a powerful tool which can help to determine wind conditions and other climatic parameters in the full-scale research. The portable devices, such as multifunctional AMI 310 can definitely be used to assess basic environmental data, but the fact that they can measure only one wind direction component at a time makes it more useful in unidirectional flow condition, rather than in real wind flow. Due to this fact the results can be treated as initial ones giving the general overview on the problem which can be precisely solved with use of the second part of the system. The more advanced part of the system composed of ultrasonic anemometers can allow for measurements of wind flow speed in few points at time, in two or three directions, giving more reliable results. Ultrasonic anemometers provide data which allow consideration of the dynamic wind action on the structure which, especially in urban environment, is usually difficult to predict. Both systems could be applied to determine environmental parameters before design process as well as can provide useful data about environmental actions on already existed structures, as it is presented in the paper.

Figure 7. Measured values: a) humidity and temperature, $h -$ ○, $T -$ □, b) wind speed, c) wind direction, d) rose plots of wind direction against the facade of scaffolding.
Figure 8. 10-min mean values of wind speed and its direction, a) scaffolding P10, b) scaffolding W07.

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