EVALUATION OF MICROCLIMATIC CONDITIONS IN URBAN ENVIRONMENT FROM THE HUMAN COMFORT PERSPECTIVE

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ABSTRACT

The paper presents a new assessment method for microclimatic conditions in the urban environment. The proposed model defines quantitative and qualitative features of the study area from the human comfort aspect. Two main elements of the urban environment, weather conditions and urban development are evaluated.

To determine whether the environment is comfortable for inhabitants, a simple criterion of comfort has to be established. This criterion must take into account the complex nature of heat exchange between a man and environment. In the light of extensive research carried out in many countries it can be demonstrated that there is a correlation between the intensity of heat fluxes with air temperature and wind speed, which allows approximations to be applied. This parameter can be used for the relative comparison of different environmental conditions. Taking into account the efficiency ranges of the thermoregulatory systems (applied in thermophysiology), criteria for thermal comfort can be established.

For the assessment of weather conditions, a weather typology is proposed. Human thermal sensation caused by the reaction of the thermoregulatory system to atmospheric stimuli (air temperature, wind speed) are related to the specific type.

The second important element affecting the final assessment of microclimatic conditions is the structure of the urban area i.e. participation of the various urban structures, tall vegetation and open area in the total surface as well as zones with wind comfort and discomfort. The above estimation is carried out using numerical simulations, assuming wind speed 4m/s and by simultaneously taking into account frequencies of wind flow occurring from 8 or 12 directions and related air temperature.

The proposed method in its current version constitutes an approximation only. Many parameters, such as land profile, shadow fall, or heat loss by the external surfaces of the building, are not included. However further future developments and incorporation of other parameters are possible.

Keywords: microclimate, human comfort, CFD

INTRODUCTION

Dense urban structures in city areas affect unique microclimatic conditions and hence greatly influence residents' comfort. In some situations, local problems associated with excessive airflow in the vicinity of buildings or formation of strong turbulences, may arise. At the same time, tall, concentrated buildings may significantly decrease urban ventilation thus resulting in deterioration of hygienic conditions and potential local accumulations of snow or pollution. The degree of urban areas ventilation also depends on the climatic conditions of individual residential districts, as these may enhance or counteract the influence of urban development. The assessment of environmental impacts on human presence is a complex issue, as the consideration of a great number of variables that characterise individual occurrences, are necessary. The descriptive method and the model method are the most frequently used for these purposes. The quantitative and qualitative structure of the external environment should be considered in the assessment of microclimatic conditions. For this purpose two models: an exponential function model and a model analogous to Ohm's law can be used. In the exponential function model, the function base characterises quantitative features of the environment $y = x^z$, while the index exponent – its qualitative features. The value of the function y ranges between 0 and 1. No favourable features of the environment occur for $y = 0$, and the ideal state is recorded for $y = 1$. Values x fall within the range of variable between 0 and 1 whereas z may range between 0 and $+\infty$. For the most favourable qualitative features $z = 0$ the function y equals 1, [1]. The second model can be described by:

$$y_i = \frac{P_i}{R_i} \tag{1}$$

where:

y_i – value of a given parameter

P_i – potential, treated as favourable features of the environment

R_i – resistance, treated as the conditions that make long-term human occupation difficult or impossible

Finally, the proposed model is a combination of two above mentioned models and has the following form:

$$y = \left(\frac{P_x}{R_x}\right)^{\frac{R_z}{P_z}} \tag{2}$$

where:

P_x, R_x – potential and resistance of quantitative features

P_z, R_z – potential and resistance of qualitative features

HUMAN COMFORT CRITERIA

The comfort sensation is associated with changes in body temperature caused by an increase or decrease in ambient temperature, the cooling effect of wind, and the convective and the radiative heat loss from the body. There are a number of factors which affect the heat exchange between man and the external environment. The most important physical parameters include: air temperature, wind speed, solar radiation, relative humidity and radiation temperature. Equally important are the parameters related to the individual person, such as the activity, exposure time, clothing thermal insulation and finally the psychological factors associated with the level of adaptation, expectations or previous experiences, [2,3]. The inclusion of so many factors requires the application of complex models and detailed meteorological and physiological data, which in practice are difficult to obtain. As a result there is a need for a more simplified method of determining criteria for human comfort in open areas.

In the light of extensive research carried out in many countries described by [4] it can be demonstrated that there is a correlation between the intensity of heat fluxes with air temperature and wind speed, which allows approximations to be applied. In order to identify thermal criteria based on heat balance equations, some assumptions have been made:

Metabolism M – 70W/m^2

Thermal insulation of the cloths 1 clo

Solar radiations absorption R – 30W/m^2

Heat exchange through evaporation Q_E – 8W/m^2 for T_a < +5^{o}C, 20W/m^2 for T_a ≥+5^{o}C

Heat exchange through conduction Q_K is not taken into account

Heat loss caused by respiration Q_R - 8W/m^2

Furthermore heat transfer by convection and long wave radiation, based on temperature and wind speed, are specified thus:

For weather conditions where wind speed U≤4m/s and temperature T_a≥+5^{o}C

$$Q_C + Q_L = 3{,}4T_a + 0{,}2\overline{U} - 118{,}8 \tag{3}$$

Where the wind speed U≤4m/s and temperature T_a<+5^{o}C

$$Q_C + Q_L = 1{,}7T_a + 6{,}0\overline{U} - 101{,}4 \tag{4}$$

Where the wind speed U>4m/s and temperature T_a≥+5oC

$$Q_C + Q_L = 3{,}3T_a + 0{,}2\overline{U} - 127{,}8 \tag{5}$$

Where the wind speed U>4m/s and temperature T_a<+5^{o}C

$$Q_C + Q_L = -1{,}5T_a + 0{,}3\overline{U} - 126 \tag{6}$$

By applying the above to the heat balance equation, thermal loads on the body were derived.. The parameter can be used for the relative comparison of different environmental conditions.

In weather conditions where wind speed U≤4m/s and temperature T_a≥+5^{o}C

$$\Delta Q = 2{,}8T_a - 4{,}8\overline{U} - 29{,}8 \tag{7}$$

Where the wind speed U≤4m/s and temperature T_a<+5^{o}C

$$\Delta Q = 1{,}7T_a - 6{,}0\overline{U} - 23{,}0 \tag{8}$$

Where the wind speed U>4m/s and temperature T_a≥+5^{o}C

$$\Delta Q = 2{,}3T_a - 3{,}5\overline{U} - 35{,}4 \tag{9}$$

Where the wind speed U>4m/s and temperature T_a<+5^{o}C

$$\Delta Q = 1{,}5T_a - 3{,}0\overline{U} - 34{,}0 \tag{10}$$

Taking into account the efficiency ranges of the thermoregulatory systems, which are applied in thermophysiology, the criteria for thermal comfort were established based on the following thresholds for heat loads on the body ΔQ.

$|\Delta Q|$ < 20W/m^2 - comfortable condition

$|\Delta Q|$ in ranges 20 – 40 W/m^2 – unfavourable loads on the body,

$|\Delta Q|$ in ranges 40 - 80 W/m^2 – strong unfavourable loads on the body

$|\Delta Q|$ > 80W/m^2 - dangerous loads on the body

ASSESSMENT OF WEATHER CONDITIONS

For the purpose of the study, a weather typology was proposed. As the basic feature of the weather type, human thermal sensation caused by the reaction of the thermoregulatory system to atmospheric stimuli (air temperature, wind speed) were used. Three types of weather conditions and twenty groups were determined.

In the assessment of weather conditions, quantitative features are represented by the occurrence of favourable and unfavourable weather types from a human comfort point of view. Qualitative features of weather conditions may be described by the parameters of the intensity of wind speed, wind direction and air temperature changes. Intensity changes were defined as the relation of a standard deviation to mean value.

$$K_w = \left[\frac{cA_1 + cA_2 + cA_3 + cA_4 + cA_5}{1 + \left(cC_1 + cC_2 + cC_3 + ...cC_8 \right)} \right]^{\left[\frac{\left(1+I_U^C\right)\left(1+I_k^C\right)\left(1+I_T^C\right)}{\left(1+I_U^A\right)\left(1+I_k^A\right)\left(1+I_T^A\right)} \right]} \tag{11}$$

where:

cA_1, cA_2, cA_3, cA_4, cA_5 – occurrence frequency of favourable weather conditions, defined by groups A_1, A_2, A_3, A_4, A_5,

cC_1, cC_2, $.....cC_8$ – occurrence frequency of unfavourable weather conditions, defined by groups C_1, C_2, $.....C_8$,

I_U^A, I_U^C - intensity of wind speed changes in *A* and *C* weather groups, I_k^A, I_k^C - intensity of wind direction changes in *A* and *C* weather groups,

I_T^A, I_T^C - intensity of air temperature changes in *A* and *C* weather groups.

ASSESSMENT OF URBAN DEVELOPMENT

The second important element having an effect on the final assessment of microclimatic conditions is the structure of the urban area i.e. participation of the various urban structures, tall vegetation and open area in the total surface as well as zones with wind comfort and discomfort. The above estimation is carried out using numerical simulations, assuming wind speed 4m/s and by simultaneously taking into account frequencies of wind flow occurring from 8 or 12 directions and also it's related temperature.

The participation of the open area Z_w in the total surface was considered to be the potential of quantitative features of the land development coefficient Z_t and the participation of various urban structures and green areas in relation to the study area was considered to be their resistance (Z_m). The quantitative features may be described by:

$$x = \frac{Z_w}{1 + Z_m} \tag{12}$$

The qualitative features z may be described by:

$$z = \left[\frac{1 + Z_1^C}{1 + Z_1^A} . \frac{1 + Z_2^C}{1 + Z_2^A} ..... \frac{1 + Z_8^C}{1 + Z_8^A} \right] \tag{13}$$

From the human sensation point of view, uncomfortable conditions are influenced by wind flow and air temperature. Weak air flow in built-up areas is leading to deterioration of hygienic conditions and encourage local accumulation of pollution whereas increased speeds can trigger dynamic loads. Simultaneously even at moderate wind conditions the local discomfort may appear, due to low or high temperature. This fact was considered in proposed qualitative features.

The resistance of qualitative features was determined from the equation

$$Z_k^C = Z_k^{C(U)} + Z_k^{C(T)} \tag{14}$$

The first element in the equation describes situations in which, due to low wind speed ventilation of the area, is problematic (U<1m/s) and situations in which high wind speed can cause discomfort (U>4m/s). In order to assess wind flow conditions around buildings and determine size of zones in which wind speed reaches values lower than 1m/s and over 4m/s numerical simulations can be used.

$$Z_k^{C(U)} = \left[\frac{S_k^{U<1}}{S_{Lg}} + \frac{S_k^{U>4}}{S_{Lg}} \right] \cdot f_k^{U=4} \tag{15}$$

where: $\frac{S_k^{U<1}}{S_{Lg}}$ and $\frac{S_k^{U>4}}{S_{Lg}}$ - ratios of the areas of zones in which wind speed U < 1 m/s and U > 4 m/s to the surface S_{Lg}, which is characterised by clear fluctuations in wind speed caused by buildings. Surface size S_{Lg} is determined on the basis of principle pro-posed by Bottema [5]. The length L_g is specified using the formula

$$L_g / H = \frac{W/H}{1 + 0{,}5W/H} \tag{16}$$

where:

L_g – geometrical influence scale [m],

W – building width [m],

H – building height [m].

Since the wind speed U_{ref} = 4 m/s (wind speed measured at the meteorological station at a height of 10m) assumed in the numerical simulation as the inflow wind speed occurs with different probability on different directions, it was necessary to introduce weighting coefficient , resulting from meteorological data analysis.

The second element in eq. 14 refers to conditions when de-spite comfortable wind speed thermal loads of human body exceeded 40W/m^2.

$$Z_k^{C(T)} = \left(\frac{S_k^{1 \le U \le 4}}{S_{Lg}} \right) \cdot f_k^{U=4} f_k^{U=4, \Delta Q>40} \tag{17}$$

where:

$f_k^{U=4, \Delta Q>40}$ - weighting coefficient taking into account the thermal conditions on the direction of k, when the heat loss of the body exceeds 40 W/m^2, and the inflow wind speed is at the level of 4 m/s.

The potential of qualitative features describes situations in which human comfort is achieved through moderate wind speed (1≤U≤4) and temperature which guarantee thermal loads ΔQ≤20W/m^2.

$$Z_k^A = \left(\frac{S_k^{1 \le U \le 4}}{S_{Lg}} \right) f_k^{U=4} f_k^{U=4, \Delta Q \le 20} \tag{18}$$

where:

$f_k^{U=4,\Delta Q\leq 20}$ - weighting coefficient taking into account the thermal conditions considered as comfortable on the direction of k, when the thermal loads $\Delta Q \leq 20 W/m^2$ and the inflow wind speed is at the level of 4m/s.

The above mentioned qualitative features were determined by use of numerical simulation of wind flow around buildings and analysis of meteorological data.

After all the urban development coefficient was described by:

$$Z_t = \left(\frac{Z_w}{1+Z_m} \right)^{\left[\frac{1+Z_1^C}{1+Z_1^A} \cdot \frac{1+Z_2^C}{1+Z_2^A} \cdots \frac{1+Z_8^C}{1+Z_8^A} \right]} \quad (19)$$

After all the urban development coefficient was described by:

$$B_k = \left[0{,}2K_w + 0{,}8Z_t \right] \quad (19)$$

CONCLUSION

The paper presents a proposition of an assessment method for microclimatic conditions in the urban environment. An assessment model defines quantitative and qualitative features of the study area from the human comfort aspect. Two main elements of the urban environment, local climate and urban development are evaluated. The proposed method constitutes a certain approximation due to many unincluded parameters, such as the lay of the land, shadow fall, or heat lost by the external surfaces of the building. Construction of the model also allows the taking into account of other elements. Knowledge of environmental conditions, as well as the appropriate application of the assessment results, greatly contributes to increasing the quality of resident's living conditions.

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