INFLUENCE OF URBAN STRUCTURE ON MICROCLIMATIC CONDITIONS IN VIRTUAL RESIDENTIAL DISTRICTS

Katarzyna Klemm

Summary

An assessment method of microclimatic conditions in urban regions is presented. The proposed method defines quantitative and qualitative features of the study area. Two elements of the urban environment, wind conditions and urban development, are evaluated. Meteorological data analysis and simulation methods were used to determine individual parameters.

Keywords: Microclimate, urban structure, wind

1 Introduction

The external environment, determined by natural conditions, such as the climate or topography, and anthropogenic factors, that is urban development, the density of urban structures or the size of green areas, has a major impact on living conditions. Dense urban structures in city areas affect unique microclimatic conditions that greatly influence residents' comfort. Local problems connected with excessive air flow in the vicinity of buildings or the formation of strong turbulences may arise in some situations. At the same time, groupings of tall, concentrated buildings sometimes cause a significant decrease in urban ventilation. This may lead to the deterioration of hygienic conditions and encourage local accumulations of snow or pollution. The ventilation degree of urban areas also depends on climatic conditions of individual residential districts as they may enhance or counteract the influence of urban development. The knowledge of environmental conditions and the appropriate application of the assessment results greatly contribute to increasing residents' living comfort. An assessment model used to examine wind conditions in selected urban organisation structures is proposed and discussed.

2 Assessment model of microclimatic conditions

The suitability of its elements for defined aspects of human occupation is the basic assessment criterion of the microenvironment. Factors such as the climate or urban development play an important role in this respect [1]. The quantitative and qualitative structure of the external environment may be considered in the assessment of environmental conditions using two models: an exponential function model and a model based on Ohm's law. 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 +∞. For the most favourable qualitative features z = 0 the function y equals 1.
In the model based on Ohm's law:

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

- y_i value of a given parameter
- U_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

In accordance with Blazejczyk's [1] conception, who proposed combining both models, accepting the condition $z = y_i^{-1}$ for qualitative features, the assessment model of microenvironmental features has the following form.

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

- U_x, R_x potential and resistance of quantitative features
- U_z, R_z potential and resistance of qualitative features

2.1 Assessment of wind conditions

In the assessment of wind conditions, occurrence frequencies of favourable and unfavourable wind speeds in a given year constitute quantitative wind features. The frequency of weather types favourable for subjective human heat perception is accepted to be potential (U_x) and the frequency of unfavourable conditions to be resistance (R_x).

$$x = \frac{NA_2 + 0{,}75NA_3}{1 + NA_1 + N(BC)} \tag{3}$$

- NA_1, NA_2, NA_3 occurrence frequency of wind conditions classified as A_1, A_2 and A_3
- N(BC) occurrence frequency of wind conditions B and C unfavourable for people in the study period

For the purposes of this assessment, a weather classification based on the subjective perception of various weather types was used. Following the weather typology devised by the Institute of Geography and Spatial Organization, Polish Academy of Sciences [2], human heat perception caused by the reaction of the thermoregulatory system to atmospheric stimuli (air temperature, wind speed) and the wind's mechanical effect on people and environment were used as the basic features of weather types.

Tab. 1 Types of wind weather

Weather type	A_1	unfavourable wind conditions due to decreased aeration	Wind speed [m/s]	0÷1,0
	A_2	wind conditions tolerable for active relaxation and work, clothes flapping		1.0÷3.0
	A_3	conditions in which dust and paper are lifted		3.0÷5.0
	B_1	wind force perceptible on the body, possible tripping		5.0÷8.0
	B_2	impeded walking, unpleasant sounds		8.0÷10
	C	difficulty in controlling walking, difficulty in keeping balance		>10

Qualitative features of wind conditions may be described by the parameters of the intensity of wind direction changes and the mean participation of the n wind direction. They may be determined using the equation:

$$z = \frac{1+I_N}{1+I_K} \cdot \frac{1+N_N}{1+N_K} \tag{4}$$

I_N intensity of wind direction changes for wind speeds lower than 1m/s and greater than 5 m/s

I_K intensity of wind direction changes for wind speeds 1÷5 m/s

N_N mean wind participation for wind speeds >5 m/s and <1 m/s and n wind directions in the study period

N_K mean wind participation for wind speeds 1÷5 m/s and n wind directions in the study period

The intensity of wind direction changes may be determined from the equation:

$$I_N = \frac{1{,}07\sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}\left(N_{Ni}-\langle N_{Ni}\rangle\right)^2}}{\langle N_{Ni}\rangle} \quad \text{for wind speeds <1 m/s and > 5 m/s} \tag{5}$$

$$I_K = \frac{1{,}07\sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}\left(N_{Ki}-\langle N_{Ki}\rangle\right)^2}}{\langle N_{Ki}\rangle} \quad \text{for wind speeds 1÷5 m/} \tag{6}$$

N_{Ni} occurrence frequency of speeds <1 m/s and >5 m/s for i wind directions in the study period

N_{Ki} occurrence frequency of speeds 1÷5 m/s for i wind directions in the study period, i = 1,2,...8

$$\langle N_N\rangle = \frac{\sum_{i=1}^{n} N_{Ni}}{n} \qquad \langle N_K\rangle = \frac{\sum_{i=1}^{n} N_{Ki}}{n} \tag{7}$$

Having substituted x, z in the general model, a dimensionless coefficient of wind conditions is obtained:

$$W_k = \left[\frac{NA_2 + 0{,}75NA_3}{1 + NA_1 + N(BC)} \right]^{\left[\frac{1+I_N}{1+I_K} \cdot \frac{1+N_N}{1+N_K} \right]} \tag{8}$$

Climatic conditions may be assessed using the categories of the coefficient W_k as follows:

≤ 0.20 – unfavourable
0.20 ÷ 0.40 – relatively unfavourable
0.40 ÷ 0.60 – moderate
0.60 ÷ 0.80 – favourable
≥0.80 – very favourable

The above classification is the present author's suggestion. Other quantitative and qualitative parameters may be used instead of the proposed features of weather conditions.

2.2 Assessment of urban development

The impact of urban development on microclimatic conditions is assessed using the organisation of a dense urban structure and the range of tall and low vegetation areas. 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 occurrence of zones for which wind speeds ranged between 1m/s and 5m/s (S_{Ki}) was accepted as the potential of qualitative features and the participation of zones with threatened human balance in the study area and poorly aerated zones (S_{Ni}) for the i direction, i = 1,2 ... n, was accepted as their resistance.
The urban organisation coefficient is as follows:

$$Z_t = \left(\frac{Z_w}{1 + Z_m (1 + R_{zs})} \right)^{\left[\frac{1+S_{Ni}}{1+S_{Ki}} \cdots \frac{1+S_{Nn}}{1+S_{Kn}} \right]} \tag{9}$$

$Z_w = 1 - Z_m(1+R_{zs})$

Coefficients S_{Ni} and S_{Ki} are determined from the equation:

$$S_{Ni} = \frac{S_{Ni}}{S_o} \int_w \int_v \qquad S_{Ki} = \frac{S_{Ki}}{S_o} \int_w \int_v \tag{10}$$

S_{Ni} zone surface with speeds <1 m/s and >5 m/s, caused by a varied urban structure for i wind direction
S_{Ki} zone surface with speeds 1÷5 m/s for i wind direction
$\int_w$ weight factor dependent on the wind direction
$\int_v$ weight factor dependent on wind speed changes
S_o surface of the total urban study area
R_{zs} coefficient of urban structure density

The values of the coefficient Z_t may be grouped depending on the suitability degree of urban development (**Tab. 2**).

Tab. 2 Coefficient of urban development assessment depending on area suitability

Z_t	Urban organisation
≤ 0.2	unfavourable
0.2 ÷ 0.3	relatively unfavourable
0.3-0.4	moderate
0.4-0.5	favourable
≥ 0.5	very favourable

The classification accepted after K. Blazejczyk's [1] conception in the bioclimatic assessment.

2.3. Overall assessment of environmental conditions

The overall assessment of environmental conditions may be described by the coefficient B_k expressed by:

$$B_k = \frac{W_k + Z_t}{2} \tag{11}$$

Coefficient values may be classified on the basis of Blazejczyk's [1] conception (tab. 3).

Tab. 3 Coefficient of the overall assessment of environmental conditions

B_k	Conditions
≤ 0.175	unfavourable
0.176 – 0.317	relatively unfavourable
0.318 – 0.459	moderate
0.460 – 0.574	favourable
≥ 0.575	very favourable

3 Application of the method: example

The wind microclimate of two virtual residential districts was assessed using the above equations. **Fig. 1** and **Fig. 2** present the urban organisation of the districts. Each system consists of six buildings located in the suburban area. Two building types were examined in the systems: 5-storey cubes and 12-storey rectangular prisms. Minimum distances for transport and green areas were designed between the buildings. An area located in Warsaw was analysed. Meteorological data used in the assessment of wind conditions covered the decade between 1976 and 1985.

Quantitative features of wind conditions were determined using the occurrence frequency analysis of individual groups and subgroups of wind conditions. Using the equations given in part 2 and the determined occurrence frequencies of wind weather types, the dimensionless assessment coefficient of wind conditions, $W_k = 0.66$, was calculated. Urban development was assessed next. Urban structures with constant urban development value $S_o = 3360\ m^2$ were considered. The surface of the area studied was a circle with the radius $R_o = 140$ m. Coefficients S_{Ni} and S_{Ki} were determined in numerical simulations of the air flow around the urban systems analysed for eight directions of air inflow and the urban development coefficient was calculated.

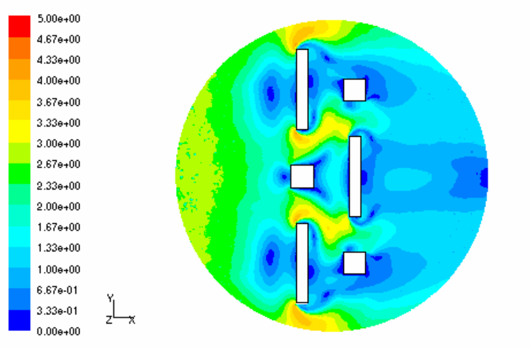

Fig. 1 Wind speed distribution for west wind direction. System I

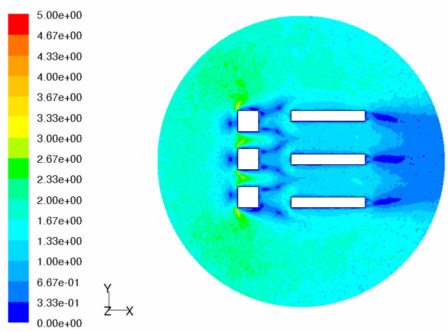

Fig. 2 Wind speed distribution for west wind direction. System II

Tab. 4 Values of basic factors

Urban structure (variant)	Percentage of urban structures and green areas in total area Z_m	Structure density coefficient R_{zs} $(1- R_{sr}/R_o)$	Urban development assessment coefficient Z_t	Overall coefficient of wind microclimate assessment B_k	Conditions
I	0,05	0,717	0,59	0,54	favourable
II	0,05	0,802	0,35	0,42	moderate

4 Conclusion

The proposition of an assessment method of wind condition in urban structures is presented in the paper. In the second part of the paper two virtual residential districts with different urban organisation have been investigated. In order to predict wind flow patterns around buildings numerical simulation based on the K - ε turbulence model has been used. Application of this method allows for determination the size of the zones with different levels of influence on pedestrian comfort and ventilation. The overall assessment of environmental condition based mainly on wind parameters demonstrated that in the case of system I wind condition can be described as favourable. The urban organisation cause wind speed acceleration, especially near the corners of the buildings and thereby improve ventilation process. The second system is characterised by moderate condition. This is caused mainly by lower wind speed values comparing with previous system. Application of the above method allows for initial comparison of different urban structures in order to create the comfortable environment for residents. However this proposition refers only to wind condition. Assessing environmental impacts on human presence is a complex issue as the consideration of a number of variables that characterise individual occurrences is required. In the future works more elements will be take into the consideration.

References

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Katarzyna Klemm, Ph.D.
✉ Institute of Architecture and Urban Planning Technical University of Lodz
Al. Politechniki 6
90-924 Lodz, Poland
☎ +4842 631 35 56
🗐 +4842 631 35 56
☺ katarzyna.klemm@p.lodz.pl
URL www.arch.p.lodz.pl