UNIVERSITY OF SZEGED
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ASSESSMENT OF THERMAL COMFORT CONDITIONS IN PUBLIC URBAN AREAS OF SZEGED WITH SPECIAL REGARD TO SUBJECTIVE HUMAN REACTIONS

theses of PhD dissertation

NOÉMI KÁNTOR

Supervisor:
DR. JÁNOS UNGER
head of department – associate professor

Advisor:
DR. ÁGNES GULYÁS
assistant professor

DEPARTMENT OF CLIMATOLOGY AND LANDSCAPE ECOLOGY
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1 RESEARCH PROBLEM AND OBJECTIVES

Many people are exposed to the effects of the altered urban atmospheric conditions due to the fact that more than half of the global population lives in urban environments. Furthermore, considering the regional challenges arisen from the global climate change, Hungary has to be prepared for more frequent, longer lasting and more intense heat waves in order to avoid such dramatic increase in mortality like in France in summer, 2003. The harmful effects of the predicted deteriorating thermal conditions in the warm season can be mitigated in urban environment by adequate land use planning strategies.

My dissertation is related to the field of **urban bioclimatology** (urban human bioclimatology), an interdisciplinary science investigating the physiologycal impacts of the urban atmospheric conditions on the human body. Out of the wide-ranging fields of urban bioclimatology, my study focuses on the so called thermal complex, i.e. the climatic parameters affecting thermal sensation and human thermal comfort by influencing on the thermoregulation. According to my opinion, results of the urban bioclimatology may be valuable basic information for urban planners and contribute to the development of climate(change)-conscious planning and design strategies. However, professional proposals require profound investigation of outdoor thermal comfort, particularly the way how inhabitants react to thermal conditions. Therefore, my work deals not only with the thermal characteristics in different urban public places and their physiological (bioclimatological) impacts, but also the triggered physical (behavioral) and psychological (mental) human reactions.

Major motivation during my PhD work was to contribute with results and with their comprehensive discussion to the extensive international and the initial Hungarian database about urban thermal comfort. Additionally, in order to facilitate future researches in this field in Hungary and the reproduction of my measurements in other cities, an investigation protocol is provided for the complex examination of open-air thermal comfort conditions based on a tentative background model. Therefore, great emphasis is placed on the clear documentation of the applied (adopted and adapted) research techniques, especially on the less-known human bioclimatological methods in Hungary and their theoretical fundamentals necessary for understanding.

In the light of above-mentioned my **objectives** can be summarized as follows:

- To provide a thorough overview about the human bioclimatological evaluation of the thermal environment, i.e. about the most important measures (as the objective basis for the assessment) and the complex international termal comfort studies in urban areas.
- To present the complex investigations carried out in Szeged, as well as the obtained results focussing on the:
  - effect of public space design on the micro-bioclimatological conditions at different weather conditions;
  - impacts of thermal parameters of the actual weather on the spatio-temporal patterns of the area usage, as well as the behavioral reactions of the visitors;
  - various manifestations of the subjective assessment of the thermal environment, emphasizing the way how individuals' thermal sensation changes according to the objective parameters of the thermal environment.
- To discuss the primer outcomes on local as well as international scales and extend the results according to the findings:
  - to interpret the on-site thermal conditions, as well as the patterns of area usage and behavioral responses in the light of the subjective thermal assessment of local individuals;
  - to compare the results obtained in Szeged with the outcomes of international studies based also on simultaneous human and environmental monitoring;
  - to integrate the Hungarian data into the largest European thermal comfort database in order to reveal more accurately the role of the climatic background (determined by the geographical location) on the way how local individuals rate the thermal environment.
- To draw conclusions on the different levels of adaptation (physiological, physical and psychological) to the atmospheric environment, as well as on the applied research methodology.

2 RESEARCH METHODS

In order to reveal the complex cause and effect relationship-system releated to the outdoor thermal comfort, a comprehensive investigation-series was started in Szeged (46°N, 20°E, 78-85 m asl.) in the spring of 2008. Over the years, within the scope of the Department of Climatology and Landscape Ecology (University of Szeged), these investigations have been extended to an independent urban bioclimate project.

Study areas of the project were 7 outdoor public spaces locating (mainly) in the inner-city of Szeged, with different design and functional characteristics. Short descriptions of these places are the following: (i) a small public park with high proportion of green area (Ady Square), (ii) a large park with several old trees (Széchenyi Square), (iii) a park covered mainly with artificial materials (Dugonics Square), (iv) a park covered mainly with grass and with some little trees (Szt. István Square), a pedestrian area with artificial surface cover (Kárász Street), (vi) a playground with significant amount of trees (Honvéd Square), and (vii) an other playground with less vegetation (Retek Street). Artificial and natural obstacles (buildings, street furniture, trees) as well as the surface cover were carefully mapped before the on-site investigations. Georeferenced maps have been constructed with ArcView GIS software.

The selected investigation design was based on measurements on the site, taking the advantage of its several methodology-groups:

- From objective side this means the **detection of the micrometeorological parameters** on the selected places with a special mobile station, having sensors placed at 1.1 m (average height of a standing man's centre of gravity). These parameters are the air temperature (T_a), the relative humidity (RH), the wind speed (v) as well as the short- and longwave radiation fluxes (K_i, L_i). During the data processing phase, bioclimatological indices were calculated from the collected datasets. At first the °C-dimension measure of thermal radiation, i.e. the mean radiant temparature (T_{mrt}) was calculated from the individual K_i, and L_i fluxes. Thereafter, the RayMan model was used to compute the most acceptable and widely used measures of the thermal strain and human thermal sensation, i.e. the bioclimate indices PET (physiologically equivalent temperature) and UTCI (universal thermal climate index) from the measured T_a, RH, v, and the calculated T_{mrt}.

- Thermal factors of the actual weather conditions, i.e. T_a, RH, v and G (global radiation) were also processed. 10-minute averages of these parameters were downloaded from the database of the inner-city meteorological station of Szeged run by the Hungarian Meteorological Service. Before the bioclimate index calculation values of wind velocity measured at approximately 26 m agl. were reduced to 1.1 m according to the human bioclimatological guidances.
- Human monitoring involved observations and questionnaires (structured interviews). The applied techniques can be characterized by a number of minor changes and some significant improvements compared to the international practice of human monitoring.
  - The **observation** protocol aimed to obtain a broader database than the international investigations by measuring not only the total attendance (*momentary number of visitors*), which is the simplest indicator of the area usage. Besides, behavioral responses (*clothing, solar exposure, type of activity*) and some personal characteristics (*sex, age group*) of the visitors were also recorded in specific time intervals. These detailed observations were completed by marking the exact *location* of the individuals on maps, and (later) a GIS-supported data processing (within ArcView).
  - The **questionnaire** survey obtained its present form according to the experiences of field measurements as well as data processing. The structured interviews contain several items to measure the subjective assessments about the thermal environment (*thermal sensation*, *perceptions* of individual meteorological factors and *preferences* for any changes in terms of these parameters), personal factors and behavioral reactions too. The Hungarian questionnaire differs remarkably from the international ones, for example in terms of the semantic different scales applied to measure the visitors' perception votes. These scales don't direct the interviewees' attention to the middle votes. In addition, there are separate scales for the measurement of the individuals' thermal sensation and temperature perception. In the case of the former, beyond the 9 main thermal sensation categories (very cold to very hot) finely graduated scales support the subjective evaluation.

Objective and subjective databases were coupled within Microsoft Excel worksheets and **analysed statistically** with the help of SPSS and PASWStatistics software. The observation-based results were illustrated in many cases also with **area usage maps** created by ArcView software.

3 RESULTS AND CONCLUSIONS

1. First part of my dissertation provides a **detailed overview**
   - about the ***bioclimatological evaluation*** of thermal conditions concerned not only the theoretical background (*UNGER ET AL. 2012*) but also the main methodological problems. Determination of the mean radiant temperature was highlighted as it is the most problematic variable in the outdoor thermal comfort analysis (*KÁNTOR AND UNGER 2011*);
   - about the significant urban human comfort projects with complex methodology (*KÁNTOR ET AL. 2010A*).
2. A theoretical background model was set related to the relationship-system of outdoor thermal comfort and area usage (*KÁNTOR ET AL. 2012A*).
3. A complex investigation protocol consisting of on-site measurements of thermal factors, questionnaire surveys and observations was firstly developed in Hungary (*KÁNTOR AND GULYÁS 2010*). The applied human monitoring methodology contains a number of minor changes and some significant improvements compared to the established international practice. These innovations, as well as the careful data processing allowed broad-spectrum analyses and resulted in more clearly relationships compared to several foreign studies.

Based on the micrometeorological measurements on the sites:

4. The modifying effects of the space design was demonstrated in the example of two downtown public places. The great discrepancies of bioclimate indices characterizing the thermal conditions of nearby squares can be explained primarily by the changes in the radiation conditions, and secondly by the reduced wind speed. While the former can be attributed mainly to the woody vegetation, the latter is connected to the size and orientation of the outdoor space.

Based on the observations (*KÁNTOR AND UNGER 2010, KÁNTOR ET AL. 2010B*):

5. Monotonous increasing quadratic function proved to be the best to describe the connection between the average number of (passive) visitors and the PET index in the transient seasons. (This tendency

could not be found in case of the more active subjects.) According to the fitted curves, maximal attendance may be occur at very hot thermal conditions. This can not be explained solely by the behavioral adaptation of visitors (e.g. by altering the clothing or solar exposure). Visitors with different gender and age did not show obviously dissimilar area usage patterns.

6. In order to illustrate and to examine statistically the dependence of the spatial patterns of area usage on the thermal conditions specific sectors (sub-areas) were separated in the sample area (Ady Square). Each sectors had the highest number of visitors at clear sky and warm thermal conditions, however, the relative attendance of the selected sub-areas showed remarkable tendencies depending on sunshine and thermal comfort categories. At overcast–cloudy sky and cooler thermal circumstances the relative usage of the benches was predominant. With the increasing amount of global radiation (clear sky) and at higher PET ranges even greater portion of visitors stayed in the grassy sector. Higher relative attendance of the shady sectors during warm–hot conditions indicated one option of the physical adaptation.

Based on the questionnaires (*KÁNTOR ET AL. 2011A, 2011B, 2012A*):

7. The strength of the relationships was quantified between the perceptions and preferences concerning the individual meteorological parameters, as well as these subjective assessments was studied according to the corresponding objective factors (T_a, RH, v and T_{mrt}). People proved to be more sensitive against the changes of radiation and air temperature, wheresas they had difficulties with the estimation of humidity.

8. I have demonstrated that people are usually quite good at the perception of the individual thermal factors (except humidity), but they wish their values to increase or decrease (preference) according to the subjective thermal comfort sensation. As thermal comfort depends on all of the thermal parameters, a complex bioclimate index (PET) proved to be better predictor for preferences than the basic measures (T_a, RH, v and T_{mrt}). It could be observed that local people prefer for lower air temperature, stronger wind and less sun from PET=27-28°C, which values are in the category of slight heat stress, and they want the humidity to decrease below PET=25°C.

9. Very strong positive correlations are between the mean thermal sensation of the interviewees and the bioclimatological indices (PET, UTCI). Based on the fitted regression functions (PET: quadratic, UTCI: linear) neutral temperatures and new thermal sensation ranges was determined for the Hungarians in terms of PET and UTCI.
10. The mentioned thermal sensation–bioclimate index connections are slightly affected by some personal factors. Abstinent people and interviewees who consume alcohol only occasionally estimated that the thermal conditions were not so extreme (hot or cold). Nervous people proved to be more sensitive against the decrease of PET values in the neutral–cool domain. Smoking habit and nutritional status had an obvious effect only in such PET intervals where the sample size was low, so these analyses will be repeated in the future based on a larger database.
11. Despite the perceived temperature (T_{perc}) by the interviewees correlated stronger with bioclimatological indices (PET, UTCI) than with air temperature (T_a), T_{perc} took values more similar to T_a. T_{perc} exceeded the corresponding bioclimate indices at thermal conditions when PET or UTCI were under 21.5°C, while over this value the indices were higher than T_{perc}.

Beyond the obvious forms of behavioral adaptation the **discussion of the results at local and international level** offered more evidences of the mental adaptation (*KÁNTOR AND UNGER 2010, KÁNTOR ET AL. 2012B*).

12. Through the **international discussion of the questionnaire-based outcomes** concerning the local individuals' mean thermal sensation against the PET index very different neutral PET values have been arisen. The neutral temperature seems to be determined by the background climate, moreover, it shifts on seasonally basis according to the actual thermal experiences. These experiences act not only on physiological level (adaptation to the regional climatic conditions and acclimatization to the weather) but also on mental level: inhabitants in a given geographical region are psychologically prepared to the thermal characteristics of the location at the given time of the year.
13. The more **detailed analysis of the Hungarian observational database** revealed seasonally different tendencies in terms of the thermal conditions-dependent area usage and behavioral reactions of visitors. In spring, after the cold winter season with less

environmental stimulation, people tend to visit outdoor spaces in a greater extent and tend to opt sunny position in the area more frequently than during autumn. These findings are also valid even in the case of the bioclimatologically stressful warm conditions.

The outcomes derived from the seasonal separation of observational data seems to be in contrast with the findings based on questionnaires and draws attention to the difference between thermal neutrality and thermal preference. In the transient season following winter the human organism is not prepared physiologically to the greater thermal stress. Accordingly the springtime neutral temperature is lower than the neutral temperature values of summer and autumn. Notwithstanding this, the tolerance level against the stressful thermal environment proved to be higher in spring than in autumn. This can be explained by adopting the phenomenon of alliesthesia on seasonal scale. According to this psychological mechanism, people keep longing for the warmth of summer during the winter season, while they wish for the cool conditions of winter during the warm–hot months of summer. Thus the increased need for sunshine in spring exceeds the discomfort due to the thermal stress.

LIST OF PUBLICATIONS DIRECTLY RELATED TO THE DISSERTATION

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12. *ÉGERHÁZI L, KÁNTOR N, UNGER J* (témavezető) (*2008*): Kerthelyiségek preferáltsága a termikus viszonyok tükrében – esettanulmány Szegeden. Egyetemi Meteorológiai Füzetek 22, ELTE Meteorológiai Tanszék, Budapest, 135-138
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