# 406: Urban/rural thermal comfort changes over the past half-century in Budapest (Hungary)

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**Abstract**

Although the analysis of thermal bioclimate in urban environment is extremely timely, until now very limited studies were performed in this direction in Hungarian capital city Budapest. The aim of this study to evaluate the changes of the thermal comfort conditions in the last half-century based on measurements of two meteorological stations (one in the downtown and other in the suburban area). For characterization of thermal comfort the Physiologically Equivalent Temperature [1] was calculated for 6, 12, 18 and 0 UTC in the period of 1961–2010 and then these values were averaged for three climatic normal periods: 1961–1990, 1971–2000 and 1981–2010. For the last ten year period we analyzed the thermal comfort conditions in more detail (by hours). According to the results the annual and seasonal averages of PET are higher in the downtown in every time and the PET averages increase in every consecutive 30-year period, and also at every timepoint. Analyzing the hourly data, significant difference (3–5℃) can be found between downtown and suburb at 12 UTC, and the smallest difference (1–3℃) appears in early evening.

Keywords: thermal comfort, physiologically equivalent temperature, Budapest

## 1. Introduction

Thermal comfort is one of the determining factors of human health and quality of life. This is especially true in urban areas where the thermal conditions (in addition to air pollution and noise) can be stressful for humans. Therefore, it is important to understand the thermal comfort conditions in our cities and their changes, hereby helping the urban planners, the public health authorities, or the tourism operators' work.

There are extensive urban climatological studies in progress in Szeged (in Southern Hungary). These studies include detailed examinations of human comfort too [2, 3]. For example, in a recent research the relationship between the area usage and comfort conditions of public squares is examined [4].

Budapest (capital of Hungary) has nearly 2 million inhabitants and additionally, the urban thermal environment affects the quality of life at least 200.000 commuters each day, too. Even so, in Budapest any detailed human comfort examinations has not been performed until now [5]. The aim of this research is therefore to ground a detailed comfort investigation in this large urban environment based on currently available data.

The urban planning or decision-making processes often do not consider the human biometeorological aspects in Hungary. A complete change of attitude in this field is needed.

## 2. Materials and methods

### 2.1 Study area

In this study the measured data of two meteorological stations of Hungarian Meteorological Service were used (Fig.1). One station (Budapest-OMSZ) is located in the downtown, in a densely populated area of the city. However, the location of this station is not ideal because in its data the effects of Buda Hills are already detected. In addition the measurements conditions have changed significantly since April of 1985 as the previous regular, street-level measurements moved to the roof terrace of the central building of the Hungarian Meteorological Service. Thus, the measurements continued until now at the roof level of the surrounding buildings [6].


*Fig 1. Geographical location of the examined meteorological stations*

The other station (Budapest-Pestszentlőrinc) is located in suburban region. The measurements take place in a large observing garden, in regular conditions. Further advantage of this station is that during the examined period (1961–2010) there was no change in its location, so the data series can be regarded as homogeneous.

### 2.2 Methods

Determining urban human comfort one of the best known and most widely used bioclimate indices, the physiologically equivalent temperature (PET) was used [1]. PET is defined as a fictive ambient temperature where same physiological responses occur as in the current outdoor environment. The PET values were defined according to different thermal perceptions for temperate climate (Table 1) [7]. The meteorological parameters, which are needed to calculate the PET, at the mentioned two meteorological stations were available. (Only the cloudiness data of downtown station at 24 UTC are exception, because there is no visual observation there at this time.) In the examined period there were observations every six hours (6, 12, 18 and 24 UTC). However in the period 2001–2010 more detailed, hourly data were available. The applied bioclimate index was determined by RayMan model [1,8]. From the PET values monthly, seasonal, annual, 10-year and 30-year averages were calculated. Additionally, bioclimate diagrams of both stations were constructed where the 10-day relative frequencies of PET are shown.

Table 1: The range of the physiologically equivalent temperature values for different grades of thermal perception and physiological stress [7]. **Remark: The original range of values does not include these two categories. They are used in practice only in Hungary!*

| PET (℃) | Thermal perception | Grade of physiological stress |
|---|---|---|
| above 41 | very hot | extreme heat stress |
| 35 – 41 | hot | strong heat stress |
| 29 – 35 | warm | moderate heat stress |
| 23 – 29 | slightly warm | slight heat stress |
| 18 – 23 | comfortable | no thermal stress |
| 13 – 18 | slightly cool | slight cold stress |
| 8 – 13 | cool | moderate cold stress |
| 4 – 8 | cold | strong cold stress |
| 0 – 4 | very cold | extreme cold stress |
| *-10 – 0* | *frosty** | *extreme cold stress** |
| *below -10* | *very frosty** | *extreme cold stress** |

## 3. Results and discussion

### 3.1 Diurnal studies

According to the bioclimate diagrams (Fig.2 and Fig.3) the number of cold stress days at 0 UTC in the period 1961–1990 is less by 2.5% in the downtown, than in suburban area. This difference increases to 5% in the period 1981–2010. Thus inhabitans of the downtown must be adapted to less cold stress in winter than in the suburbs.

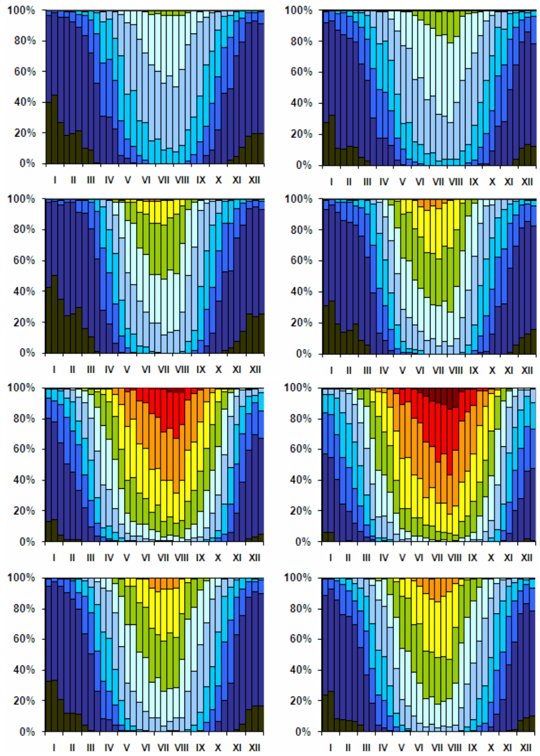


*Fig 2. The 10-day relative frequencies of PET categories in the suburban area (left) and the downtown (right) for period 1961–1990, at 0, 6, 12 and 18 UTC (top down)*

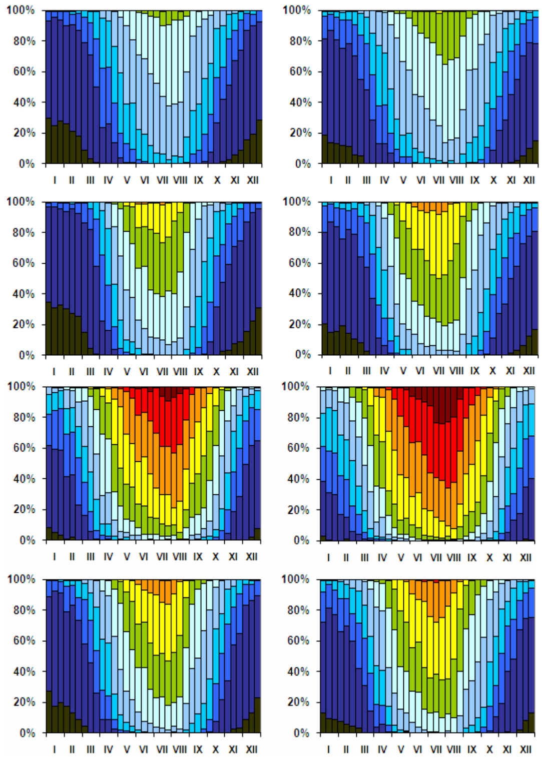


*Fig 3. The 10-day relative frequencies of PET categories in the suburban area (left) and the downtown (right) for period 1981–2010, at 0, 6, 12 and 18 UTC (top down)*

However, the heat load increased in the city centre in summer and therefore the body is generally less able to regenerate during the night. In mid-summer the slightly warm heat stress category appears at this time in the second period (1981–2010). Presumably, the difference between the bioclimatic conditions of measuring points is a consequence of the developed urban heat island.
The tendency of differences between the stations is similar also at 6 UTC. For example in the summer mornings the relative frequency of moderate heat stress is around 10% in downtown, while it is minimal in the suburbs.
In the early afternoon period (12 UTC) the city centre shows also a high heat load during the summer months. The combined frequency of two most extreme heat stress category (very hot and hot) is higher by 5.4% and 7.5% in downtown. However the cold stress is lower by 7.6% than in suburban area, which has declined by 1% further in the later period
At 18 UTC a similar tendency can be observed but the difference is much smaller than the mid-day period. At this time the warm stress in the examined periods is higher by 3.3% and by 4.4% in the city, but the cold stress is lower by 5.1% and by 6.3%. In summer the evening relaxation or ventilation opportunity may be limited in the downtown which can have extremely negative effects on the human body. It should not be overlooked that the relaxation may be even less effective in the high heat capacity, poor ventilated homes (eg. block of flats). Here much more unfavourable conditions can develop than in outdoor.

### 3.2 Hourly studies

The intra-day changes of thermal comfort in the 2001–2010 period can be analyzed in detail based on the hourly PET values.

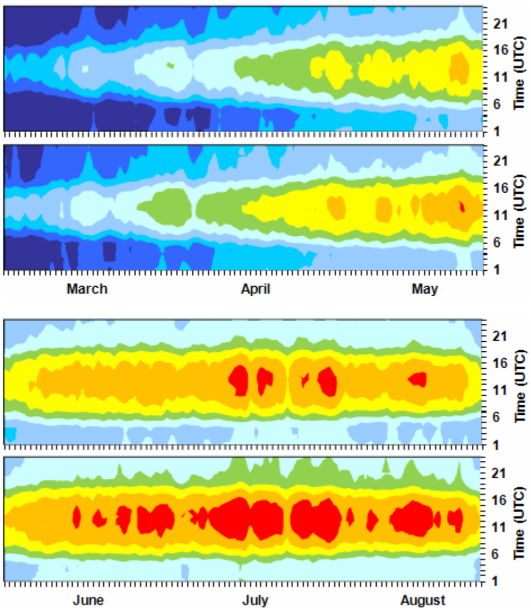


*Fig 4a. The hourly PET categories of downtown (lower) and suburban area (upper) sorted by seasons (spring and summer, 2001–2010)*

During the whole ten years, the average PET values are higher by 3°C in the downtown. The maximum PET in the city centre is only slightly higher (0.9°C) but the difference in the minimum value is much higher, about 5°C. Generally, more hot stress and less cold stress can be observed in the downtown. In the late spring (Fig.4a) the city centre has already a significant ratio of warm sensation-category and appears also the hot category, while the suburbs have only low ratio of warm category. In summer the hot stress becomes dominant at noon in the downtown (Fig.4a). (Short decreases of the PET values observable in a few days' time can be related to weather fronts.)

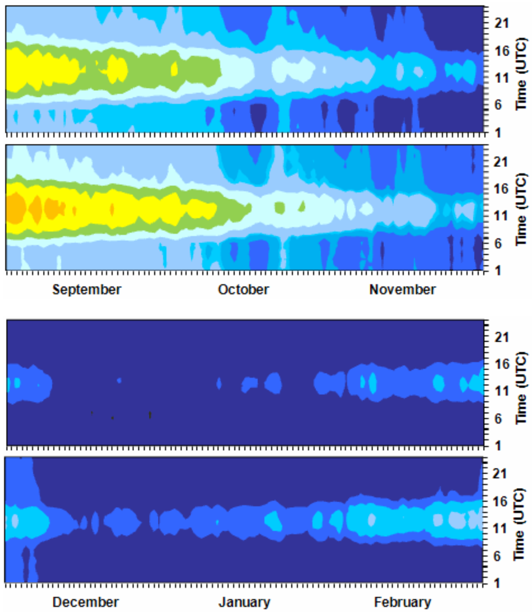


*Fig 4b. The hourly PET categories of downtown (lower) and suburban area (upper) sorted by seasons (autumn and winter, 2001–2010)*

In early autumn (Fig.4b) the warm category is already missing in daytime, by the end of autumn (except at noon) the cold or extremely cold categories become prevalent in the suburbs. According to the ten years average the extreme cold stress is dominant in both areas in winter (Fig.4b), but during the daytime smaller cold stress affects the population in the downtown. This may affect positively the thermal comfort.

### 3.3 30-year studies

We examined the three climate normal period (1961–1990, 1971–2000, 1981–2010), what changes can be detected in the PET based on many-years averages. In terms of differences between the two stations, there is higher PET in the downtown for each climate normal period and all seasons, which is consistent with the previous results. The highest difference (approximately 4.5°C) can be shown at noon in spring (Fig.5), while the smallest (around 2°C) can be observed at 18 UTC, in the same season.
Between the 30-year periods (the pairwise differences between 1971–2000 and 1961–1990,

and 1981–2010 and 1971–2000) an increase can be detected in almost all cases. An additional characteristic is noticeable: for the last 30 years the PET average increased slightly in both stations and each time in winter, sometimes it stagnated or decreased. To find an explanation of this, we analyzed the 30-year averages of some input variables of PET (air temperature, air humidity and wind speed). We found that the air temperature may cause this trend, because the mean temperatures are smaller at both station in the third 30-year period than in the earliers.

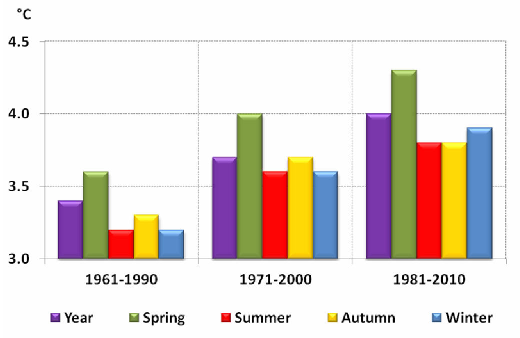


*Fig 5. Differences between downtown and suburban values of annual and seasonal averages of PET at 12 UTC*

## 4. Conclusion

According to the results the following main conclusions can be drawn related to features, differences and changes of human comfort conditions in Budapest.

- The main features of the bioclimatic differences of measuring points are same in all four observation times: the heat load is stronger, or the cold stress level is less in the downtown than in the suburbs. The largest differences appear in daytime period, while the smallest in the evening and at night.
- The detected trends between the two presented normal periods indicate that the warm stress has become more common while the cold heat load decreased in both station at each examined time. Their effect on human comfort can be also advantageous and disadvantageous, depending on the season.
- In terms of annual and seasonal averages of PET in the three climate normal periods, there are higher values unambiguously in the downtown and the differences increase in all seasons except in winter for the third examined period.

In relation to the presented results it should not be ignored that the downtown station's location is not really ideal for the urban climatological researches. However, sufficient long data series, which are necessary for analysing the urban climate and bioclimate, are not available elsewhere.

Therefore, in the near future, it is necessary to establish a few a meteorological stations at street-level, which would represent better the downtown environment.

## 5. References

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