# Monitoring and modeling of the urban micro-climate

*Aida Maleki, Kristina Orehounig, Ardeshir Mahdavi*

(Aida Maleki MSc., Vienna University of Technology,
Department of Building Physics and Building Ecology, Karlsplatz 13, 1040 Vienna, Austria, ida.maleki@gmail.com)
(Dr. Kristina Orehounig, Vienna University of Technology,
Department of Building Physics and Building Ecology, Karlsplatz 13, 1040 Vienna, Austria, k.orehounig@tuwien.ac.at)
(Univ. Prof. Dr. Ardeshir Mahdavi, Vienna University of Technology,
Department of Building Physics and Building Ecology, Karlsplatz 13, 1040 Vienna, Austria, bpi@tuwien.ac.at)

## 1 ABSTRACT

Urban heat island phenomenon (UHI) is considered to be one of the major challenges encountered this century by the human kind. This phenomenon is characterized mainly by air temperatures in the city that are higher than those in the surrounding areas. Reasons are, amongst other things, the morphology and density of urban spaces as well as the thermal and radiative properties of outdoor surfaces. The UHI effect represents a challenge for careful and proper building design and operation, as micro-climatic data are typically available only for few locations in the city. As a result, planning, retrofit, and mitigation measures for buildings cannot count on reliable weather information for the exact locations of intended building projects. In this context, this paper presents results of an ongoing research project, which is concerned with prevention, adaptation, and mitigation measures pertaining to the urban heat island phenomenon. An important component of this project addresses the variation in the mirco-climatic conditions in different locations in the city and if and how such variations could be accounted for. Specifically, weather information was collected with a mobile weather station at various locations within the city of Vienna. Collected data from multiple – morphologically differentiated – locations around the city were compared with the simultaneously monitored general weather conditions via a stationary weather station. The findings are expected to support the development and validation of high-resolution climatic boundary condition models for building design and operation support.

## 2 INTRODUCTION

Urban heat island phenomenon (UHI) is considered to be one of the major challenges encountered this century by the human kind. This phenomenon is characterized mainly by air temperatures in the city that are higher than those in the surrounding areas. Reasons are, amongst other things, the morphology and density of urban spaces as well as the thermal and radiative properties of outdoor surfaces (OECD 2010, Oke 1982). The UHI effect can raise air temperatures in a city by 2-5 K. In the evening differences can be even as high as 12 K (Okeil 2010). Since global warming is not likely to recede, heat waves are likely to become more frequent and intensive in central Europe during the next decades (OECD 2010), the UHI effect is expected to increase even more (Douglas 2002, referenced in Corburn 2009). Higher temperatures increase the energy consumption for cooling commercial and residential buildings. Increased energy demand requires increased electricity generation by power plants, which results in higher emissions of gases and suspended particulates contributing to global warming and climate change. The Urban Heat Island can decrease the outdoor thermal comfort of urban population and negatively affects people's labor and leisure-time activities. UHI effect represents thus a challenge for careful and proper building design and operation. To conceive and implement effective mitigation and adaptation measures, climatic data for the immediate environment of buildings is necessary, which is typically available only for few locations in the city.
In this context, the present contribution reports on the results of an ongoing research project, which is concerned with prevention, adaptation, and mitigation measures pertaining to the urban heat island phenomenon in the city of Vienna. An important component of this project addresses the variation in the mirco-climatic conditions in different locations in the city and if and how such variations could be accounted for. Specifically, weather information was collected with a mobile weather station at various locations within the city of Vienna. Collected data from multiple – morphologically differentiated – locations around the city were compared with the simultaneously monitored general weather conditions via a stationary weather station. Results pertaining to temperature, solar radiation, wind speed, and water vapour content of the specific places are presented. Additionally, correlations between a number of salient variables were studied.

The findings are expected to support the development and validation of high-resolution climatic boundary condition models for building design and operation support.

## 3 METHOD

Weather information pertaining to air temperature, humidity, global solar radiation, wind speed as well as fish-eye images of sky conditions were collected with a mobile weather station (see Figure 1) at various locations within the city of Vienna. Data were collected around the city centre at 13 morphologically differentiated locations. Locations varied in terms of typological category (street, plaza, park, courtyards) as well as sky view factors, presence of vegetations, albedo and thermal properties of surrounding surfaces, and presence or absence of water bodies. The 13 measurement locations are depicted in Figure 2 and described in Table 1. Data was collected with the mobile weather station during the months of June to September in 2010 and 2011 on very hot and sunny days. Thereby, measurements were conducted for about 10 min at each location. Since the collected data are not directly comparable (given varying monitoring periods and corresponding weather conditions), general weather conditions were monitored continuously with our Department's stationary weather station (BPI) located in the proximity of the measurement locations.

Fig. 1: Mobile weather station

| Name of location | Category | SVF [%] | Orientation | Vegetation | Surface properties | | Water body | Intensity of traffic | Streets' H/W ratio |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | sealed | soil or green | | | |
| S1 | street | 30 | E-W | no | 100 | | no | medium | 1.3 |
| S2 | street | 29 | N-S | no | 100 | | no | medium | 1.3 |
| S3 | street | 59 | NE-SW | heavy | 86 | 14 | no | heavy | 0.5 |
| S4 | street | 16 | NW-SE | heavy | 82 | 18 | no | heavy | 0.5 |
| S5 | street | 67 | NE-SW | no | 100 | | no | heavy | 0.4 |
| S6 | street | 47 | NW-SE | no | 98 | 2 | no | heavy | 0.8 |
| P1 | plaza | 16 | n/a | heavy | 75 | 25 | no | no | n/a |
| P2 | plaza | 88 | n/a | no | 100 | | yes | no | n/a |
| P3 | plaza | 82 | NW-SE | no | 100 | | no | heavy | n/a |
| C1 | courtyard | 20 | n/a | no | 100 | - | no | little | n/a |
| C2 | courtyard | 18 | n/a | medium | 78 | 22 | no | little | n/a |
| G1 | park | 90 | n/a | medium | 30 | 70 | no | no | n/a |
| G2 | park | 68 | n/a | heavy | 30 | 70 | yes | no | n/a |

Table 1: Selected measurement locations with information regarding category, SVF, orientation, vegetation, surface properties, water body presence, intensity of traffic, H/W ratio (of streets).

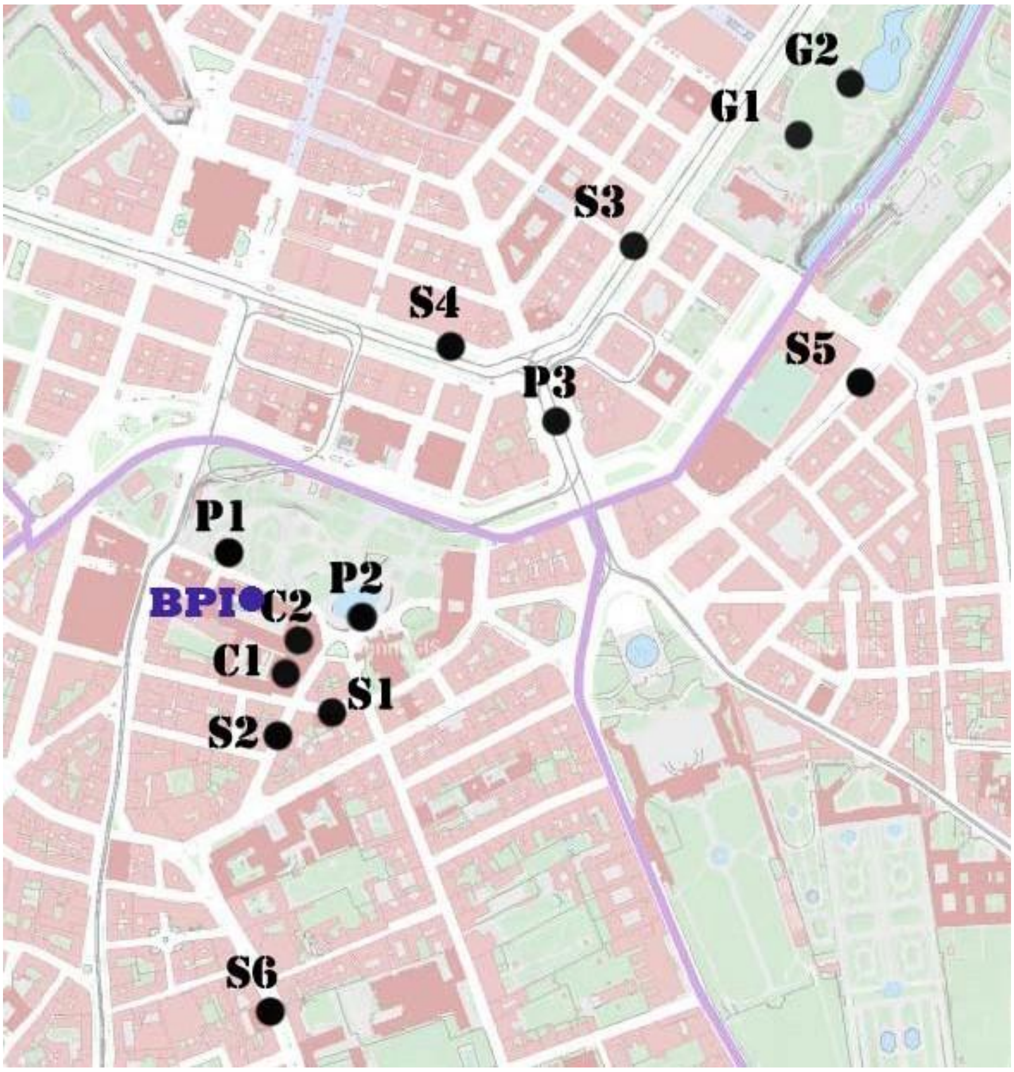

Fig. 2: Measurement locations and reference weather station (BPI) marked on an area map.

## 4 RESULTS AND DISCUSSION

The results of the study are shown in Figures 3 to 13. In these Figures, "MW" denotes mobile weather station, whereas "BPI" denotes stationary weather station. Data are analyzed in terms of box plots for the entire data set, data represented in terms of reference days for each location, as well as correlations between a number of variables. The reference day representation of the data is generated as follows: The hourly temperature of each hour of the reference days represents the mean temperature for that hour over all measurements of the respective location.

### 4.1 Box plots

Figure 3 shows boxplots pertaining to temperature differences of MW and BPI for the 13 different locations (as per Table 1). As expected, median temperatures of the MW are generally higher than the referenc e weather station, with 2 exceptions, namely C1 and C2, which are courtyards with low sky view factors. Temperatures at P2 and P3 (category plaza) show significantly higher values for the MW. P1 is also of the same category, but it has a lower SVF and more vegetation.

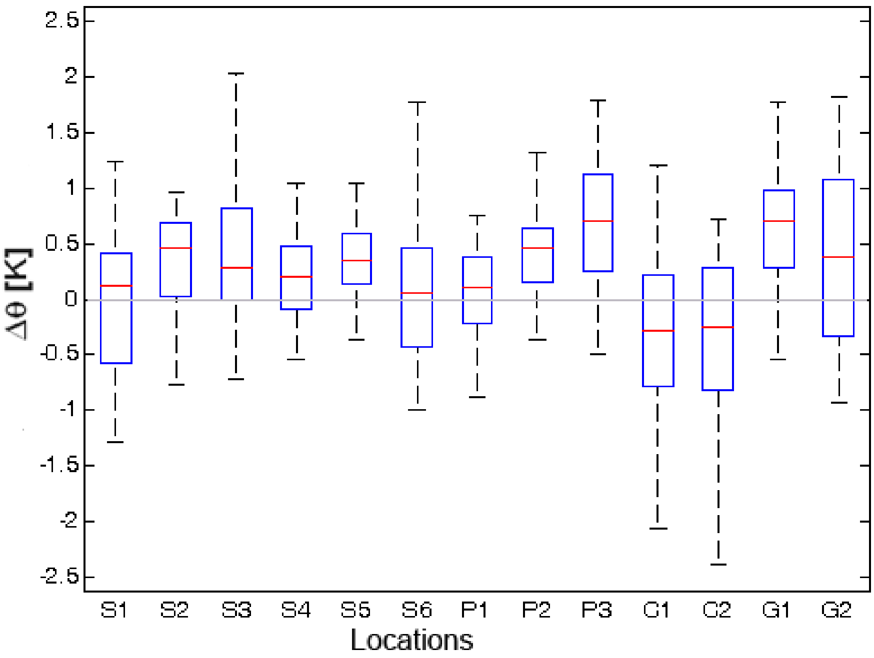


Fig. 3: Box plots of temperature differences (MW – BPI) for all 13 locations

Figures 4 to 6 show relative differences for solar radiation [%], wind speed [$m.s^{-1}$], and water vapor concentration [$g.m^{-3}$]. The relative solar radiation difference in case of G1, G2, S5, P2, and P3 are rather similar, which is consistent with their rather high SVF (above 60%). The rest of the locations display a significantly higher relativ solar radiation differences. Wind speed values obtained by MW are, as expected, lower than BPI. Median values pertaining to water vapor content are higher for G2 and G1, which have more vegetation and, in case of G2, also a body of water. The lowest values can be found for S1 and P3, places with little or no vegetation.

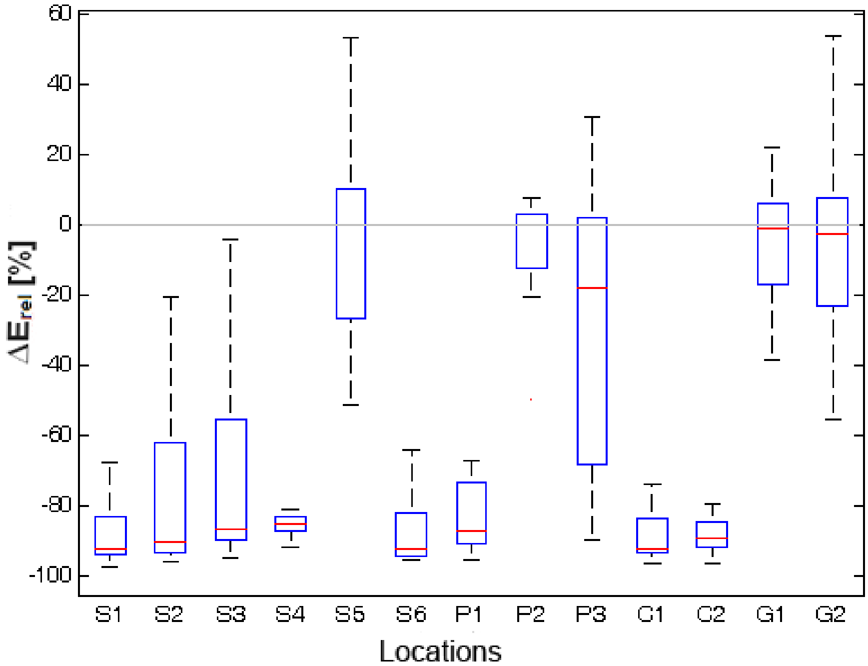


Fig. 4: Box plots of relative solar radiation difference (MW – BPI) for all 13 locations

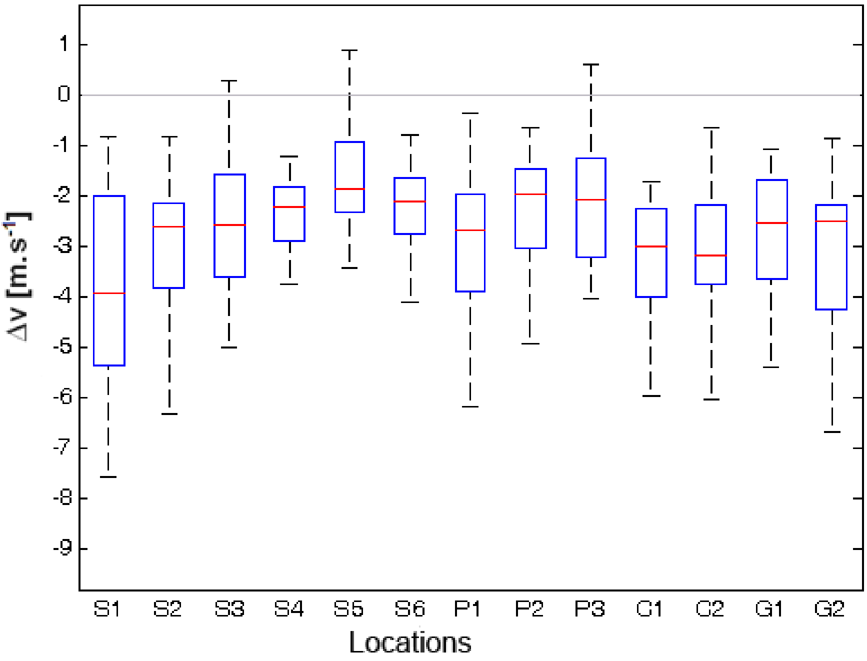


Fig. 5: Box plots of wind speed difference (MW – BPI) for all 13 locations

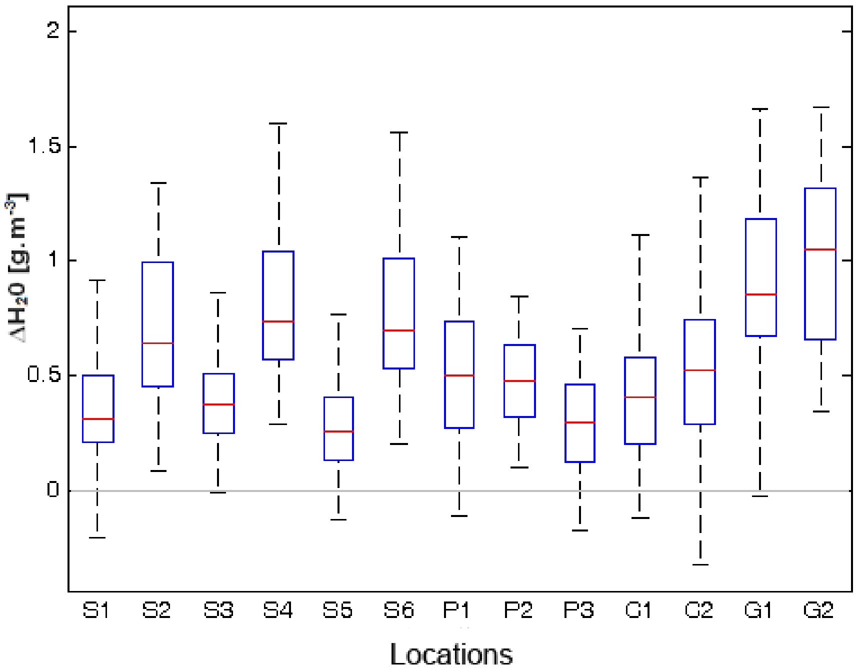


Fig. 6: Box plots of water vapor concentration difference (MW – BPI) for all 13 locations

### 4.2 Reference day analyses

Figure 7 shows the temperature difference between MW and BPI for the 13 locations for a reference day. N-S oriented street S2 shows higher temperatures at around 2:00 o'clock. E-W street (S1) shows the lowest values, which do not change much during the day. This may be due to the circumstance, that the respective measurement point is shaded most of the day. Courtyards display tendentially lower values. C1 however, shows an increase in temperature at the time of 2:00 to 3:00 o'clock. Green areas such as parks show relatively high values throughout the day. This might be due to the fact that although vegetation is present, SVF are very high at the measurement locations. In the category of plazas, the lowest temperatures were measured at location P1. This location has, as compared to P2 and P3, more vegetation and a significantly lower SVF.

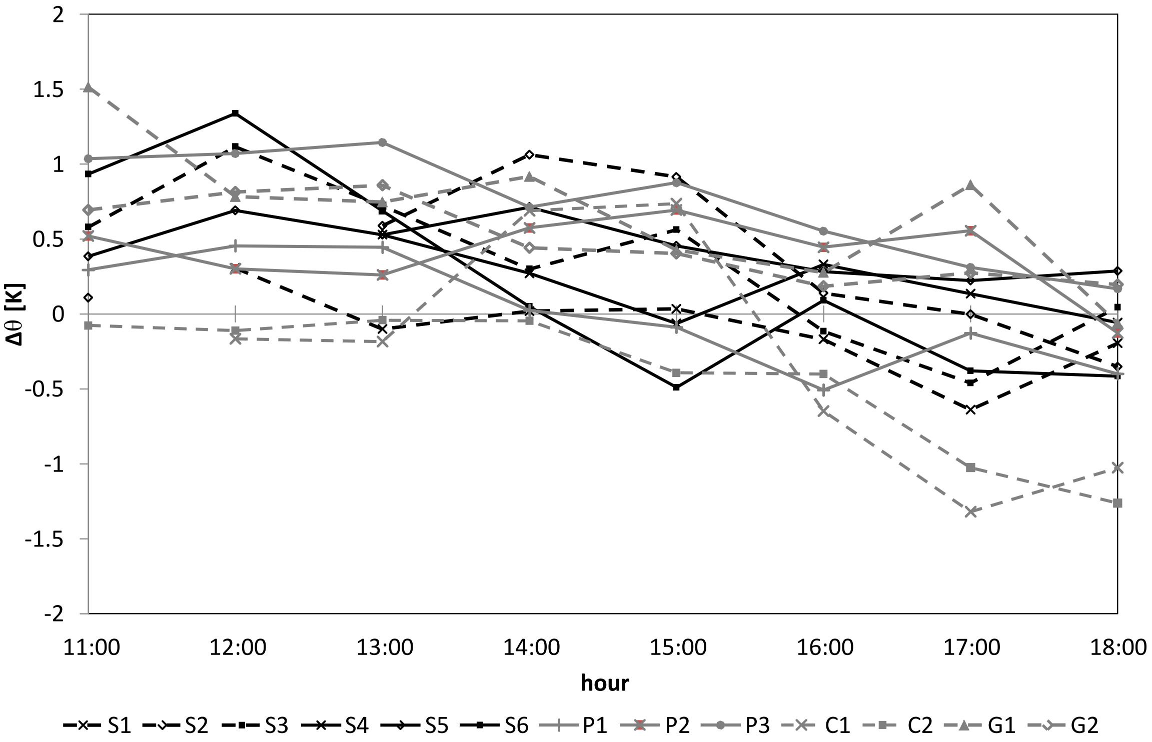


Fig. 7: Temperature differences (MW – BPI) for a reference day (from 11:00 to 18:00) for all 13 locations

Figure 8 shows a reference day for the relative solar radiation difference [%] for the 13 locations. Results of solar irradiance at the measurement locations appear to be consistent with the orientation of the streets or plazas. For example, the E-W oriented S1 shows little variance, as it is mostly shaded. The N-S oriented S2 shows, as it could be expected, higher values around early afternoon, due to increased solar exposure. The NE-SW oriented S5 shows higher values in the afternoon, which is again consistent with increased solar exposure. The NW-SE oriented P3, on the other hand, shows the reverse tendency. The park locations G1 and G2 show high values, given the respective high SVF values. Courtyards, on the other hand, show rather lower values, given the lower SVF values.

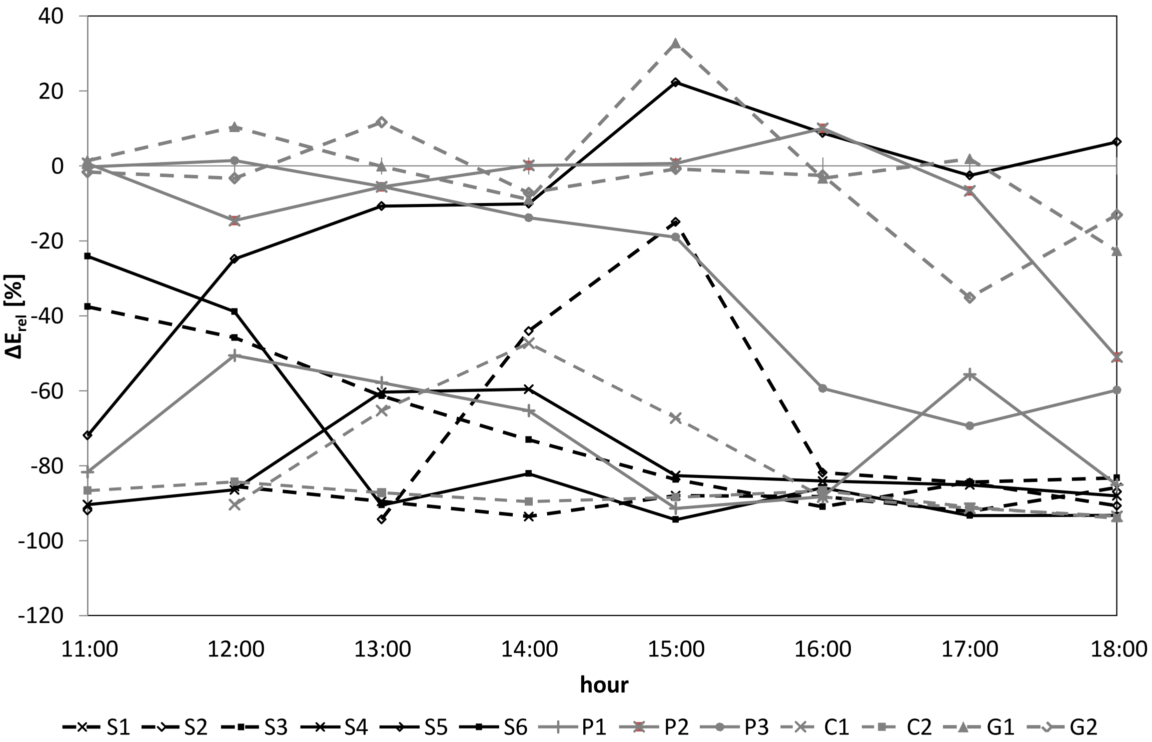


Fig. 8: Relative solar radiation differences (MW – BPI) for a reference day (from 11:00 to 18:00) for all 13 locations

Figure 9 shows a reference day for the wind speed difference [m.s$^{-1}$] for the 13 locations. Likewise, Figure 10 shows reference day information for humidity difference [g.m$^{-3}$].

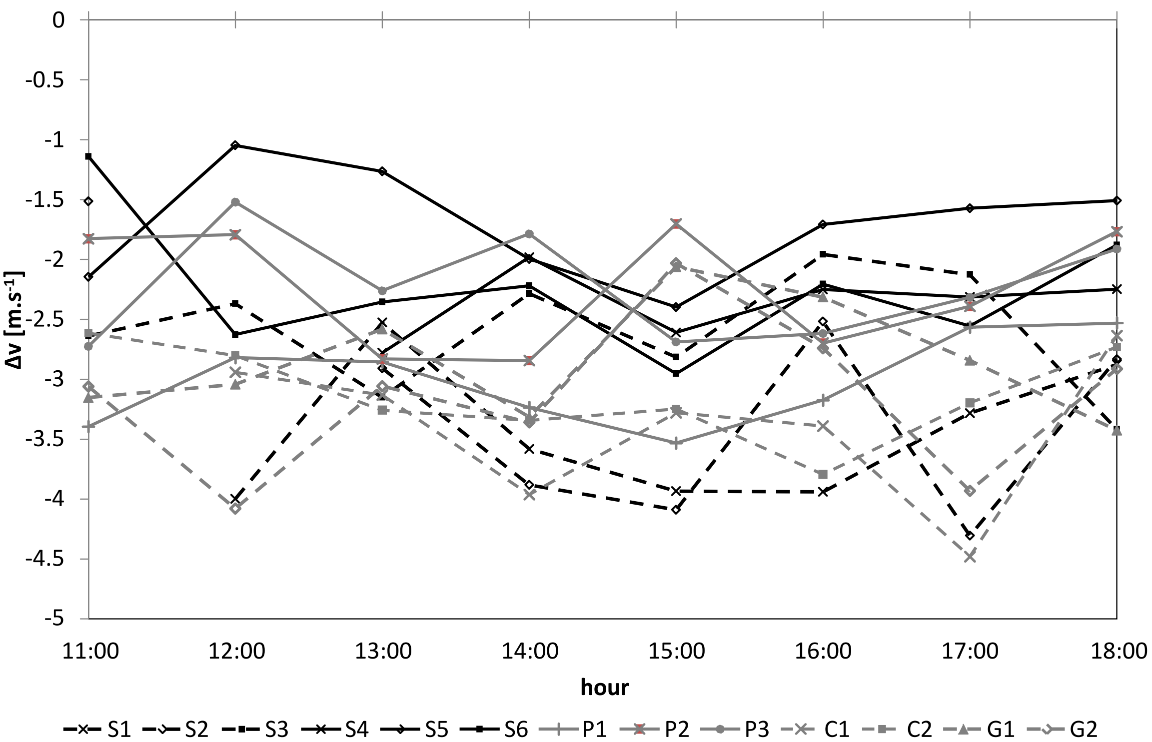


Fig. 9: Wind speed differences (MW – BPI) for a reference day (from 11:00 to 18:00) for all 13 locations

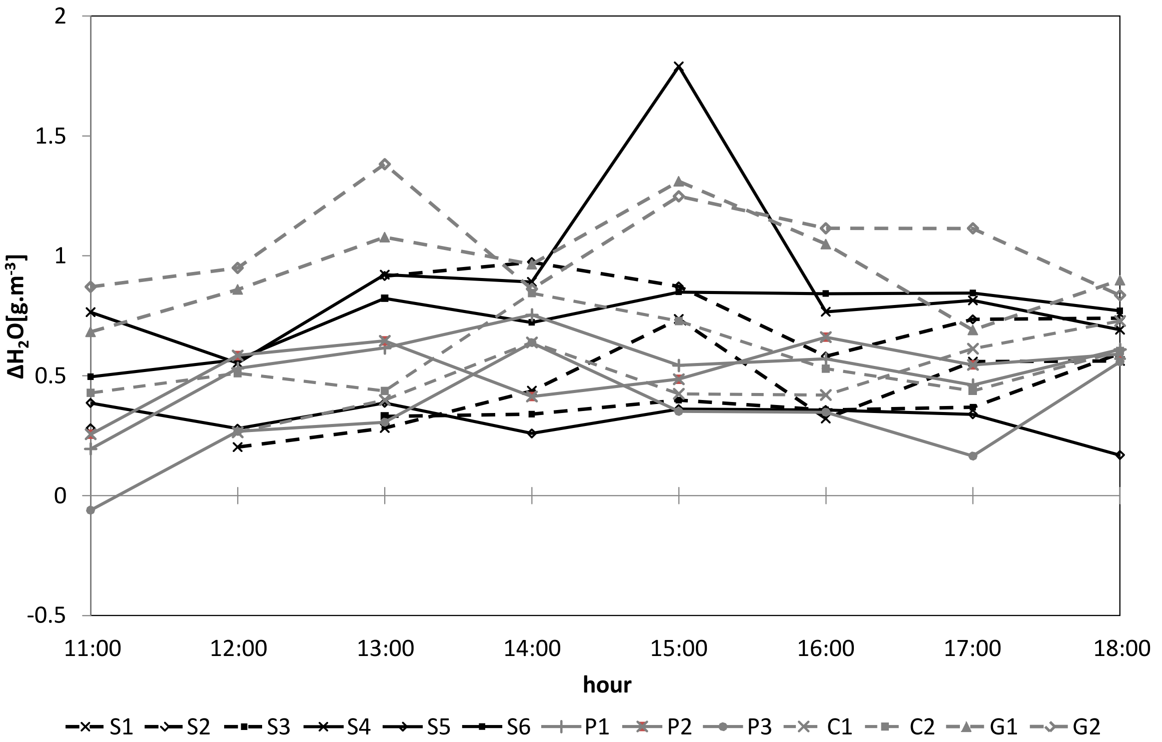


Fig. 10: Water vapor concentration differences (MW – BPI) for a reference day (from 11:00 to 18:00) for all 13 locations

### 4.3 Correlational studies

Figure 11 shows, for all locations, the correlation between relative solar radiation and temperature differences (median values). Likewise, Figure 12 shows the correlation between sky view factor (SVF) and the temperature differences. Figure 13 shows the correlation between SVF and relative solar radiation differences (median values) for the entire data set. In all cases, significant correlations ($R^2$ between 0.59 and 0.79) is visible between the pertinent variables of the measurement locations (Figure 11 to 13).

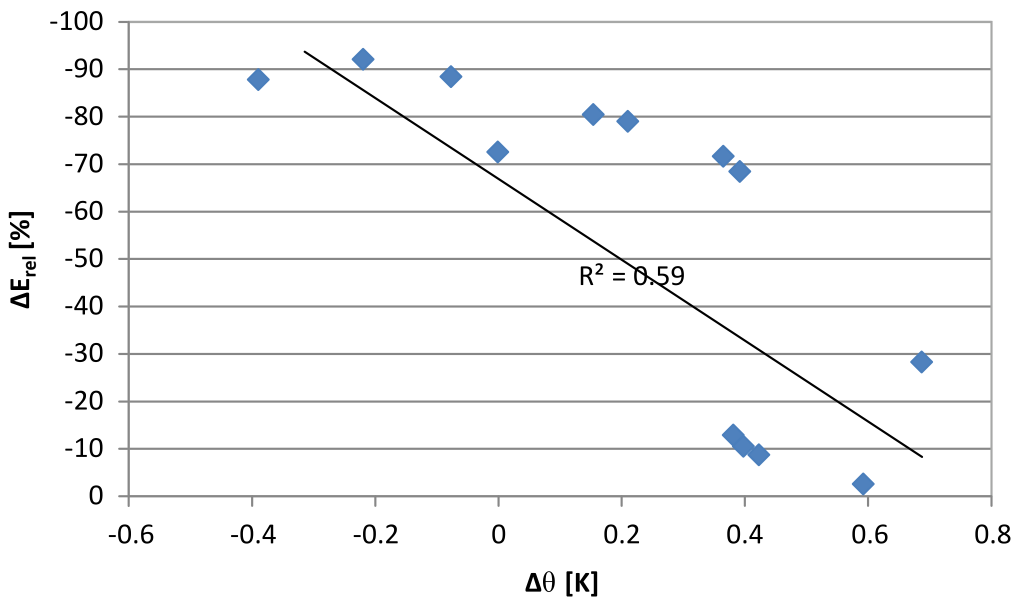


Fig. 11: Relationship between relative solar radiation and temperature difference

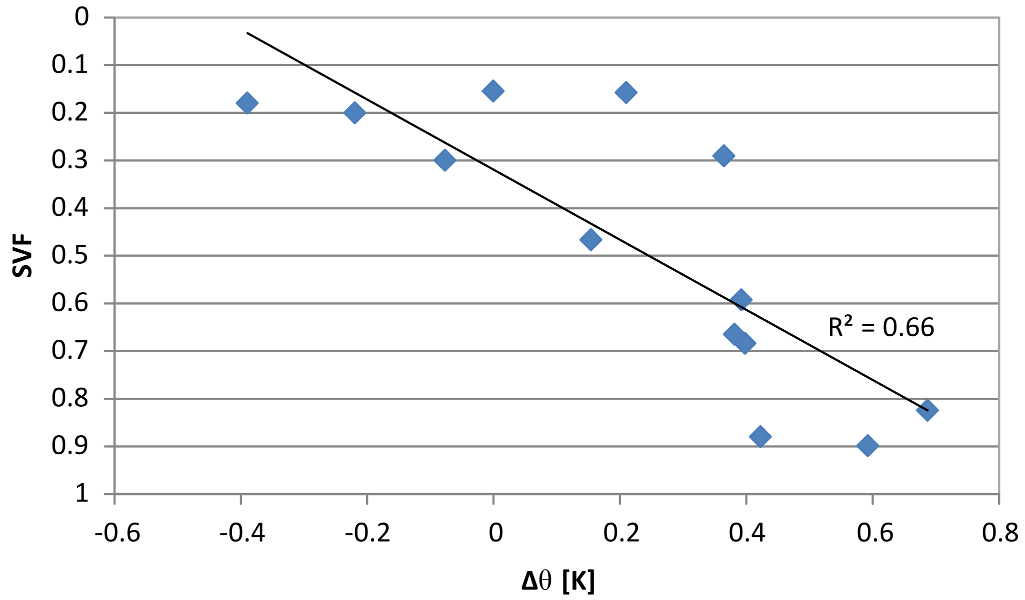


Fig. 12: Relationship between temperature difference and SVF

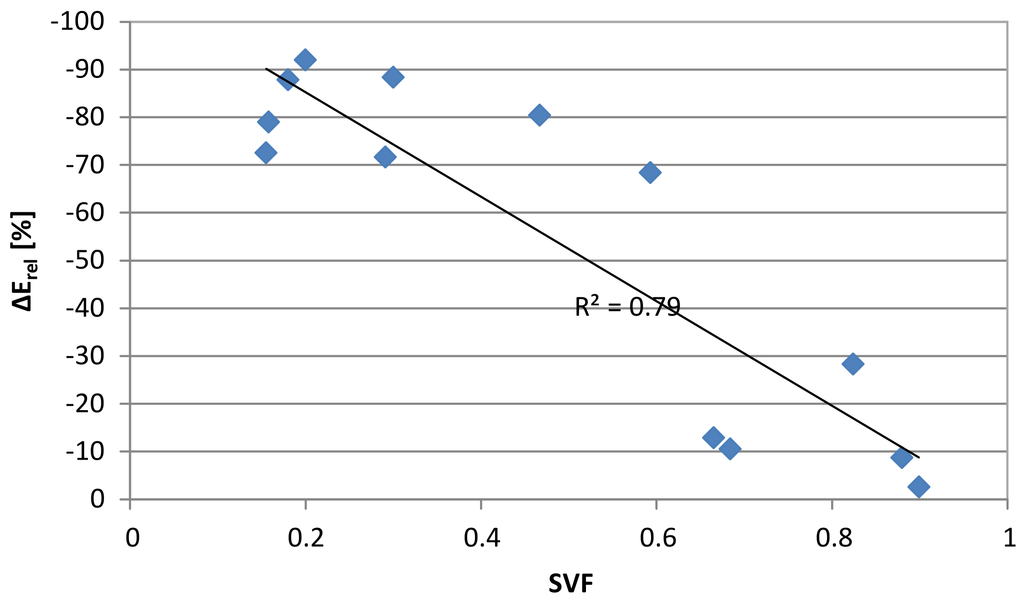


Fig. 13: Relationship between relative solar radiation difference and SVF

## 5 CONCLUSION

We presented the initial results of an ongoing research effort regarding monitoring and modeling of the urban micro climate in the city of Vienna. Thereby, weather information was collected with a mobile weather station at various locations within the city. Collected data from multiple – morphologically differentiated – locations were compared with the simultaneously monitored general weather conditions via a stationary weather station. These results suggest that the microclimatic conditions at different location vary considerably. Moreover, these variations appear to be related to certain characteristic features of the locations (e.g., sky view factor, vegetation, etc.). Highest tempeartures were monitored at open plazas and parks. Whereas shaded courtyards and streets displayed the lowest temperatures during the day. The readings for the air temperature and solar irradiance showed a significant congruence a correlation with sky view factor. These initial findings are expected to supp ort the development and validation of high-resolution climatic boundary condition models for building design and operation support.

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## 7 ACKNOWLEDGMENT

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