CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 9

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 9*. Department of Civil Engineering, Aalborg University.

The scope and implications of the urban microclimate variance: a case study

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Abstract

Recently, a number of research efforts have been initiated towards a better understanding of the microclimatic variance in urban areas, due to factors such as urbanization, presence and density of industrial or commercial buildings, green areas, bodies of water, etc. Moreover, the habitability of cities is subject to change especially with regard to climate change. Both of these aspects may have a decisive effect on the performance of buildings. In this context, the present contribution focuses on assessing the site-specific microclimatic conditions for a number of locations within the city of Vienna, Austria. The selected sites include both high-density urban areas and low-density suburban domains. The results point towards a considerable variance in urban microclimate in Vienna. Additionally, the impact of this location specific weather information on building performance simulation results is evaluated. For this purpose, a number of buildings was selected and made subject to systematic thermal performance simulations using the above mentioned location specific weather information as boundary conditions. The computed performance indicators are then compared and analyzed across all locations. Moreover, the results are also compared to performance indicators derived from simulations based on the standardized weather data commonly used for Vienna. Furthermore, this variance has important ramifications for the simulation-based assessment of the energy performance of buildings. This is especially problematic when conducting simulations using standardized weather data due to the major misestimations of the thermal performance of buildings.

Keywords - microclimate; weather data; building performance

1. Introduction

Recently, a number of research efforts have been initiated towards a better understanding of the microclimatic variation in urban areas. The urban microclimate is greatly influenced by factors such as urbanization, presence and density of industrial or commercial buildings, green areas, bodies of water, etc. [1,2,3]. Moreover, the habitability of cities is subject to change especially with regard to climate change [4]. Both of these aspects may have a decisive effect on the performance of buildings [5,6].

In this context, the present contribution focuses on assessing the site-specific microclimatic variations for a number of locations within the city of Vienna, Austria. The selected sites include both high-density urban areas and low-density suburban domains.

The site-specific weather information pertaining to air temperature, solar radiation, humidity, and wind speed, is obtained for the years 2010 to 2013 and systematically studied. For this purpose, the variance of each weather parameter over all locations was calculated annually, over the whole period, and seasonally. Analysis of the data points toward a considerable variance in urban microclimate in Vienna. This in turn may lead to major uncertainties in conclusions drawn from simulation-based predictions of building performance. Thereby, we evaluated the impact of this location specific weather information on building performance simulation. For this purpose a number of buildings was selected and made subject to systematic thermal performance simulations using the above mentioned location specific weather information as boundary conditions. The computed performance indicators are then compared and analyzed across all locations. Moreover, the results are also compared to performance indicators derived from simulations based on the standardized weather data commonly used for Vienna.

2. Methodology

The study was conducted for six distinct areas in the city of Vienna, Austria (Figure 1). Specifically, the selected locations include high-density urban, low-density suburban, and non-urban typologies (Table 1).

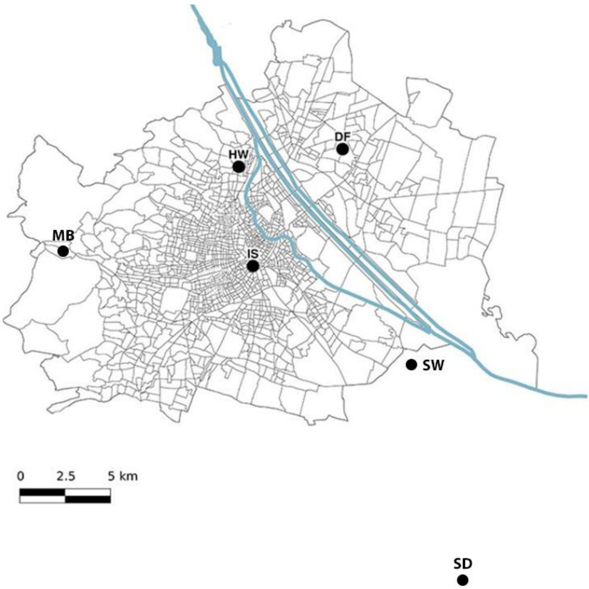

Fig. 1 Position of selected urban, suburban and non-urban locations in and around Vienna

Table1. Overview of deployed weather stations

Abbr.	Name	Type	Coordinates	Elevation [m]
IS	Innere Stadt	Urban (central)	N 48°11'54.0" E 16°22'1.0"	177
HW	Hohe Warte	Urban (peripheral)	N 48°14'55.0" E 16°21'23.0"	198
DF	Donaufeld	Urban (peripheral)	N 48°15'27.0" E 16°26'0.0"	161
MB	Mariabrunn	Suburban	N 48°12'25.0" E 16°13'46.0"	225
SW	Schwechat	Non-urban (airport)	N 48°06'39.0" E 16°34'15.0"	184
SD	Seibersdorf	Non-urban (agricultural land)	N 47°58'35.00" E 16°30'18.00"	185

To systematically address the local variation of climatic circumstances, high-resolution site-specific weather information (pertaining to air temperature, solar radiation, humidity, and wind speed) was collected and analyzed. All weather stations are operated by the Central Institution for Meteorology and Geodynamics [7]. It should be noted that for one location (Schwechat) solar radiation data was not available. Thus the radiation data used as input to the building performance simulation for this one location was generated by the global meteorological database Meteonorm [8]. The collected datasets represent a period of four consecutive years (2010 – 2013). The mean hourly variance of each weather parameter (ΔP_n) was calculated annually, over the whole period, and seasonally (for meteorological seasons) for all locations, in respect to the weather station SD, as follows:

$$\Delta P_n = P_{n,ws} - P_{n,SD} \tag{1}$$

Here $P_{n,ws}$ denotes the respective weather parameter for a given timespan (mean annual, mean over the whole period, and mean seasonal), and $P_{n,SD}$ denotes the corresponding weather parameter obtained at weather station SD. Furthermore, the temporal and spatial variance of all parameters was analyzed, whereas the temporal variance compares the annual data for one weather station over the selected years, and the spatial variance compares the data for all weather stations in the same year (e.g. the temperature variance over the year 2010 between the stations). It should be noted that this variance was also computed in respect to the weather station SD.

To determine the temporal variance (V_T) of a parameter, the difference between the highest and lowest annual value in one location was calculated. For the spatial variance (V_S) the values for one parameter in one year in all locations were compared and the maximum difference was calculated.

To further evaluate of the extent of microclimatic variation between the locations, we calculated the mean daily amplitude of air temperatures ($\Delta\theta_{amp}$ [K]) including standard deviation for each location.

Additionally, four buildings representing different building typologies (as seen in Table 2) were selected and made subject to systematic thermal performance simulations. Thereby, each building was virtually placed within each location, and its performance evaluated using the above-mentioned location specific weather information as boundary conditions. Additionally, for each building one simulation was conducted using a standardized weather file commonly used for Vienna [10]. Input assumption (calendar, occupancy, internal gains, solar gains, ventilation, thermostat settings, etc.) are based on the Austrian standard: ÖNORM B 8110-3 [11], B 8110-5 [12] and B 8110-6 [13]. In some cases, they were adapted for the purpose of this research. Simulations were conducted using Thermal Analysis Simulation Software – EDSL TAS [9]. Once the simulations were conducted, the computed performance indicators were compared and analysed across all locations.

Table 2. General information about the selected buildings

	MFH 1	**MFH 2**	**MFH 3**	**OFFICE**
Type	residential, multi-family	residential, multi-family	residential, multi-family	office building
Year	2014	1960's	1900's	2010
h [m]	18	24.3	23.3	26.5
A_b	1407	1434	1949	15472
V_b	4062	4307	7357	58412

3. Results

Figures 2 to 5 show the mean annual daily air temperature, relative humidity, wind speed, and global solar radiation data, respectively, for each of the six weather stations over the observed years. Figures 6 and 7 show the mean seasonal air temperature (averaged over the whole period), including standard deviation, for summer and winter period respectively. Tables 3 and 4 provide an overview of the mean annual air temperature variance (in respect to the weather station SD) and mean wind speed across five locations, respectively, along with the spatial and temporal variance, and Table 5 shows the mean seasonal temperature variance in respect to SD. Figure 8 shows the mean daily amplitude of air temperature for all locations including standard deviation.

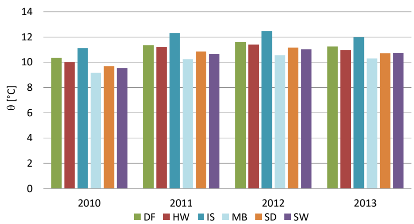

Fig. 2 Mean annual daily temperature for each weather station over the observed years

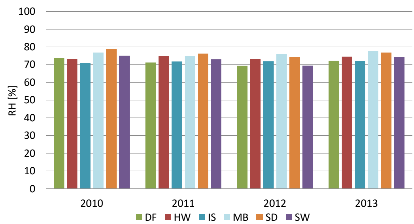

Fig. 3 Mean annual relative humidity for each weather station over the observed years

Fig. 4 Mean annual wind speed for each weather station over the observed years

Fig. 5 Mean annual global solar radiation for each weather station over the observed years

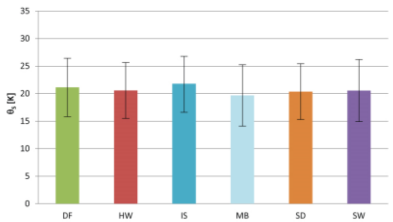

Fig. 6 Mean seasonal air temperature for each weather station with standard deviation, summer season

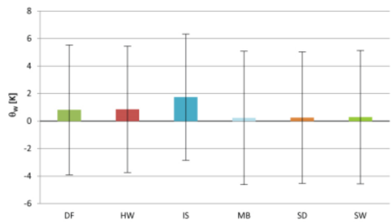

Fig. 7 Mean seasonal air temperature for each weather station with standard deviation, winter season

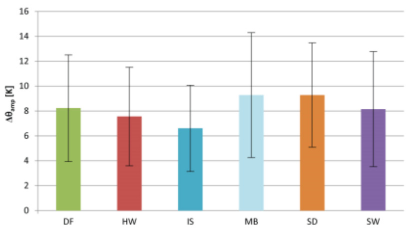

Fig. 8 Mean daily air temperature amplitude for each weather station over the whole period, with standard deviation

Table 3. Mean annual air temperature spatial variance (V_S) and temporal variance (V_T) (expressed in K) across locations

Year	IS	HW	DF	MB	SW	V_S
2010	1.44	0.33	0.67	-0.52	-0.14	**1.95**
2011	1.47	0.37	0.51	-0.60	-0.18	**2.07**
2012	1.32	0.25	0.46	-0.60	-0.13	**1.92**
2013	1.27	0.26	0.54	-0.42	0.03	**1.69**
V_T	**0.20**	**0.12**	**0.21**	**0.18**	**0.21**	

Table 4. Mean annual wind speed spatial variance (V_S) and temporal variance (V_T) (expressed in $m.s^{-1}$) across locations

Year	IS	HW	DF	MB	SW	V_S
2010	-0.55	0.83	0.46	-0.74	1.82	**2.55**
2011	-0.50	0.93	0.52	-0.67	1.79	**2.45**
2012	-0.62	0.80	0.46	-0.82	1.85	**2.67**
2013	-0.67	0.75	0.44	-0.80	1.80	**2.61**
V_T	**0.17**	**0.18**	**0.08**	**0.15**	**0.07**	

Table 5 Mean seasonal air temperature spatial variance (V_S) and temporal variance (V_T) (expressed in K) across locations

Year	IS	HW	DF	MB	SW	V_S
Spring	1.39	0.34	0.48	-0.67	-0.17	**2.05**
Summer	1.25	0.01	0.57	-0.88	-0.20	**2.13**
Fall	1.41	0.29	0.62	-0.53	0.00	**1.94**
Winter	1.45	0.57	0.53	-0.06	-0.04	**1.51**
V_T	**0.20**	**0.56**	**0.14**	**0.82**	**0.20**	

Fig. 9 and Fig. 10 provide an overview of the differences in the mean annual heating and cooling load for each building and each location compared to the corresponding standardized case.

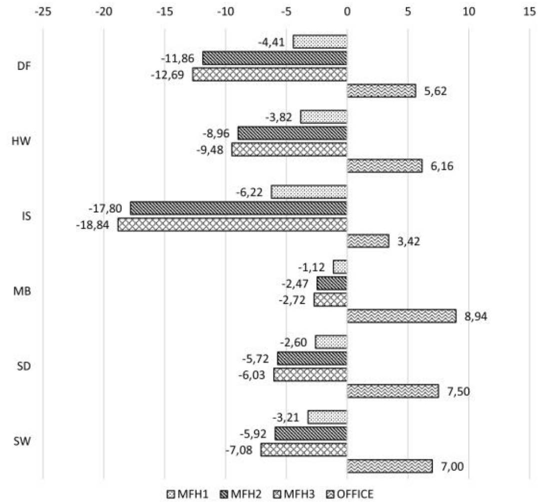

Fig. 9 Differences [kWh.m-2]in mean annual heating load for all buildings in all locations compared to the corresponding standardized case

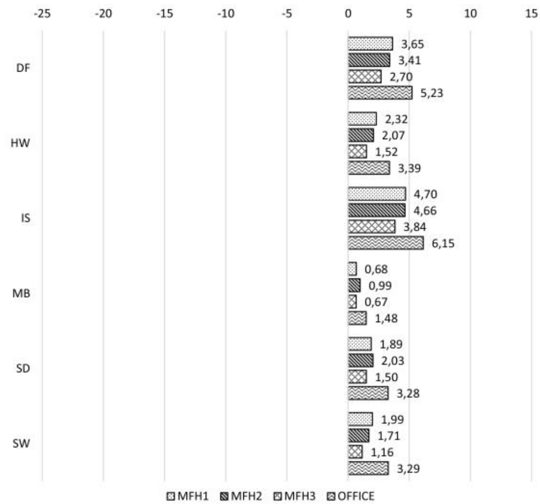

Fig. 10 Differences [kWh.m^{-2}]in mean annual cooling load for all buildings in all locations compared to the corresponding standardized case

4. Discussion

The results clearly demonstrate significant differences of all four weather parameters across the observed locations (Figures 2 to 5). Mean annual daily air temperature is constantly higher at location IS over the observed years. This is consistent with the circumstance that highly developed central urban areas have higher heat storage capacity. Mean annual relative humidity is higher in SD and MB. This may be explained with regard to the high fraction of vegetative cover within these areas. As expected, the wind data show a clear peak at SW due to the unobstructed surroundings. This circumstance further points to the potentially higher ambient temperatures in the urban areas due to the reduced advective heat removal. The highest global solar radiation values are observed at DF and the lowest at MB. However, the variation between the areas is rather small. The seasonal differences are also visible (Figures 6 and 7), with central urban area IS being the hottest in both summer and winter.

Furthermore, the annual and seasonal temporal and spatial variance of air temperature data (Table 3 and 5) clearly show that the temporal fluctuation is negligible compared to the intra-urban differences. The highest temporal variance is 0.21 K, while the spatial variance ranges from 1.69 K to 2.07 K. This circumstance may be attributed to the effects of the surrounding urban context, as distinct urban features such as building density, building height, vegetation fraction, are believed to play an important role in microclimatic development. The same holds true for the other weather parameters e.g. wind speed (table 4).

The mean daily amplitude of air temperature varies from 6.6 to 9.2 K between the locations. Apart from MB (no difference to SD), all other locations have lower mean daily temperature amplitude than SD. This suggests impeded potential for night-time long-wave radiative heat loss in the city, especially in the densely built urban areas. In turn, this aspect may have major consequences for the thermal performance of buildings.

The annual heating load for the residential buildings (MFH1, MFH2, and MFH3) is in all locations lower than the standardized case. The office building (OFFICE) shows higher results for all locations compared to the standardized case. Looking at the different locations IS shows the highest deviation in heating load compared to the standardized case. The simulation results for cooling load show a different picture. The standardized case for all buildings results in lower cooling loads compared to those with actual weather files. However, in absolute numbers the difference lies between 0.67 $kWh.m^{-2}\ a^{-1}$ and 6.15 $kWh.m^{-2}\ a^{-1}$, and is therefore less significant than the deviation for the heating load.

It can clearly be seen that there is a significant difference in both the simulated heating and cooling load of all the building in all locations compared to the respective standardized case.

5. Conclusion

In the present contribution, the site-specific microclimate peculiarities in the city of Vienna were systematically analysed. Significant differences in the four relevant weather parameters (air temperature, solar radiation, humidity, and wind speed) were observed.

It was thus established that urban microclimate displays a notable variance across a city on both temporal and spatial scale.

Moreover, this variance has important ramifications for the simulation-based assessment of the energy performance of buildings. An additional comparison of these results with the results of a simulation with standardized weather data highlights the potential for major misestimations of the thermal performance of buildings. This demonstrates the need for location specific and dependable weather data in order to properly predict a buildings thermal performance.

Acknowledgment

The research work presented in this paper was supported in part within the framework of the EU-Project "Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Island phenomenon" (Central Europe Program, No 3CE292P3).

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