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

The Microclimate of Urban Courtyards: A Case Study

Laura Glasberg[1], Milena Vuckovic[2], Kristina Kiesel[3], Ardeshir Mahdavi[4]

Building Physics and Building Ecology, TU Vienna
Karlsplatz 13, 1040 Vienna, Austria

[1]lauraglasberg@gmail.com

[2]milena.vuckovic@tuwien.ac.at

[3]kristina.kiesel@tuwien.ac.at

[4]bpi@tuwien.ac.at

Abstract

The growth of the cities influences the urban climate and may lead to localized increase of air temperature. Elevated air temperatures, especially during the summer season, may have major implications for building energy demand, local air quality, and outdoor thermal comfort. The present study investigates the thermal behavior of a number of courtyards in the city of Vienna, Austria. Specifically, we explored the diversity of microclimatic conditions in and around a number of geometrically different courtyards. We collected the weather data pertaining to the air temperature, humidity, wind speed and CO_2, using both mobile and stationary weather stations. Results show the importance of the specific geometry of a courtyard (height-to-width ratio, shading circumstances) in view of the courtyards' microclimate (day-night temperature differences, potential for night-time cooling within the courtyard). When compared to the adjacent street, geometrically open courtyards show slightly more favorable thermal conditions, especially during morning and evening hours.

Keywords – urban climate; courtyards; geometry; measurements

1. Introduction

The development and growth of the cities can influence the urban climate and may lead to localized increase of air temperature [1,2,3]. Elevated air temperatures, especially during the summer season, may have major implications for issues such as building energy demand, local air quality, and outdoor thermal comfort [4,5]. The energy balance of the city is generally affected by its complex urban morphology, along with the high heat-absorbing properties of sealed structures, which may lead to considerable heat storage in urban fabric [6]. However, the resulting thermal circumstances may vary based on specific urban context [7,8,9]. Therefore, a city may harbor a cluster of many different microclimatic conditions, making thus the study of urban climate a complex matter.

In this context, the present study is concerned with the thermal behavior of courtyards in the city of Vienna, Austria. The courtyard typology was considered due to its standing as a prominent architectural element in many European cities and its potential role in view of adequate mitigation measures pertaining to heat stress in urban areas. Specifically, we explored the diversity of microclimatic conditions in a number of geometrically different courtyards and further compared them to the climatic circumstances of adjacent street canyon. We collected the weather data pertaining to the air temperature, humidity, wind speed and CO_2, using both mobile and stationary weather stations. We also compared humidity, wind speed, and CO2 concentrations in courtyards and adjacent streets.

2. Methodology

The study is carried out for a number of geometrically different courtyards in the city of Vienna, Austria (Figure 1, Tables 1 and 2). The data was collected on multiple days between April and July 2015. All locations are situated within the inner districts of Vienna and include courtyards that vary significantly in size, height-to-width ratio (H/W), and amount of vegetation. The extent of vegetation, referred to as the Pervious surface fraction (PSF), was expressed as the ratio of pervious surface cover within a courtyard (A_p) to total courtyard ground area (A_c):

$$PSF = A_p / A_c \quad (1)$$

The data acquisition was subdivided into two different phases. For the first phase, measurements were conducted at 10 different locations in Vienna using two mobile weather stations [10], which were attached to bicycles at the height of 1.5 meters (Figure 1). Both bicycles were equipped with temperature and humidity sensors, a low power anemometer for wind speed, a pyranometer for global solar radiation, and equipped with CO_2 sensors. At each location, conditions were captured simultaneously during afternoon hours (13:00-17:00) inside and outside the courtyard. Additionally, in 3 of these locations (P1, R1, and M3) morning (08:00-12:00) and nighttime (20:00-24:00) measurements were conducted.

In the second data acquisition phase, temperature sensors were installed in 4 different courtyards in order to record full diurnal cycles (G, K, OB, and T, as shown in Figure 1). Data was collected during the 3-week period between 8^{th} and 29^{th} July 2015.

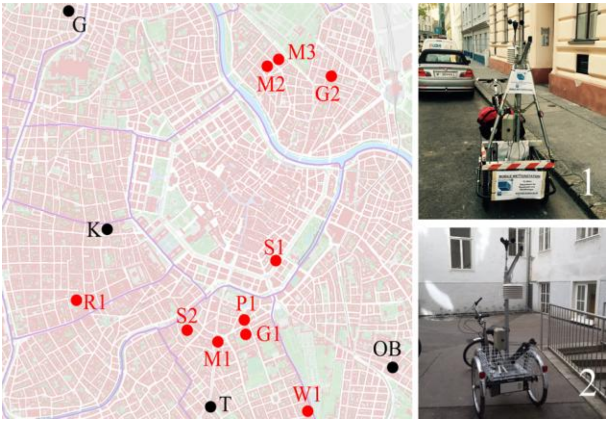

Fig. 1 The selected courtyards in the city of Vienna: mobile weather stations (1 and 2) are marked in red, stationary weather stations are marked in black (source: wien.gv.at)

Table1. General information about the selected courtyards for mobile measurements. A is courtyard area in m^2, h_b is building height in m, H/W ratio is the aspect ratio.

G1		**G2**		**M1**		**M2**		**M3**	
									
A	620	A	240	A	90	A	90	A	2750
h_b	22	h_b	20	h_b	27.3	h_b	22	h_b	24
H/W	0.95	H/W	1.66	H/W	2.40	H/W	1.95	H/W	0.42
PSF	0.6	PSF	0.5	PSF	0	PSF	0	PSF	0.75

P1		**R1**		**S1**		**S2**		**W1**	
									
A	44.5	A	290	A	38.5	A	190	A	180
h_b	28	h_b	22	h_b	28	h_b	16	h_b	23
H/W	4.40	H/W	1.26	H/W	4.50	H/W	1.90	H/W	1.60
PSF	0	PSF	0.56	PSF	0	PSF	0.47	PSF	0

Table2. General information about the selected courtyards for stationary measurements. A is courtyard area in m^2, h_b is building height in m, H/W ratio is the aspect ratio.

G		K		OB		T	
							
A	1570	A	49	A	3305	A	845
h_b	27	h_b	20	h_b	25	h_b	23
H/W	0.6	H/W	2.9	H/W	0.4	H/W	0.7
PSF	0.95	PSF	0	PSF	0.6	PSF	0.75

3. Results

Using the collected data, site-specific microclimatic conditions inside selected courtyards were systematically studied. For this purpose, the mean value of a climatic parameter under study (ΔP_i) is computed as a difference between specific value obtained inside the courtyard at interval *i* (C_i), and value obtained at adjacent street at the same interval (S_i), as follows:

$$\Delta P_i = C_i - S_i \quad (2)$$

Figure 2 shows the mean air temperature difference between courtyards and adjacent street at 10 study locations measured during the afternoon hours. Figure 3 shows the hourly distribution of air temperature difference between courtyards and adjacent streets for the same period. Figures 4 and 5 show the hourly distribution of air temperature difference between courtyards and adjacent streets at 3 different locations measured during the morning and evening hours, respectively.

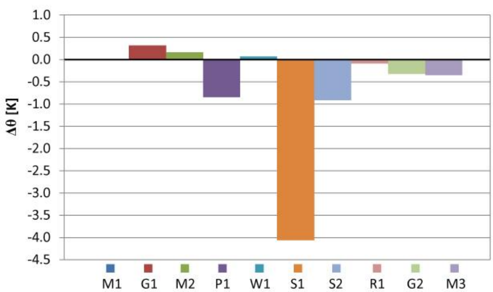

Fig. 2 Mean courtyard-street temperature difference at 10 different locations measured during the afternoon hours (13:00 – 17:00)

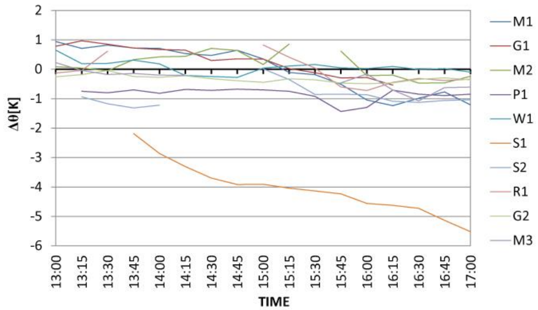

Fig. 3 Hourly distribution of courtyard-street temperature difference at 10 different locations measured during the afternoon hours (13:00 – 17:00)

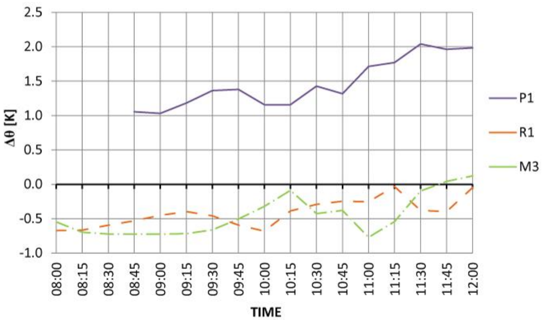

Fig. 4 Hourly distribution of courtyard-street temperature difference at 3 different locations measured during the morning hours (08:00 – 12:00)

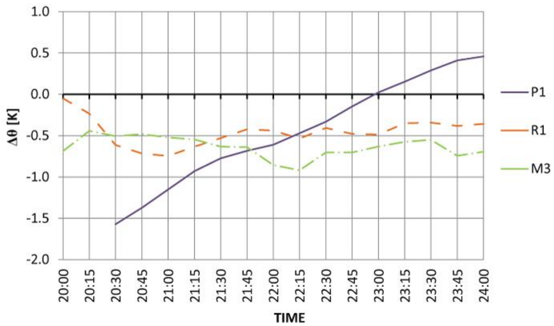

Fig. 5 Hourly distribution of courtyard-street temperature difference at 3 different locations measured during the evening hours (20:00 – 24:00)

Figure 6 shows the mean wind speed between courtyard and street at 10 locations measured during the afternoon hours. Figure 7 shows the mean CO_2 concentrations between courtyard and street measured during afternoon hours obtained at 6 locations (data from the remaining four courtyards could not be used for the analysis due to technical issues).

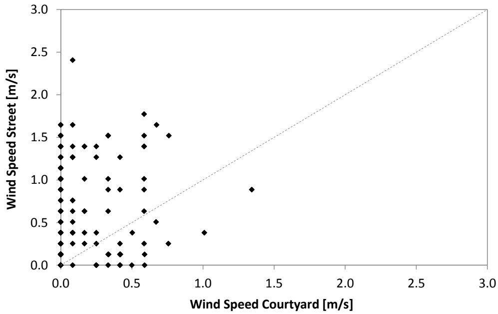

Fig. 6 Mean courtyard-street wind speed difference at 10 locations measured during the afternoon hours (13:00-17:00)

Fig. 7 Mean courtyard-street CO_2 concentration difference at 6 different locations measured during the afternoon hours (13:00 – 17:00)

Figure 8 shows the diurnal air temperature at 4 courtyards measured between 17^{th} and 22^{nd} July 2015. A subset of this data (for 18^{th} July 2015) is shown in Figure 9.

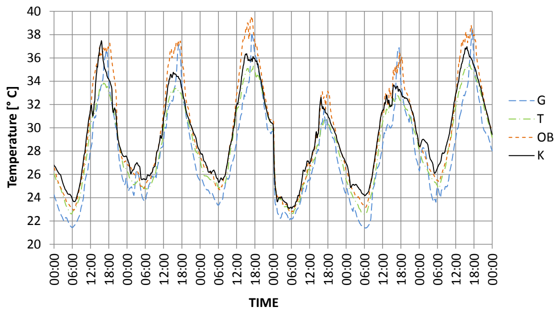

Fig. 8 Diurnal air temperature distribution of 4 courtyards between 17th and 22nd July 2015

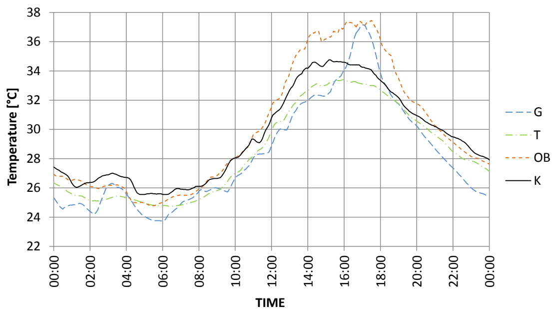

Fig. 9 Air temperature distribution of 4 courtyards on July 18th 2015

4. Discussion

The results clearly demonstrate significant microclimatic differences between the courtyards and adjacent street canyon. During the afternoon hours (13:00-17:00) courtyards are generally cooler than the street, with an average air temperature difference of 0.8 K (Figure 2). The only exception from this trend can be observed in location S1, where the air temperature difference was 4 K. This circumstance may be attributed to the relatively high height-to-width ratio that limits the amount of incoming solar radiation, making thus the courtyard cooler. Additionally, a higher temperature can be observed inside the courtyards during the early afternoon hours when the sun is at its highest position (Figure 3). Starting from 15:00, this trend is then reversed with temperature inside the street canyon exceeding the one inside the courtyard. This circumstance further stresses the importance of the specific geometry of a courtyard and the corresponding shading extent of building walls in view of the courtyards' microclimate.

Figures 4 and 5 show that during morning and evening hours, geometrically open and large courtyards (R1 and M3) with low height-to-width ratio display slightly more favorable thermal conditions when compared to the adjacent street canyon. In contrast, relatively small courtyards with high height-to-width ratio (P1) display higher air temperature during morning hours. However, in the evening, the air temperature recorded in P1 was lower than in the urban canyon, with noted upward trend toward the midnight (as seen in Figure 5). This circumstance further highlights the important role of height-to-width ratio and small sky-view factors in view of the potential for night-time long-wave radiative heat loss within the courtyard. These aspects may have major consequences for the thermal performance of buildings.

The recorded wind speeds are constantly lower within the courtyards, which points to the reduced convective heat removal and potential for higher air temperatures (Figure 6). Likewise, the recorded CO_2 levels were found to be lower within the courtyards (Figure 7), which could be partly attributed to the high traffic frequency outside the courtyards.

Figures 8 and 9 reveal very different microclimatic conditions amongst the 4 geometrically different courtyards. In general, relatively open and very large courtyards (G, T, and OB) displayed increased potential for night-time cooling. However, during the daytime, they may show a potential towards higher solar gain. Smaller courtyards with higher height-to-width ratio (K) revealed smaller diurnal fluctuations of air temperature. Additionally, the night-time air temperature was constantly higher, further stressing the impeded potential for night-time cooling.

5. Conclusions

We presented the results of a study concerned with the extent of the microclimatic variation of geometrically different courtyards. Results show the importance of the height-to-width ratio in view of the courtyards' microclimate, as it appears to be consequential for the day-night temperature differences. The specific geometry of a courtyard and the corresponding shading extent of building walls were found to influence the potential for night-time cooling within the courtyard. When compared to the adjacent street, geometrically open courtyards show slightly more favorable thermal conditions, especially during morning and evening hours. Only during the early afternoon hours, when the sun is at its highest position, such courtyards remain warmer than the adjacent street canyon. In contrast, courtyards with high height-to-width ratios remain warmer than the street during morning and evening hours. We also compared humidity, wind speed, and CO2 concentrations in courtyards and adjacent streets. The results point towards slightly more favorable conditions inside courtyards.

These findings encourage further explorations in this direction. It would be noteworthy to observe how different design variants of courtyards, which have been shown to be advantageous over the summer, behave thermally during winter months. Thereby, additional long-term data collection efforts are needed to comprehensively observe time-dependent (diurnal, nocturnal, and seasonal) patterns of climatic parameters and resulting implications for the thermal performance of buildings. Furthermore, extended research on the cities with different climatic conditions may further a more global understanding of the urban climate and how it is influenced by the cities' different physical, typological, and morphological attributes.

References

[1] C. S. B. Grimmond. Urbanization and global environmental change: local effects of urban warming. The Geographical Journal. 173 (2007) 83–88.

[2] B. Y. Tam, W. A. Gough, T. Mohsin. The impact of urbanization and the urban heat island effect on day to day temperature variation. Urban Climate. 12 (2015) 1–10.

[3] Gartland, L. Heat Islands: Understanding and Mitigating Heat in Urban Areas. London, Earthscan, 2008.

[4] D. M. Yow. Urban Heat Islands: Observations, Impacts, and Adaptation. Geography Compass. 1 (2007) 1227–1251.

[5] V. Dorer, J. Allegrini, K. Orehounig, P. Moonen, G. Upadhyay, J. Kämpf, J. Carmeliet. Modelling the urban microclimate and its impact on the energy demand of buildings and building clusters. BS2013, 13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28.

[6] B. Offerle, C. S. B. Grimmond, K. Fortuniak. Heat storage and anthropogenic heat flux in relation to the energy balance of a central European city centre. International Journal of Climatology. 25 (2005) 1405–1419.

[7] J. Allegrini, V. Dorer, J. Carmeliet. Influence of morphologies on the microclimate in urban neighbourhoods. Journal of Wind Engineering and Industrial Aerodynamics. 144 (2015) 108 – 117.

[8] A. Almhafdy, N. Ibrahim, S. Sh Ahmad, J. Yahya. Courtyard Design Variants and Microclimate Performance. Procedia - Social and Behavioral Sciences. 101 (2013) 170 – 180.

[9] N. Shishegar. Street Design and Urban Microclimate: Analyzing the Effects of Street Geometry and Orientation on Airflow and Solar Access in Urban Canyons. Journal of Clean Energy Technologies. 1 (2013) 52-56.

[10] Synotech Onset HOBO data loggers, 2015: http://www.onsetcomp.com.