

Thermal human biometeorological conditions and subjective thermal sensation in pedestrian streets in Chengdu, China

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Abstract The outdoor thermal environment of a public space is highly relevant to the thermal perception of individuals, thereby affecting the use of space. This study aims to connect thermal human biometeorological conditions and subjective thermal sensation in hot and humid regions and to find its influence on street use. We performed a thermal comfort survey at three locations in a pedestrian precinct of Chengdu, China. Meteorological measurements and questionnaire surveys were used to assess the thermal sensation of respondents. The number of people visiting the streets was counted. Meanwhile, mean radiant temperature (T_{mrt}) and the physiological equivalent temperature (PET) index were used to evaluate the thermal environment. Analytical results reveal that weather and street design drive the trend of diurnal micrometeorological conditions of the street. With the same geometry and orientation, a street with no trees had wider ranges of meteorological parameters and a longer period of discomfort. The neutral temperature in Chengdu (24.4 °C PET) is similar to that in Taiwan, demonstrating substantial human tolerance to hot conditions in hot and humid regions. Visitors' thermal sensation votes showed the strongest positive relationships with air temperature. Overall comfort level was strongly related to every corresponding meteorological parameter, indicating the complexity of people's comfort in outdoor environments. In major alleys with multiple functions, the number of people in the street decreased as thermal indices increased; T_{mrt} and PET had significant negative correlations with the number of people. This study aids in understanding pedestrian street use in hot and humid regions.

Keywords Outdoor human comfort · Human perception · Pedestrian street · Hot and humid regions

Introduction

The urban public places attract thousands of local residents and visitors and provide several social, cultural, and economic benefits. Meteorological conditions, together with other natural resources, significantly impact the mood and behaviors of visitors for tourism and recreation (Freitas 2003).

Micrometeorological conditions in a particular location are affected by the design of the built environment (Lin et al. 2007; Wong et al. 2007), which in turn affects the subjective evaluation of thermal comfort and use of outdoor space (Eliasson et al. 2007; Nikolopoulou et al. 2001; Nikolopoulou and Lykoudis 2007; Thorsson et al. 2004). As a type of public place with a unique morphology, the pedestrian street is both architecture and an urban interface. The micrometeorological conditions of such streets are largely dependent on the physical design of the surroundings (Ali-Toudert and Mayer 2006; Johansson 2006; Shashua-Bar and Hoffman 2003). Several research works have discussed the contributions of street design, such as street geometry, solar orientation, and urban shade trees, toward the understanding of human thermal comfort in pedestrian areas within hot and arid regions (Ali-Toudert et al. 2005; Ali-Toudert and Mayer 2007; Pearlmutter et al. 1999, 2006) as well as hot and humid regions (Abreu-Harbach et al. 2014; Johansson and Emmanuel 2006; Potchter et al. 2006; Shashua-Bar et al. 2010a, 2012).

Outdoor public places are normally categorized into routes and recreational areas, and the exposure time to a given thermal condition is shorter on walkways than that on other public places (Kántor et al. 2012a; Nikolopoulou et al. 2001). Many thermal comfort investigations have focused on recreational open spaces (Eliasson et al. 2007; Nikolopoulou and

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Lykoudis 2006; Oliveira and Andrade 2007; Thorsson et al. 2007), such as public squares (Lin 2009; Nikolopoulou and Lykoudis 2007) and parks (Lin et al. 2013; Mahmoud 2011; Thorsson et al. 2004), to understand the relationships between environmental issues, perceptions of human biometeorological comfort, and conditions of use. There have been only a limited number of investigations of the thermal conditions of pedestrian streets, carried out together with human monitoring (Köppen-Villadiego and Velay-Dabat 2014; Pearlmutter et al. 2014). The pedestrian precinct investigated in the present study is a multifunctional area, with walking as the dominant behavior. It is unclear whether the characteristic of subjective perception and use of space there would be differently perceived relative to other open spaces.

The main objective is to investigate thermal human biometeorological conditions of pedestrian streets and how this type of public space is perceived and used in hot and humid regions. We investigated a pedestrian precinct using meteorological measurements, unobtrusive observations, and questionnaire surveys on thermal comfort. This was done to (1) examine the relationship between outdoor micrometeorological conditions and pedestrian thermal perception and (2) examine correlations between meteorological parameters and space use in a pedestrian precinct in the hot and humid conditions of Chengdu.

Methods

Study area

Chengdu is the provincial capital and largest city of Sichuan Province, China. It is located at 30° 39' N, 104° 3' E, with altitude 500 m. The city has a monsoon-influenced humid subtropical climate, Cwa, according to the Köppen–Geiger climate classification (Peel et al. 2007). Figure 1 shows long-term meteorological data obtained by the National Observatory of Chengdu meteorological station (No. 56294). Average air temperature is highest in July at 25.8 °C and lowest in January at 5.8 °C. Relative humidity is generally greater than 80 %, especially in summer. Precipitation is 927.5 mm, and mean wind speed in summer is 1.4 m/s.

A pedestrian precinct called Kuan Zhai Alley was selected as the study area. This precinct is 1.2 km from the city center. It is a historical and cultural preservation district with a compact urban fabric and includes three main ancient alleys (Kuan, Zhai, and Jing), oriented west–northwest to east–southeast (WNW-ESE), and several shorter alleys perpendicular to these. The alleys are flanked by buildings of one to three stories, with pitched tile roofs. The main alleys are made of bluestone flags and are 6–9 m wide. Some deciduous trees, such as *Platanus acerifolia* and *Ficus virens*, and evergreen trees, such as *Osmanthus fragrans*, grow along the streets.

The buildings surrounding the pedestrian precinct are almost of equal height, typically four to seven stories.

The research concentrated on three study locations representing different street patterns (Fig. 2). Location A is on the southern side of Kuan Alley, with trees standing to the south. The tree crown shades approximately 70 % of the ground. Location B is at the eastern edge of south–north alley, a north–northeast to south–southwest (NNE-SSW) street flanked by buildings of three stories. The exposure time of direct radiation at this location is shorter because of the orientation and vertical profile of the street. Location C is on the northern side of Zhai Alley. Table 1 shows a street photo, fisheye diagram, sky view factor (SVF), height/width ratio (H/W), and street orientation of each location. The RayMan model was used to generate the fisheye diagrams and calculate SVF values (Gulyás et al. 2006).

Meteorological measurement

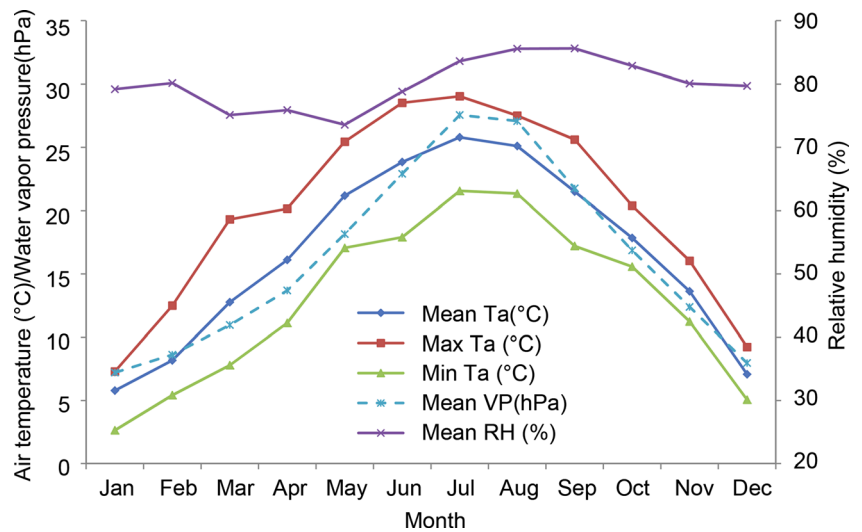
Air temperature (T_a), globe temperature (T_g), relative humidity (RH), and wind speed (v) were automatically measured at 1-min intervals from 10:30 to 16:30, because this was the period during which both solar radiation and air temperature reach their daily maxima and the pedestrian precinct has many visitors. Water vapor pressure (VP) was obtained from the conversion of RH by the RayMan model. All instruments followed the ISO 7726 standard (ISO 1998). They were positioned on a tripod 1.1 m above the ground, corresponding to the average height of the gravity center for adults (Mayer and Höppe 1987). Measurements were taken in August 2012 for a total of 9 days. The purpose of meteorological measurement at three locations is not specifically to compare the thermal environmental parameters of each street but to investigate the variety of human biometeorological conditions in the pedestrian area. Moreover, because of a lack of instruments, we measured at the sites sequentially, i.e., for three continuous days at each location, so as to sample different weather conditions (sunny/cloudy). Sunny days with no rain are appropriate for measuring meteorological parameters. Most survey days were sunny or cloudy. A cloudy day with a short drizzly period (August 22, 2012) was also included, because typical summer weather in Chengdu is overcast with occasional direct sunlight or rain showers.

In addition to the meteorological parameters recorded on-site, official weather data from the National Observatory of Chengdu meteorological station were used to analyze diurnal air temperature fluctuations of the alleys.

Thermal stress indices

Various indices of thermal stress integrating thermal factors and energy balance of the human body are used to assess thermal comfort, e.g., standard effective temperature

Fig. 1 Monthly mean/maximum/minimum air temperature, mean water vapor pressure, and mean relative humidity in Chengdu (1971–2003). Source China Meteorological Administration



(SET*) (Gagge et al. 1986), OUT_SET* (Spagnolo and de Dear 2003), and physiological equivalent temperature (PET) (Mayer and Höppe 1987).

Here, we used PET as the primary index to evaluate thermal human biometeorological conditions. According to Höppe (1999), PET is defined as the air temperature at which, in a typical indoor setting ($T_a = T_{mrt}$, $v = 0.1$ m/s, and $VP = 12$ hPa), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed. PET has been widely used in outdoor thermal comfort investigations (Ali-Toudert and Mayer 2006; Lin and Matzarakis 2011; Mahmoud 2011; Makaremi et al. 2012; Shashua-Bar et al. 2012; Thorsson et al. 2007). We used the RayMan model (Matzarakis et al. 2010) to calculate PET. The mean radiant temperature (T_{mrt}) in PET calculation is achieved by substituting T_a , T_g , and v into an equation proposed in ISO 7726 (ISO 1998), as follows:

$$T_{mrt} = \left[(T_g + 273)^4 + 2.5 \times 10^8 \times v^{0.6} (T_g - T_a) \right]^{1/4} - 273 \tag{1}$$


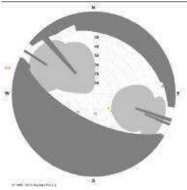

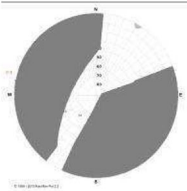

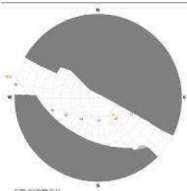
Questionnaire survey

Subjective thermal sensation was recorded by structured interviews during field measurement. The questionnaire consisted of two sections. The first section dealt with personal factors such as age and gender, activity level, clothing, residence, visit reason and frequency, and time spent in the street. The second section asked respondents to evaluate their sensations of air temperature, air humidity, and the comfort level of the outdoor environment. Subjective thermal sensation was rated on ASHRAE 7-point thermal sensation vote (TSV) scale (i.e., -3, cold; -2, cool; -1, slightly cool; 0, neutral; 1, slightly warm; 2, warm; 3, hot) (ASHRAE 2010).

Fig. 2 Studied area and measurement locations in Kuan Zhai Alley, Chengdu, China



Table 1 Location descriptions

	Street photo	Fisheye diagram	SVF	H/W	Orientation
A			0.273	1.1	WNW-ESE
B			0.3	3	NNE-SSW
C			0.305	1.1	WNW-ESE

The humidity sensation vote (HSV) was also measured by a 7-point scale ranging from -3 for “very dry” to 3 for “very humid” (0=“neutral”). A 5-degree scale (1, intolerable; 2, very uncomfortable; 3, uncomfortable; 4, slightly uncomfortable; 5, comfortable) was used to measure responders’ overall thermal comfort level (acceptability) of the outdoor environment. Each interview took an average of 5 min. Approximately 20–30 interviews were conducted each day. Correlation analysis was applied to the subjective assessments (TSV, HSV, acceptability) and recorded thermal environment indices (T_a , VP, RH, T_{mrt} , and PET), to reveal the relationships between subjective and objective estimations.

Observations and analyses of street use

Use of the alleys was observed unobtrusively for 5 min per half hour during the 9-day survey period. The number of people strolling through the survey area was recorded. We selected data obtained from 14:00 to 15:30, when the number of people in the street tends to be greatest, as the statistical number. There were 12 observations at each location. Regression analysis was used to determine the relationships between visitor attendance in the pedestrian precinct and thermal human biometeorological conditions. We focused on three representative indices, T_a , T_{mrt} , and PET, which have been proven to be associated with use of the public squares in hot and humid regions (Lin 2009). The typical Chinese male (30 years old, weight 70 kg, height 1.75 m) was used to calculate PET in

this part of the study (AQSIQ and SAC 2008). A clothing index of 0.5 clo was used, corresponding to a light shirt and trousers, as well as a metabolic heat of 120 W (ISO 1998). Statistical analyses were done with Microsoft Excel and SPSS 20.0 software.

Results

Interview subjects

The interview sample comprised 255 people. Male subjects represented 45.5 % of this sample and female subjects represented 54.5 %. The most frequent age group was 26–35 years (34.1 %), followed by 18–25 years (31.8 %). The largest share of respondents (65.1 %) originated from other provinces in China or foreign countries, followed by residents of Chengdu (21.2 %) and other cities in Sichuan Province (13.7 %). As their primary reason for visiting the study area, 74.9 % of respondents stated that they were outside to exercise or relax, while 7.1 % reported being on their way to dine or to meet someone. The remaining 18 % were neutral. About half the respondents (56.5 %) reported that it was their first time in Kuan Zhai Alley. For the remaining respondents who had visited Chengdu at least once before, 31 % stated that they came rarely, 4.7 % came every month, and 7.8 % every week. The percentage who intended to remain less than 2 h was 53.3 %, and those who hoped to spend 4–10 h, there was 15.8 %.

Meteorological conditions in the street

Table 2 summarizes the meteorological data from the National Observatory of Chengdu meteorological station over the measurement period. During the survey, mean daily T_a was 25.2 °C, and mean daily maximum (minimum) T_a was 29.9 °C (21 °C), which were close to long-term averages in Chengdu. Average RH was 74.5 % and average VP was 23.3 hPa. It is apparent that the outdoor meteorological condition during the survey was hot and humid. Figure 3 shows calculated 10-min mean values of T_a , RH, VP, and T_{mrt} over the measurement period. Location A had the highest mean daily T_a (33.6 °C) on day 1 and the highest mean daily VP (30.4 hPa) on day 3. Location B had the highest mean daily RH (73.8 %) on day 6. Location C had the highest mean daily T_{mrt} (48.2 °C) on day 9. Average daily oscillations of T_a , RH, VP, and T_{mrt} were greatest at location C. Table 3 shows differences of T_a between the measurement locations and meteorological station. The measured values were typically higher than the meteorological station data, indicating that it was warmer in the alleys. The greatest warming effect reached $T_a=8.7$ °C at 16:00 at location C on day 7. Measured T_a values at location A were sometimes lower than the meteorological station data. Generally, the diurnal T_a at location C varied across a greater range. Deviations and fluctuations of T_{mrt} during the measurement period were well matched with the partly cloudy and shading conditions at the measurement locations.

Perception of the human biometeorological conditions in the local environment

Thermal sensation vote and neutral temperature

Figure 4 shows percentage distributions of TSV of all responders. The highest percentage of people (35.7 %) felt

neutral (TSV=0). More than half (52.5 %) of TSVs were in the three middle categories (“slightly cool,” neutral, or “slightly warm”). The percentage who felt “warm” or “hot” (TSV= 2, 3, respectively) was 44.3 %. People feeling “cool” or “cold” (TSV=-2, -3, respectively) was around 9 %, although the minimal T_a was greater than 22 °C.

Neutral temperature is that for which the mean thermal sensation vote (MTSV) equals 0 (Lin 2009), representing conditions in which people feel neither cool nor warm (Nikolopoulou and Lykoudis 2006). The MTSVs of responders in each 1 °C PET interval group were calculated and are plotted in Fig. 5. The fitted regression line for thermal sensation versus PET is

$$MTSV = 0.105 \times PET - 2.6 (R^2 = 0.60) \tag{2}$$

The slope is 0.105, corresponding to 9.5 °C PET per sensation unit. The neutral temperature is 24.4 °C PET, which is assessed using fitted Eq. 2 with MTSV=0.

Perception of humidity

The questionnaires showed that the majority of people (86.7 %) chose “slightly dry,” neutral, and “slightly humid” (HSV=-1, 0, 1, respectively) for humidity conditions. The percentage who felt “humid” or “very humid” (HSV=2, 3, respectively) was 11.7 %. Only 1.6 % of responders stated that they felt “dry” or “very dry” (HSV=-2, -3, respectively). Opinions regarding humidity in the pedestrian precinct were more centralized than the sensations of thermal condition.

Overall comfort level

During the field survey, PET was 19.9–46.9 °C. Table 4 summarizes the acceptability range for each PET class in hot

Table 2 Representative meteorological data on measurement days

Date (2012)	Site	Air temperature (T_a) (°C)			Relative humidity (RH) (%)			Vapor pressure (VP) (hPa)			Wind speed (m/s)
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	
August 15 (Day 1)	A	34	22	27.7	91	37	69	30.9	19.6	24.6	2
August 16 (Day 2)	A	32	23	28.2	92	52	73	30.6	24.7	27.4	2
August 17 (Day 3)	A	29	24	26.3	93	75	84	30.6	27.4	28.7	3
August 20 (Day 4)	B	31	21	24.7	94	39	75	25.5	17.5	22.5	2
August 21 (Day 5)	B	31	22	26	91	30	63	24.7	13.4	20.4	2
August 22 (Day 6)	B	24	19	21.2	89	61	80	21.9	17.7	20.2	2
August 24 (Day 7)	C	28	19	23.3	94	49	78	25	18.5	21.7	2
August 25 (Day 8)	C	29	20	24.4	92	46	74	23.8	18.4	21.8	2
August 26 (Day 9)	C	31	19	25.2	95	43	73	26.6	19.3	22.7	3

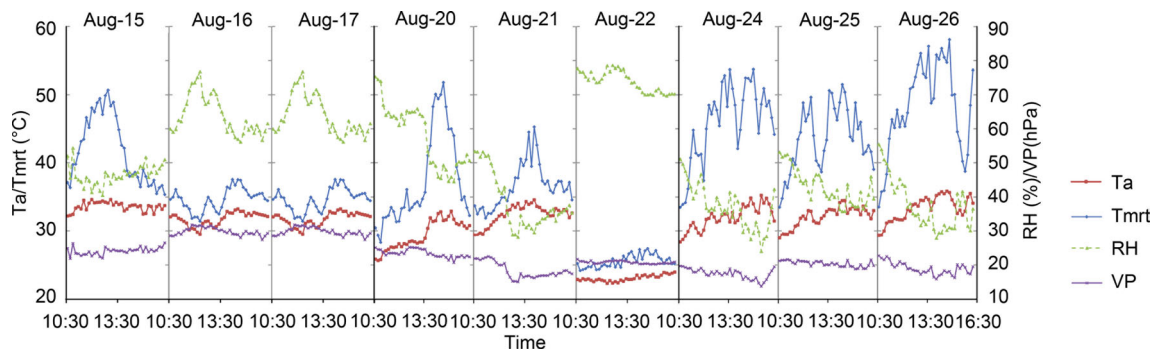


Fig. 3 Variation of measured air temperature, mean radiant temperature, relative humidity, and water vapor pressure for cases in summer

and humid regions (Lin and Matzarakis 2008). For all seven PET classes that occurred during the survey, 92–100 % of respondents rated the environment between “slightly uncomfortable” and “comfortable.” Few (0–8 %) rated the environment “very uncomfortable” or “uncomfortable,” and none chose “intolerable.” Comfortable was the usual choice among responders. A noticeable difference appeared when the PET value was warm (34.1–38 °C PET), in that slightly uncomfortable was chosen by over half of responders.

Subjective versus objective estimation

Considering the responses of all interviewees ($N=255$), TSV had significant correlations (Pearson correlation coefficients, $P<0.01$) with each meteorological factor (T_a , VP, RH, T_{mrt} , and PET). The strongest correlation was with T_a ($r=0.38$). HSV only had significant correlations with VP and RH. This result reveals that HSV correlated better with VP ($r=0.35$, $P<0.01$) than with RH ($r=0.25$, $P<0.01$). The acceptability votes had significant negative correlations with T_a ($r=-0.23$,

$P<0.01$), T_{mrt} ($r=-0.23$, $P<0.01$), and PET ($r=-0.25$, $P<0.01$) and positive correlations with VP ($r=0.13$, $P<0.05$) and RH ($r=0.26$, $P<0.01$). Furthermore, the acceptability votes were more strongly related with TSV ($r=-0.38$, $P<0.01$) than HSV ($r=-0.21$, $P<0.01$).

Thermal environment and street usage

We counted the number of people walking through the study location during the survey. In total, 12,162 individuals were recorded, with 5,524 at location A, 1,670 at location B, and 4,968 at location C. The diverse ranges of people reflected the different uses among the street locations.

Figure 6 shows the number of people in relation to T_a (a), T_{mrt} (b), and PET (c) at three measurement locations from 14:00 to 15:30. Analytical results revealed that T_a , T_{mrt} , and PET were negatively associated with the number of people at locations A and C. Correlations between thermal indices (T_{mrt} and PET) and total number of people were weak but statistically significant at location A. Correlations between T_{mrt} and number of people were also statistically significant at location C. In contrast, there were very weak positive correlations between thermal indices (T_a , T_{mrt} , and PET) and number of

Table 3 Air temperature differences (°C) between measurement locations and the National Observatory of Chengdu

Date(2012)	Site	Time (h)					
		11:00	12:00	13:00	14:00	15:00	16:00
August 15	A	3.6	2.4	1.9	-0.5	-0.3	-0.3
August 16	A	1.9	-1.2	-0.6	1.1	0.1	0.9
August 17	A	4.1	2.4	4.6	3.1	2.4	3.6
Average		3.2	1.2	2.0	1.2	0.7	1.4
August 20	B	1.8	2.4	2.4	4.1	2.7	1.6
August 21	B	0.5	2.2	2.3	3.3	2.5	3.2
August 22	B	3.8	2.8	2.5	0.9	0.2	2.1
Average		2.0	2.5	2.4	2.8	1.8	2.3
August 24	C	4.3	3.4	4.1	2.1	7	8.7
August 25	C	2.5	3.1	2.1	5.2	4.3	3.8
August 26	C	3.3	2.9	3.8	4.3	5.1	3.1
Average		3.4	3.1	3.3	3.9	5.5	5.2

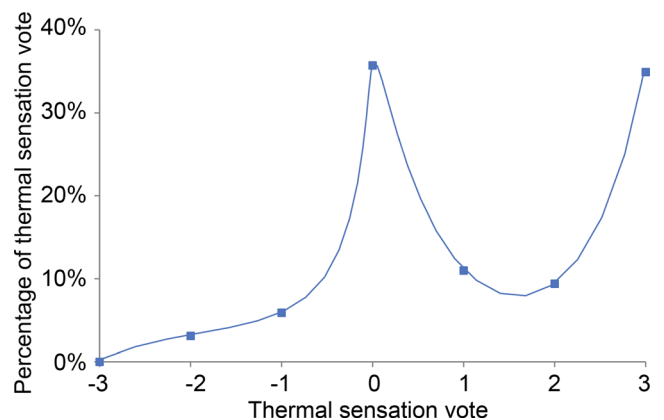


Fig. 4 Percentage distributions of thermal sensation votes (TSVs) in Chengdu

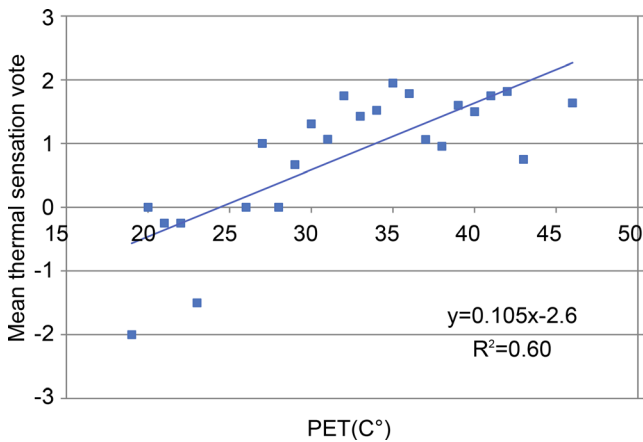


Fig. 5 Correlation between mean thermal sensation votes (MTSVs) and PET

people at location B, but these were not statistically significant.

Discussion

In general, the results herein confirm the influence of street design on micrometeorological conditions and reveal various relationships between the use of pedestrian streets and thermal human biometeorological conditions in a hot and humid region.

During the study, T_a was an average 1.6 °C warmer at location A than at the official weather station. This difference was 2.3 °C at location B and 4.1 °C at location C. These differences can be explained by street design in terms of geometry, orientation, and shade trees. When the geometry ($H/W=1$) and orientation (WNW-ESE) are the same, the street with no trees had a greater increase of T_a and a longer period of discomfort, especially in the afternoon. This finding concurs with research in Athens, which demonstrated the effect of tree canopy coverage in reducing the T_a in streets (Shashua-Bar et al. 2010b). The difference of SVF between locations A and

C is small, indicating that the SVF value for the whole upper half space is inadequate to represent the influence of shading on thermal comfort (Holst and Mayer 2011; Lee et al. 2013).

The summary of visitor personal characteristics shows that four fifths of responders in Kuan Zhai Alley were outland visitors on a transient journey. This aspect influenced their expectations of outdoor thermal environments. The number of responders who felt hot in Kuan Zhai Alley was much higher than that in other studies of hot and humid regions (KöppenVilladiego and Velay-Dabat 2014; Lin 2009), which indicates that people are sensitive to hot conditions in a pedestrian area.

Some features of thermal sensitivity common among people in hot and humid regions were found. The neutral temperature (PET value) in Chengdu during summer (24.4 °C) is close to that of Taiwan (25.6 °C) (Lin 2009). Both are higher than the value in Hungary (16.8 °C) in transient seasons (Kántor et al. 2012a). This confirms that people in hot and humid regions are better adapted to heat load than those in central Europe (Kántor et al. 2012b); so, their tolerance of hot conditions is higher. People in similar meteorological conditions have comparable thermal requirements.

According to the determination coefficients, T_a had the strongest connection with visitors' TSV. This is likely because most of the interviews were conducted in shadow; so, the effects of T_{mrt} and PET, which were significantly influenced by direct solar radiation, were underestimated. The responders' overall thermal comfort level was strongly related to almost every corresponding meteorological parameter, indicating that satisfaction with the outdoor environment is influenced by complex factors. Besides the meteorological parameters measured in the present study, the effects of psychological elements have been demonstrated in other studies (Nikolopoulou and Steemers 2003; Spagnolo and de Dear 2003).

Our study shows that the outdoor thermal environment influences the use of pedestrian areas differently, in terms of total attendance at each area. In Kuan Alley and Zhai Alley, when the values of T_a , T_{mrt} , and PET were higher, fewer people were recorded there. This result agrees well with

Table 4 Acceptability rating for physiological equivalent temperature (PET)

	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot
PET(°C) ^a	18.1–22	22.1–26	26.1–30	30.1–34	34.1–38	38.1–42	>42
Intolerable	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Very uncomfortable	0 %	0 %	0 %	0 %	1 %	2 %	4 %
Uncomfortable	0 %	0 %	0 %	8 %	1 %	6 %	4 %
Slightly uncomfortable	0 %	7 %	13 %	23 %	51 %	34 %	35 %
Comfortable	100 %	93 %	88 %	69 %	46 %	58 %	58 %

^a PET classes for Taiwan (Lin and Matzarakis 2008)

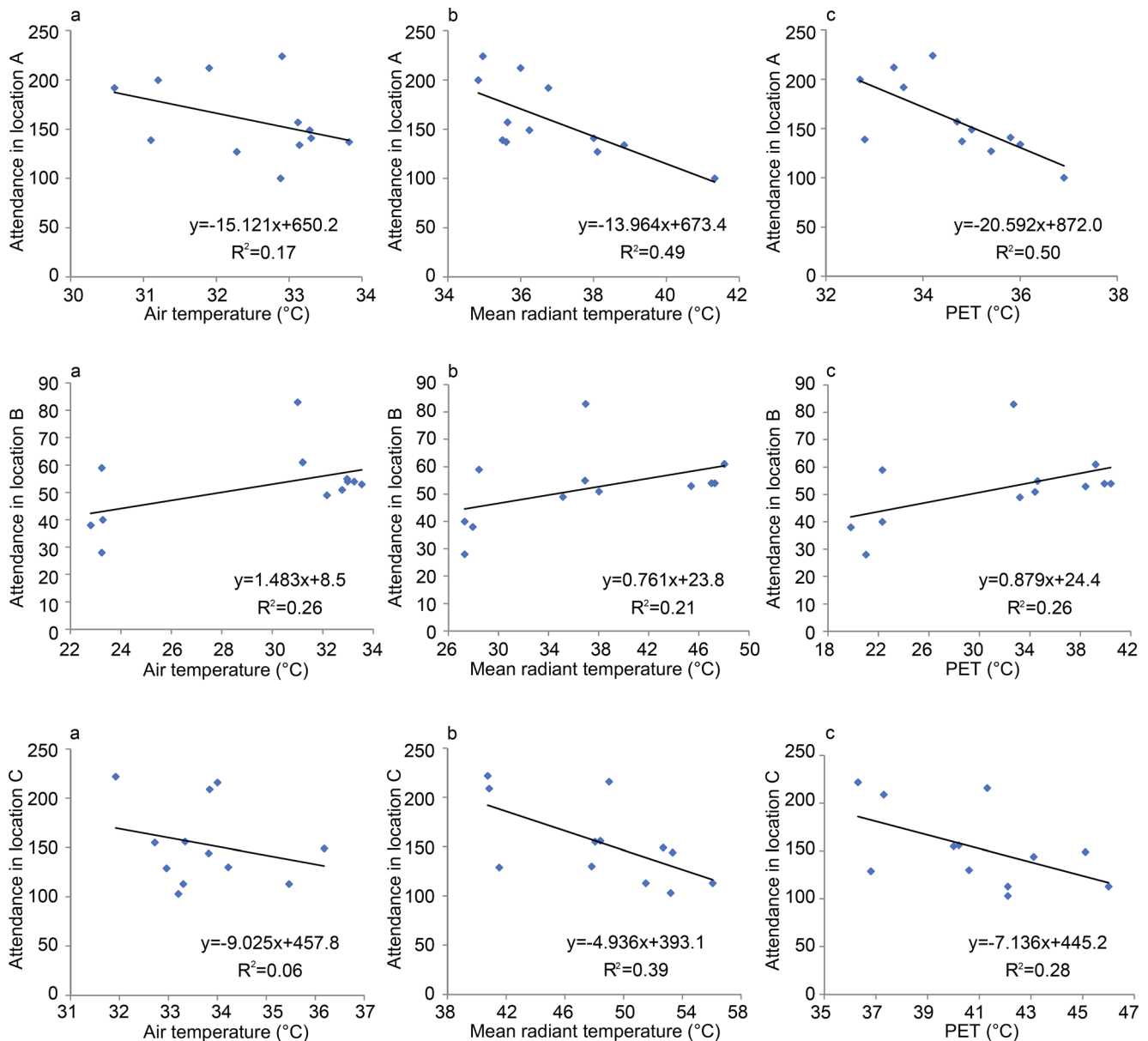


Fig. 6 Number of people in the street in relation to air temperature (a), mean radiant temperature (b), and PET (c) at three locations

findings of previous investigations in Taiwan (Lin 2009), which are indicating negative correlations between thermal conditions (T_a , T_{mrt} , and PET) and the number of people in an outdoor square during the hot season. The situation in south–north alley was opposite: When values of T_a , T_{mrt} , and PET were higher, more people were recorded there. The various functions of places can account for this discrepancy in a small area. Kuan Alley and Zhai Alley have multiple functions such as eating, drinking, resting, and performance areas. Their characteristics are similar to those of a resting place, whereas south–north alley is mostly used as a transit route. These different functions influence the subjective psychological expectation of an outdoor location and lead to varying use of different streets.

Conclusions

This study conducted micrometeorological measurements and questionnaire surveys in a pedestrian precinct in Chengdu, China, and recorded number of people passing through measurement locations. Our purpose was to investigate the relationship between micrometeorological conditions and subjective thermal sensation and its influence on the attendance of pedestrians in hot and humid regions.

Field measurement findings showed that weather and street design account for the diversity of micrometeorological conditions of a street, with longer and greater discomfort in streets with no trees.

The distributions of TSV indicated that visitors are sensitive to hot conditions in pedestrian areas. A neutral temperature similar to Taiwan demonstrates a great tolerance of people in hot and humid regions to hot conditions. Subjective thermal sensation was related more strongly to T_a than other parameters. The overall comfort level was strongly related to all recorded meteorological parameters but with stronger correlations with PET and RH. The correlation coefficients indicated that overall comfort level correlated strongly with perceptions of thermal conditions.

Varying functions of streets generate varying correlations between the outdoor thermal environment and numbers of pedestrians, which reflects the complex use factors of outdoor open spaces. In our study, in alleys with multiple functions that are regarded as recreational areas, fewer people were observed passing through the street when thermal index values were higher. T_{mrt} and PET indicated significant inverse correlations between the thermal environment and the number of people in recreational pedestrian areas in summer.

Complementary studies with longer periods, larger-scale surveys, and during other seasons will be pursued to enhance understanding of interrelationships between the outdoor thermal environment and use of pedestrian streets in hot and humid parts of the world.

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Ethical standards The authors declare that the experiments comply with the current laws of the country in which they were performed.

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