Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia

GHAFFARIANHOSEINI, Amirhosein, BERARDI, Umberto, GHAFFARIANHOSEINI, Ali and AL-OBAIDI, Karam <http://orcid.org/0000-0002-4379-6964>

Analyzing the thermal comfort conditions of outdoor spaces in a university campus in Kuala Lumpur, Malaysia

Amirhosein Ghaffarianhoseini [a,*], Umberto Berardi [b], Ali Ghaffarianhoseini [a], Karam Al-Obaidi [c]

[a] *Department of Built Environment Engineering, School of Engineering, Computer & Mathematical Sciences, Auckland University of Technology, Auckland, New Zealand*

[b] *Faculty of Engineering and Architectural Science, Ryerson University, Toronto, Canada*

[c] *Department of the Natural and Built Environment, Sheffield Hallam University, Sheffield, UK*

Abstract

The rapid urban expansion in East-Asian cities has increased the need for comfortable public spaces. This study presents field measurements and parametric simulations to evaluate the microclimatic characteristics in a university campus in the tropical climate of Kuala Lumpur, Malaysia. The study attempts to identify the thermally uncomfortable areas and their physical and design characteristics while debating on the circumstances of enhancing the outdoor comfort conditions for the campus users. Simulations in Envi-met and IES-VE are used to investigate the current outdoor thermal conditions, using classic thermal metric indices. Findings show high levels of thermal discomfort in most of the studied spaces. As a result, suggestions to improve the design quality of outdoor areas optimizing their thermal comfort conditions are proposed. The study concludes that effective redesign of outdoor spaces in the tropics, through adequate attention to the significant impacts of shading and vegetation, can result in achieving outdoor spaces with high frequency of use and improved comfort level.

Keywords: Outdoor spaces; Outdoor thermal comfort; Urban microclimate; Tropics

1. Introduction

The rapid urban expansion in East-Asian cities in current years has radically expanded the necessity for liveable outdoor environments (Ghaffarianhoseini et al., 2015; Ruiz and Correa, 2015). In particular, in the tropics, due to the abundant solar radiation and the relatively high air temperature and relative humidity levels, long periods of outdoor thermal discomfort are common (Ahmed, 2003; Niu et al., 2015). Considering also the impact of urban heat is- land (UHI) effects in the urban areas, the need for designing outdoor spaces for outdoor comfortable criteria is critical (O'Malley et al., 2015; Wang et al., 2016; Salata et al., 2016; Aflaki et al., 2017; Sharmin et al., 2017).

GRAPHICAL ABSTRACT

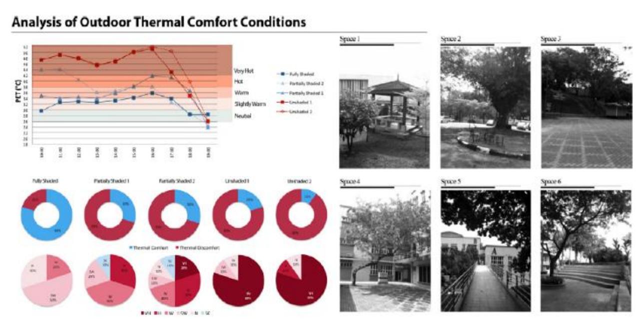

Table 1
Technical details of the field measurement equipment.

Parameters	Accuracy	Range
Solar radiation	±10 W/m^2	0 to 1500 W/m^2
Air temperature	±0.1 °C	−50 to +50°C
Relative humidity	±2%	0 to 100%
Wind speed	±0.05 m/s	0 to 50 m/s
Wind direction	1% of full scale	0–360°

According to recent studies (Sailor, 2014; Aflaki et al., 2017; Lu et al., 2017; Salata et al., 2017; Zhao and Fong, 2017), factors contributing to the UHI phenomenon and outdoor thermal discomfort include vast surface grounds with low albedo and high admittance materials such as concrete and asphalt; minimized green areas and permeable surfaces, which reduce chances of shade and evapotranspiration; highly elevated building blocks and narrow-sized streets/sidewalks that increase the total wind velocity but also trap the heat; and anthropogenic of heat-producing factors such as cars and HVAC systems. To overcome this, the efficient use of shading, greeneries and water bodies has the potential to significantly reduce the radiant air temperature in outdoor urban spaces (Berkovic et al., 2012; Makaremi et al., 2012; Taleghani et al., 2014b; Ghaffarianhoseini et al., 2015; Lobaccaro and Acero, 2015; Berardi, 2016; Fabbri et al., 2017).

The UHI in hot climates has distinctive challenges as a result of its critical impacts on users' health, outdoor thermal discomfort, air quality and building energy consumption (Sailor and Dietsch, 2007; Gartland, 2012; Martins et al., 2016; Santamouris et al., 2017). In this regard, design and development of thermally comfortable urban spaces with large green areas and sufficient shading potentials are common UHI mitigation strategies (Santamouris, 2014; Taleghani et al., 2014; Sailor, 2014).

Understanding the factors that allow a comfortable outdoor space is fundamental for urban designers (Brown et al., 2015; Morckel, 2015; Del Carpio et al., 2016; Chatzidimitriou and Yannas, 2016; Zinzi, 2016; Piselli et al., 2018). Designing climate-responsive urban outdoor spaces can provide thermally comfortable conditions, enhance satisfaction, and improve human health for users (Jamei et al., 2016). Likewise, the efficient use of outdoor spaces helps to decrease the building energy demand too (Niu et al., 2015; Berardi, 2016).

In this study, outdoor thermal comfort conditions have been evaluated using on-site measurements and parametric simulations in Kuala Lumpur, Malaysia. The study aimed to explore the thermal performance characteristics of different outdoor areas, to identify the key influential parameters affecting thermal comfort, and to suggest design guidelines for more thermally comfortable outdoor environment in the tropical climate of Kuala Lumpur.

2. Research method

This study is organized in two phases. Firstly, primary field measurements of outdoor spaces were completed. Since the study focused on both sunny and cloudy sky conditions, the analysis was conducted during May, which has highly variable cloudy sky conditions (Malaysian Meteorological Department, MMD, 2018). Secondly, parametric simulations using ENVI-met and IES were performed to further investigate the thermal interactions among different outdoor settings.

2.1. Field measurements

During the on-site measurements, HOBO U12-006 data logger weather stations were utilized. The calibration process was carried out prior to the initiation of the field study. Field measurements were conducted during the period from May 09th to May 14th. The measurements were taken from 11:00 to 16:00 (logging time: every 10 mins), considered that the highest chances of thermal discomfort in Kuala Lumpur are between 12:00 to 15:00 as found by Makaremi et al. (2012). The measurements followed the ISO 7726 (1998). The measurement height was set to be continuously 1.6 m above the ground for approximately representing the height of a local person in this region. Table 1 reports the accuracy and range of the used sensors.

2.1.1. Regional climate

The city of Kuala Lumpur is located in a tropical region, and it is the most populated city in Malaysia. Kuala Lumpur has a tropical rainforest climate with relatively high air temperature, relative humidity, and solar radiation. With 27 °C as yearly mean air temperature, the monthly mean maximum temperatures vary from 33.5 °C in March/April to 31.9 °C in December. On the other hand, the monthly mean minimum temperatures range from 23.1 °C in January to 24.3 °C in May. The relative humidity generally reaches a maximum above 90%, although its mean is between 70% and 90%. Likewise, with high rates of solar radiation (mean: from 14 to 16 MJ/m^{2}d), the wind velocity is usually insignificant although during the monsoon seasons, it slightly increases (Makaremi et al., 2012; Ghaffarianhoseini et al., 2015). To conclude, commonly high air temperature and relative humidity, intensified solar radiation, and generally overcast sky coverage as well as insignificant wind velocity be- sides heavy rainfalls distinguish the microclimate of this tropical region.

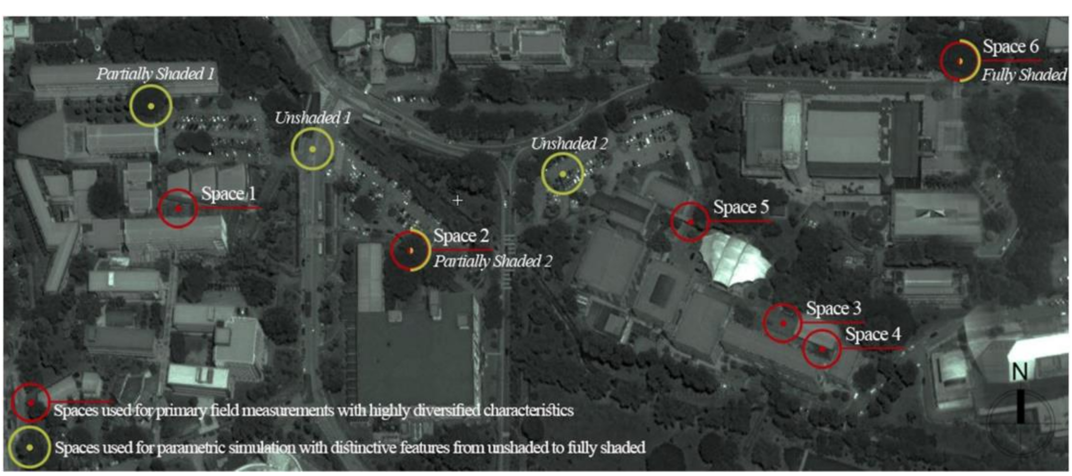

Fig. 1. Study areas in the UM campus in Kuala Lumpur Note: The six spaces highlighted in red were used during the primary field measurement phase to collectively present high levels of thermal discomfort across the UM campus regardless of the day of measurement or spatial characteristics of locations. The five spaces highlighted in yellow are the areas used for analysis of simulations according to their distinctive differences ranging from unshaded to fully shaded. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 2. The selected study areas in the UM campus in Kuala Lumpur.

2.1.2. Characteristics of the study areas

The thermal comfort conditions in the campus of the University of Malaya (UM) were investigated. The campus is located within the urbanized context of Kuala Lumpur. This study primarily focused on six outdoor areas representing diverse design configurations (See Figs. 1 and 2):

- Space 1 is a gazebo fully covered from top and totally open from all four sides. It is fully surrounded by a green area and two two-story and three-story building blocks on opposite sides. The ground surface is paved with concrete and the ceiling is made of timber;
- Space 2 is located at a pedestrian lane beside a parking lot. It is partially covered by a tall tree and is adjacent to a vast open space. The ground surface is made of grey and red colored mosaics, and the surrounded open space is fully paved with asphalt;
- Space 3 is located at a center point of a large open space, far from trees. The ground surface of the area is made of grey and red colored mosaics and there is almost no available shading;
- Space 4 is situated at the corner of two three-story building blocks and is slightly covered by a medium-sized tree. The ground surface is made of grey and red colored mosaics and the area is close to the adjacent building blocks;
- Space 5 is located at a narrow unshaded bridge which is 3 m raised on the ground area. It is slightly covered by trees and is almost open on all sides. The ground surface is made of ceramic;
- Space 6 is located at the front side of the stairs leading to one of the main streets of the campus. It is partially covered by large trees while the ground surface is made of grey and red colored mosaics. The area is slightly blocked by the stairs with a height of 2 m from two sides and is open to the street from the other sides.

Table 2
ENVI-met parameters utilized in the configuration file.

Simulations input parameters		
Location	University of Malaya, Kuala Lumpur	
Simulation day	06-March-2015	
Simulation duration	14 h, from 5:00 to 19:00	
Soil data		
Initial temperature, upper layer (0-20 cm)	[K]	301
Initial temperature, middle layer (20-50 cm)	[K]	299
Initial temperature, deep layer (N50 cm)	[K]	297
Relative humidity, upper layer (0-20 cm)	[%]	88
Relative humidity, middle layer (20-50 cm)	[%]	90
Relative humidity, deep layer (N50 cm)	[%]	93
Building data		
Inside temperature[1]	[K]	294
Heat transmission coefficient of walls	$[W\ m^{-2}\ K^{-1}]$	1.7
Heat transmission coefficient of roofs	$[W\ m^{-2}\ K^{-1}]$	2.2
Albedo walls		0.3
Albedo roofs		0.15
Meteorological data		
Wind speed, 10 m above ground	[m/ s]	1.1
Wind direction (0:N, 90:E, 180:S, 270:W)	[°]	60
Roughness length	[m]	0.1
Initial atmospheric temperature	[K]	301
Relative humidity at 2 m	[%]	75
Cloud cover		0.0
Physiological data		
Walking speed	[m/ s]	0.3
Mechanical factor	[met]	0.0
Heat transfer resistance cloths	[clo]	0.6

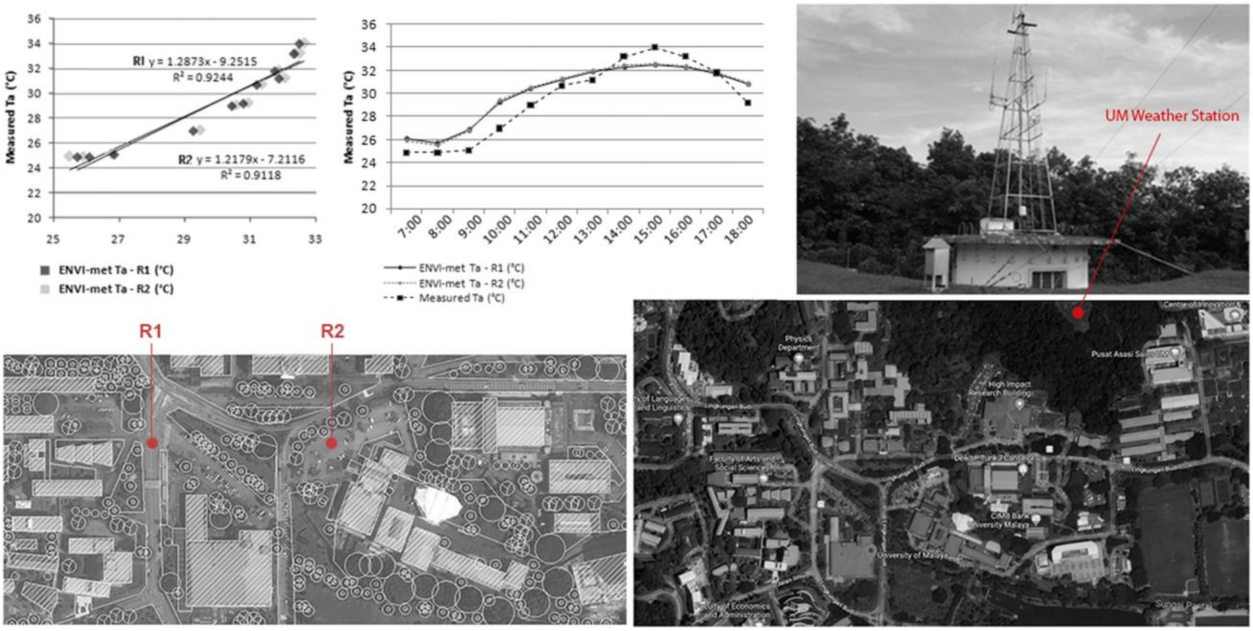

Fig. 3. Comparison of ENVI-met simulation outputs and recorded data of UM weather station.

Given the qualitative spatial characteristics of different locations in the UM campus, the significance of each space should ideally be interrelated with the thermal preferences of campus users: i.e. the type of natural or man-made canopies versus the users' preference for cross ventilation and/or shading; the arrangement of building blocks versus the users' preference for cold breezes, etc.

2.2. Urban microclimate simulation using ENVI-met

After on-site measurements, this study attempted to further explore the thermal comfort conditions of the focused outdoor spaces at UM campus using ENVI-met to calculate the predicted mean vote (PMV), mean radiant temperature (T_{mrt}), and the physiologically equivalent

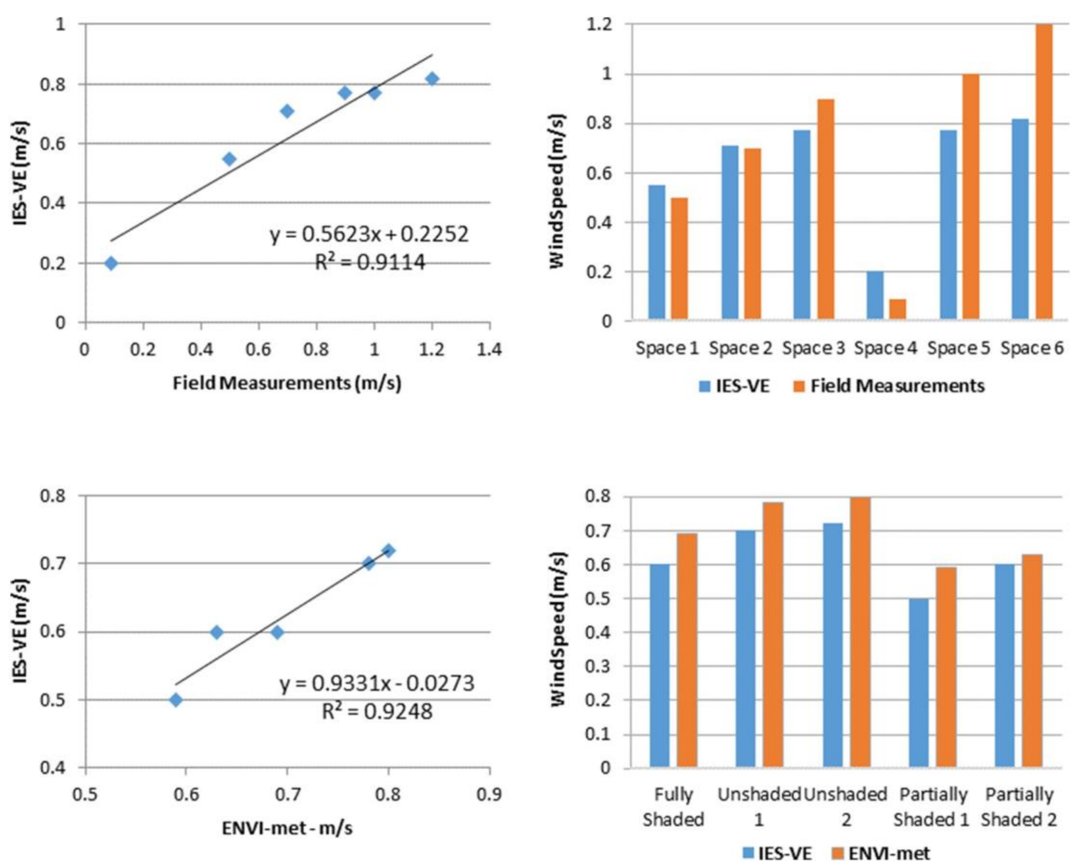

Fig. 4. Comparison of IES-VE, ENVI-met and field measurement results in UM campus.

temperature (PET) values. The main input parameters including the building, soil, and meteorological data considered during the ENVI-met simulations are shown in Table 2.

2.3. Integrated environmental solution: IES-VE

Using IES-VE simulation, the study aims to investigate the impact of solar radiation through SunCast and Apache tools while for wind speed MicroFlo (CFD) was selected for UM campus by simulating micro-scale interactions within urban environments. The study assessed the load of solar radiation based on weather data used in the simulation where the standard simulation weather files of one year for Kuala Lumpur was obtained from Subang International Airport with a distance of 10 km from the UM Campus. The MicroFlo used the External Analysis with several wind directions with a wind velocity of 1.1 m/s. The turbulence model selected for this study was the K-epsilon turbulence model with turbulence viscosity and a grid spacing of 1 m.

2.4. Validation

In the UM campus, a meteorological weather station (WS) continuously recorded hourly data of microclimatic conditions. For the purpose of validating the ENVI-met model, the measured hourly air temperature from this meteorological station was compared with the hourly air temperature derived from ENVI-met simulations. Selected locations (R1 and R2 as shown in Fig. 3) were fully open to the sky and relatively far from any buildings and trees. As shown in Fig. 3, this comparative analysis demonstrates the accuracy of simulation output compared to the weather file derived from UM weather station. However, at certain times (from 9:00 to 11:00), there is an offset of approximately 1 to 2° which is predominantly due to the reason that the UM WS is entirely surrounded by an open space adjacent to large trees which can potentially reduce the air temperature before solar radiation gets its full effect compared to the simulated results. Likewise, the analysis observes a relatively sudden offset of approximately 1 to 2° at 15:00 which is primarily due to the solar radiation change in real scenario for the measured data. This is to note that unlike real scenarios, during the ENVI-met simulation, no unexpected variation of microclimatic parameters (i.e. sudden radiation drop or increase) can happen and this ex- plains the situation in Fig. 3.

The comparison presents an acceptable level of correlation representing the agreement between the predicted values and meteorological data. Referring to the scatter plots, the R^2-values between the simulation and measurement results are 0.92 and 0.91 for receptors 1 and 2 (unshaded 1 and 2), respectively.

For the purpose of validating wind velocity and the accuracy of the IES-VE model used in this research, the readings of wind velocity from field measurements at the UM campus were compared with data from IES-VE simulation at all locations. The comparison was performed on the average of maximum readings obtained from the two investigations: field measurement and simulation. The comparison presents an acceptable level of correlation between the real data and the predicted values. Referring to the scatter plots on Fig. 4, the coefficient of determination value between the simulation and measurement value is 0.91.

Concurrently, the IES-VE model was also validated with ENVI-met simulation outputs. The comparison was conducted based on the selected locations. The comparison used the average of maximum readings derived from both simulations with same wind velocity 1.1 m/s and direction (60°), the coefficient of determination values between the simulation and measurement value is 0.92. These comparisons demonstrate the accuracy of simulation output compared to the field measurements and ENVI-met simulation outputs.

Furthermore, for the purpose of validating solar radiation loads and the accuracy of the IES-VE model used in this research, SunCast tool and Apache in IES were used to investigate the impact of solar radiation on the study area. Taleb (2014) and Saran et al. (2015) validated the Sun Cast in IES-VE in both arid and tropics region specifically on an urban

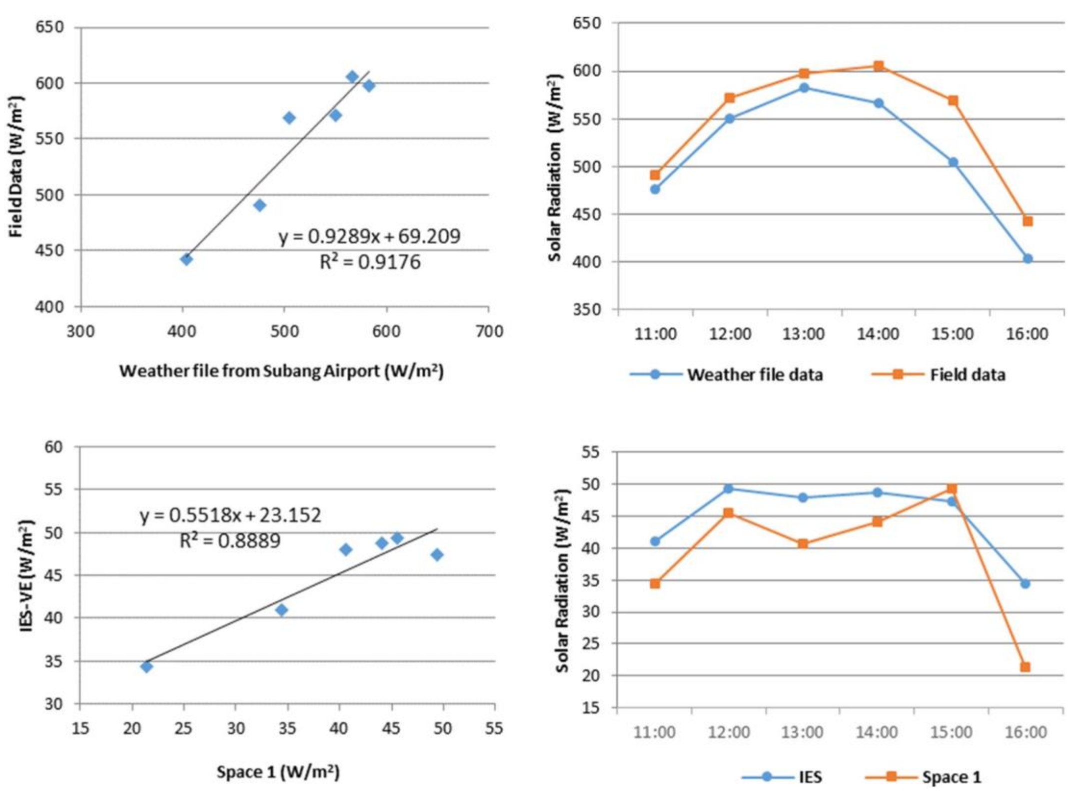

Fig. 5. Comparison of the average of maximum hourly data from UM field measurements and Subang International Airport weather file and comparison of readings of the shaded gazebo (Space 1) in IES and field measurements.

scale. The readings of solar radiation from field measurements at the UM campus were compared with weather file obtained from Subang International Airport station. Due to unsteady sky conditions ranging from fully sunny to partially and mostly cloudy, the comparison was conducted on the average of maximum hourly data from 11 am to 4 pm. Since both locations are fully open to the sky with no obstructions, the comparison presents an acceptable level of correlation representing the agreement between the field data and the predicted values. In addition, the study compared the results obtained from IES-VE with readings of field measurements of the shaded gazebo (Space 1). The comparison was conducted on the average of hourly data from 11 am to 4 pm. The coefficient of determination value between the simulation and measurement value is 0.88. Due to the continuous fluctuations and low values of solar radiations ranging from partly cloudy to cloudy conditions during field data collections, this comparison demonstrates the accuracy of simulation input compared to the field measurements (Fig. 5).

3. Results and analysis

The study examined the values and variations of several microclimatic parameters. Due to the highly variable sky conditions, ranging from sunny to partially and mostly cloudy, the changes of these parameters over the time were noticeable. In all six cases, air temperature continuously increased from 11:00 to 14:00, however, for three of the cases (study areas 2, 3 and 5) air temperature drastically decreased after this period due to cloudy and rainy conditions. Meanwhile, rapid and continuous fluctuations of solar radiation were seen. The study modelled the selected urban site with the UM campus and evaluated the spatial variations of the thermal conditions according to the simulation output. Findings generally show that there are several thermal discomfort zones within the investigated area throughout the daytime despite the existence of various green areas.

3.1. Thermal conditions: measurement of environmental parameters

As shown in Fig. 6 and Table 3, the analysis presents that the recorded air temperature in all six study spaces ranged between 23.5 °C and 37.7 °C although the relative humidity only ranged between 67% and 75%. Looking at more details, the highest levels of relative humidity (75%) and air temperature (37.7 °C) were recorded in study space 4 while the lowest level of relative humidity (67%) belongs to study space 1 and the lowest level of air temperature (23.5 °C) occurred at study space 3. Meanwhile, the extremely low standard deviation values

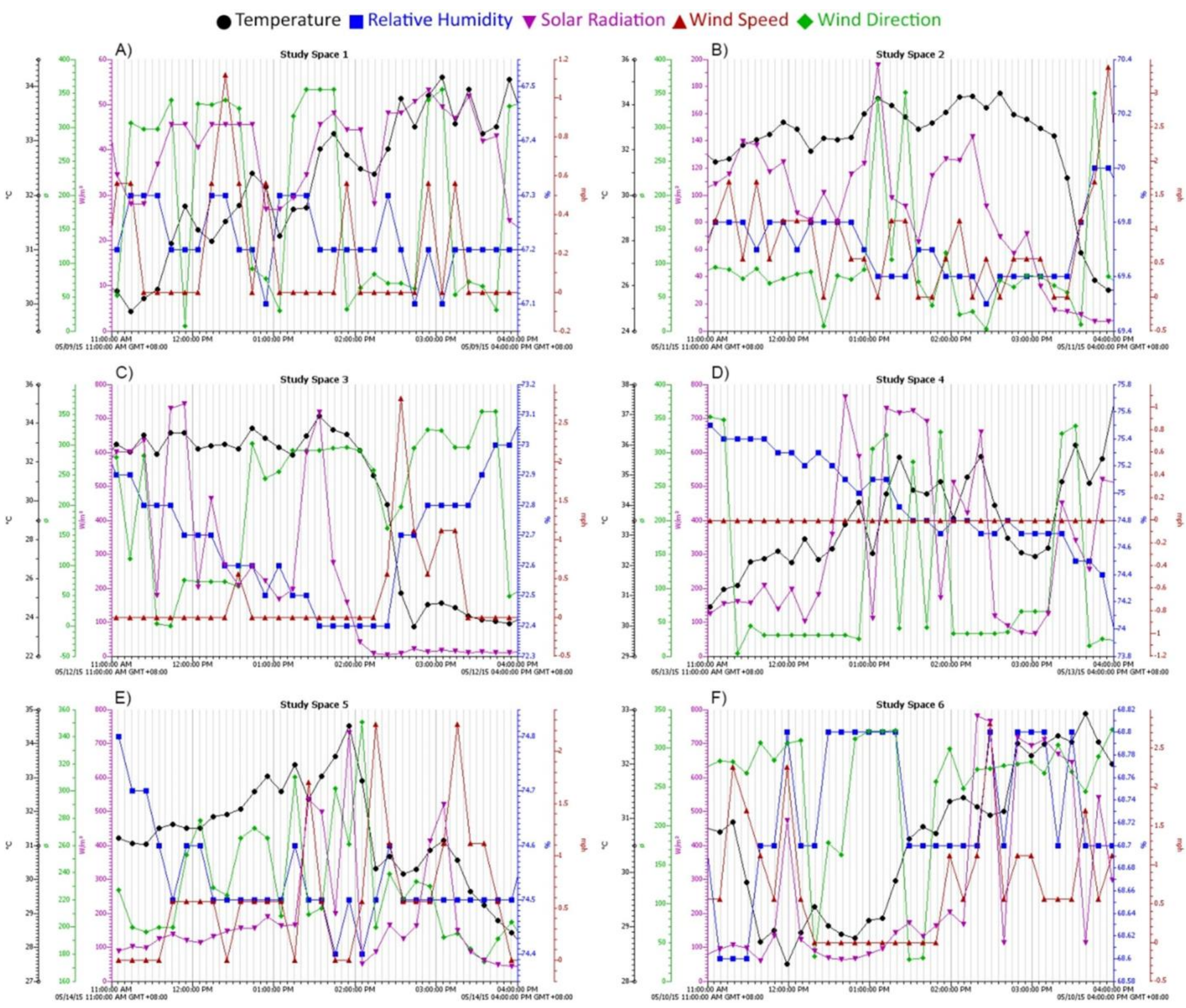

Fig. 6. The measured data for all studied spaces at the UM campus.

Table 3
Descriptive analysis of the measured data for all studied spaces.

	Air temperature	Relative humidity	Solar radiation	Wind speed
Space 1 (The shaded gazebo)	Air temperature constantly increased from 11:00 to 16:00, reaching 34.1 °C at 16:00	Relative humidity was approximately 67% throughout the day	The continuous fluctuations and low values of solar radiations confirm the unsteady sky conditions ranging from partly cloudy to cloudy conditions	Wind speed was constantly very weak, mainly from the Southwest direction
Space 2 (The pedestrian lane)	Air temperature slightly increased from 11:00 to 14:30 with the maximum value of 34.4 °C and then, it started to decrease. From 15:30 to 16:00, when it was raining, the value of air temperature drastically reduced reaching 24.3 °C	Relative humidity was approximately 70% throughout the day	The continuous fluctuations and low values of solar radiations confirm the unsteady sky conditions ranging from partly cloudy to rainy conditions	Wind speed had an average value of 0.33 m/s, mainly from the Southwest direction
Space 3 (The open public space)	Air temperature was constantly high reaching 34.3 °C at 13:30. Due to the rain from 14:30 to 16:00, the temperature started to significantly decrease dropping to 23.5 °C at 14:45	Relative humidity did not significantly vary	The continuous fluctuations and low values of solar radiations illustrate the unsteady sky conditions ranging from partly sunny to rainy conditions	Wind speed had an average value of 0.11 m/s, mainly from the Southwest direction
Space 4 (The corner of two three-story building blocks)	Air temperature mostly increased from 11:00 to 16:00 with a relatively higher maximum value of 37.7 °C due to the sunny sky condition in part of the day	Relative humidity did not significantly changed during the entire period with an average of 75%	Having both extremely high and low values of solar radiation (Max: 763 W/m^2 vs min: 66 W/m^2) besides its continuous fluctuations, it is evident that the sky condition was not steady ranging from sunny to cloudy conditions	Being surrounded by two building blocks from two sides, the wind was constantly blocked
Space 5 (The open bridge)	Air temperature continuously increased from 11:00 to 14:00 reaching 34.5 °C, however, it started to significantly drop from 14:00 onwards reaching 27.9 °C as a result of the rain	Relative humidity did not meaningfully change during the entire period and was constantly around 74% during the entire day	Solar radiation had significant fluctuation ranging from 70 W/m^2 to over 700 W/m^2	Wind speed had the low average value of 0.27 m/s, mainly from Southwest direction
Space 6 (The stairs leading to a street)	Air temperature constantly increased from 11:00 to 16:00 with the maximum value of 32.9 °C	Relative humidity did not significantly change during the entire period and did not exceed 68%	The continuous fluctuations and differences of solar radiations, ranging from 59 to 780 W/m^2, illustrate the unsteady sky conditions indicating cloudy to sunny situations.	wind speed had the average value of 0.32 m/s

for relative humidity (ranging from 0.06 to 0.39) confirm its negligible variation especially in respect to the standard deviation for air temperature (ranging from 1.34 to 4.13) and more importantly the solar radiation (ranging from 11.9 to 260.4).

The study observes that the average values of wind speed for all study areas were low ranging from 0 to 0.33 m/s. In particular, study areas 1 and 4 had the least average wind speed values, mainly due to their surrounding building blocks. In other study areas, the wind speed values were similarly low, but highly variable as for instance, at particular times during the field study, wind speed reached 1.26 m/s (at 14:30 in study space 3), 1.26 m/s (at 14:30 in study space 6) and even 1.51 m/s (at 15:50 in study space 2).

The analysis evidently represents that while study space 3 is fully open to the sky with slight shading possibility, due to the occurrence of heavy rainfall plus having a relatively average wind speed compared to other study areas, its air temperature dropped more significantly. Hence, the primary results show the enormous influence of site and its physical characteristics on microclimatic variations plus the substantial impact of sky conditions (ranging from sunny to rainy conditions). Having the study spaces mainly exposed to the sky and sun radiations excluding the study space 1 covered by a gazebo, the study compares the recorded values of solar radiation and air temperature in all spaces as shown in Fig. 7 to represent their level of agreement.

3.1.1. *Extreme cases – scenario a*

Looking into the samples of extreme cases, referring to the intense decrease of solar radiation in study space 3 from 718 W/m^2 (at 13:30) to 8.1 W/m^2 (at 14:30) within 1 h, the reduction of air temperature from 34.3 to 25.2 °C was observed. Similarly, the decrease of solar radiation in study space 2 from 125.6 W/m^2 (at 14:00) to 11.9 W/m^2 (at 15:30), within 1.5 h, resulted in the reduction of air temperature from 34.3 to 27.4 °C. On the other side, the increase of solar radiation from 80.6 W/m^2 (at 13:00) to 693.1 W/m^2 (at 15:00) within 2 h in study space 6, resulted in 3° of increase in air temperature, with a variation from 29.1 to 32.1 °C.

3.1.2. *Extreme cases – scenario b*

In contrast, looking into the relatively shorter periods of time, the extreme variations of solar radiation were not always in agreement with the changes of air temperature. For instance, in study space 6, the rapid increase of solar radiation from 133.1 (at 11:50) to 473.1 (at 12:00) W/m^2 within a 10-minute period, was concurrent with a minor decrease of air temperature from 28.9 to 28.3 °C. Similarly, in the same study area, the increased solar radiation from 166.9 (at 14:10) to 780.6 (at 14:20) W/m^2 resulted in a slight decrease of temperature value from 31.3 to 31.2 °C. Meanwhile, in study space 4, the rapid and intense increase of solar radiation from 171.9 (at 13:50) to 510.6 (at 14:00) W/m^2 was concurrent with the decreased air temperature from 34.7 to 33.5 °C. On the other side, there are also other cases which are against the aforesaid scenarios: in study space 4, the speedy increase of solar radiation from 124.4 (at 15:10) to 450.6 (at 15:20) W/m^2 was in agreement with 2.2 °C of increase in air temperature. Also, in study space 3, the increased solar radiation from 179.4 (at 11:30) to 729.4 (at 11:40) W/m^2 resulted in 1 °C of increase in air temperature within a 10-minute period. These elaborations evidently stress that the extreme variations of solar radiation within a short period of time might not necessarily be in agreement with the same direction of the alteration of air temperature, in the focused study areas.

The analysis concludes that in general, in all focused study areas, air temperature constantly increased from 11:00 to 16:00 regardless of the existence or unavailability of the heat mitigation strategies, except for specific periods of time in the study areas 2, 3 and 5 when air temperature drastically decreased due to the rain, particularly from 15:00 onwards. To conclude, the study establishes that during the most critical period of the daytime when the chance of thermal discomfort is increased, if the outdoor urban spaces in the campus are not efficiently designed, regardless of their shaded or unshaded conditions and the variation of sky ranging from sunny to partially cloudy, their air temperature might remain high and contribute to thermal discomfort.

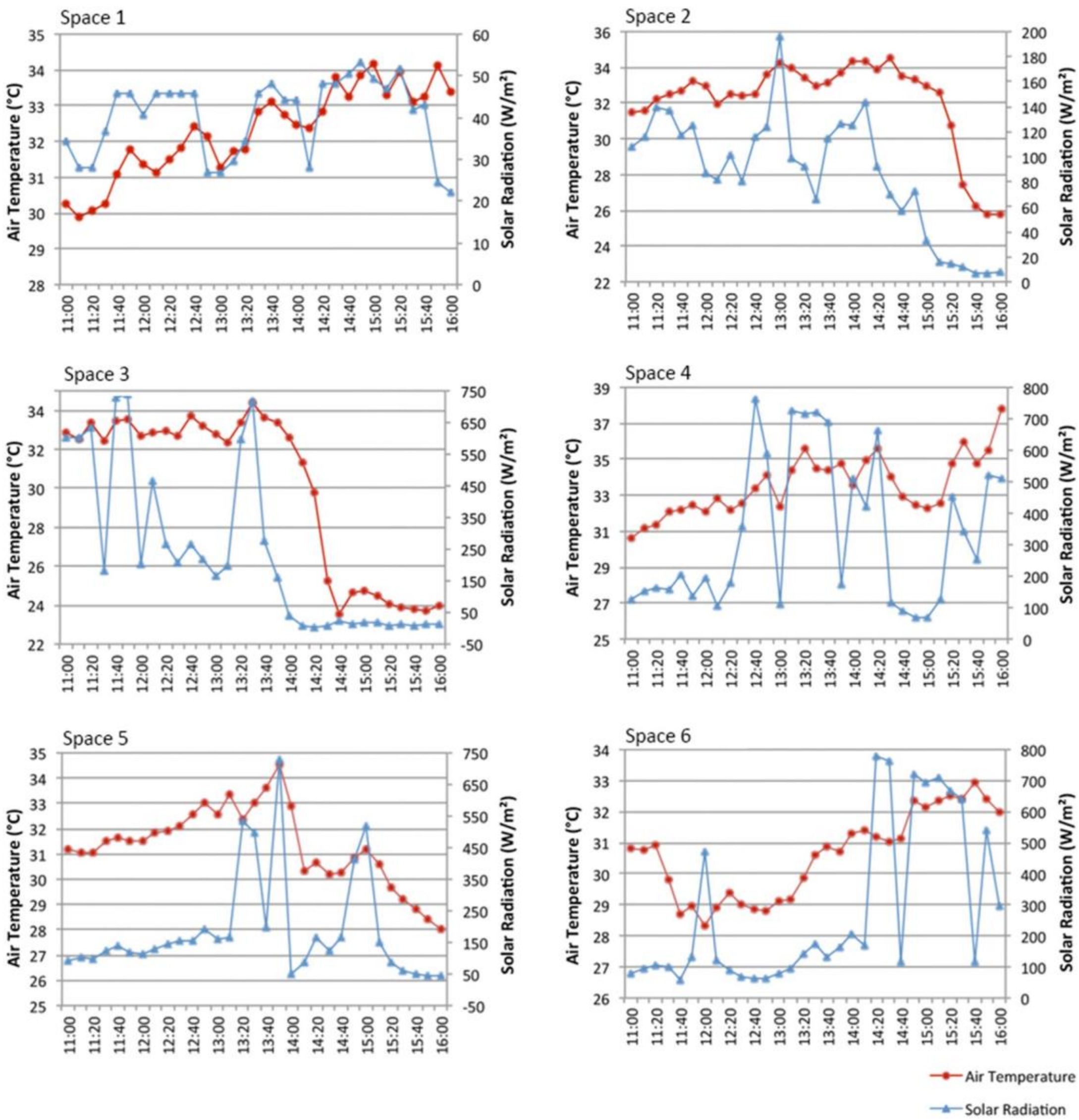

Fig. 7. Air temperature and solar radiation variations in all study spaces from 11:00 to 16:00.

3.2. Results of ENVI-met simulations

Fig. 8 presents the spatial representation of air temperature. It is apparent that the highest level of temperature difference between the existing outdoor spaces, comparing the lightest and darkest colored zones in the figure, is observed at 14:00 and 16:00. On the contrary, less temperature spatial variations can be seen at 10:00 and 18:00 indicating a more homogeneous temperature distribution. The air temperature of the majority of spaces at 10:00 range between 28.85 °C and 29.85 °C while at 16:00, the temperature goes slightly higher than this range. However, the air temperature in a considerably high portion of the study areas ranges between 30.85 °C and 32.85 °C at both 14:00 and 16:00 demonstrating 2–3° of temperature increase. Comparing all spatial distributions at various times of the day, it is inferred that most of the spaces surrounded by building blocks have a relatively lower level of air temperature in comparison to the other spaces. One of the possible reasons for this is better levels of shading achieved as a result of the blockage of sun radiations by the surrounding buildings obstruction.

Looking at the variation of temperature change, it is shown that the air temperature in the entire outdoor spaces located at this site constantly increases from 8:00 to 14:00. This partly explains why the study observes high levels of thermal discomfort during the critical period of noontime. In contrast, from 17:00 onwards (until 19:00 as the stopping point of simulation) temperature continually decreases. More interestingly, at both 15:00 and 16:00, the spatial distribution of temperature change ranges from negative to positive, indicating that while in some areas temperature increases, in other areas temperature drops. Looking at Fig. 9, it is explicitly shown that the highest spatial temperature change occurs at 10:00 as during this time, relatively higher solar radiation is received by the canopy layer and since the temperature is not yet highly increased, a significant impact can be seen. On the other hand, the lowest spatial temperature change occurs at 14:00. This is mainly because the air temperature is already high at 13:00 due to the continuous increase from the morning time. Ultimately, the highest negative temperature change is observed at 18:00. Overall, the study concludes that spatial temperature changes agree with the PMV spatial distributions.

Then, the study looks at the spatial representation of mean radiant temperature in contrast to the intensifications of solar radiation from two crucial times of the day (12:00 and 14:00). As demonstrated in Fig. 10, all areas entirely receive high rate of solar radiation (approximately 800 W/m^2). In fact, this is the key driving force towards poor levels of thermal comfort during the focused time scenarios. On the

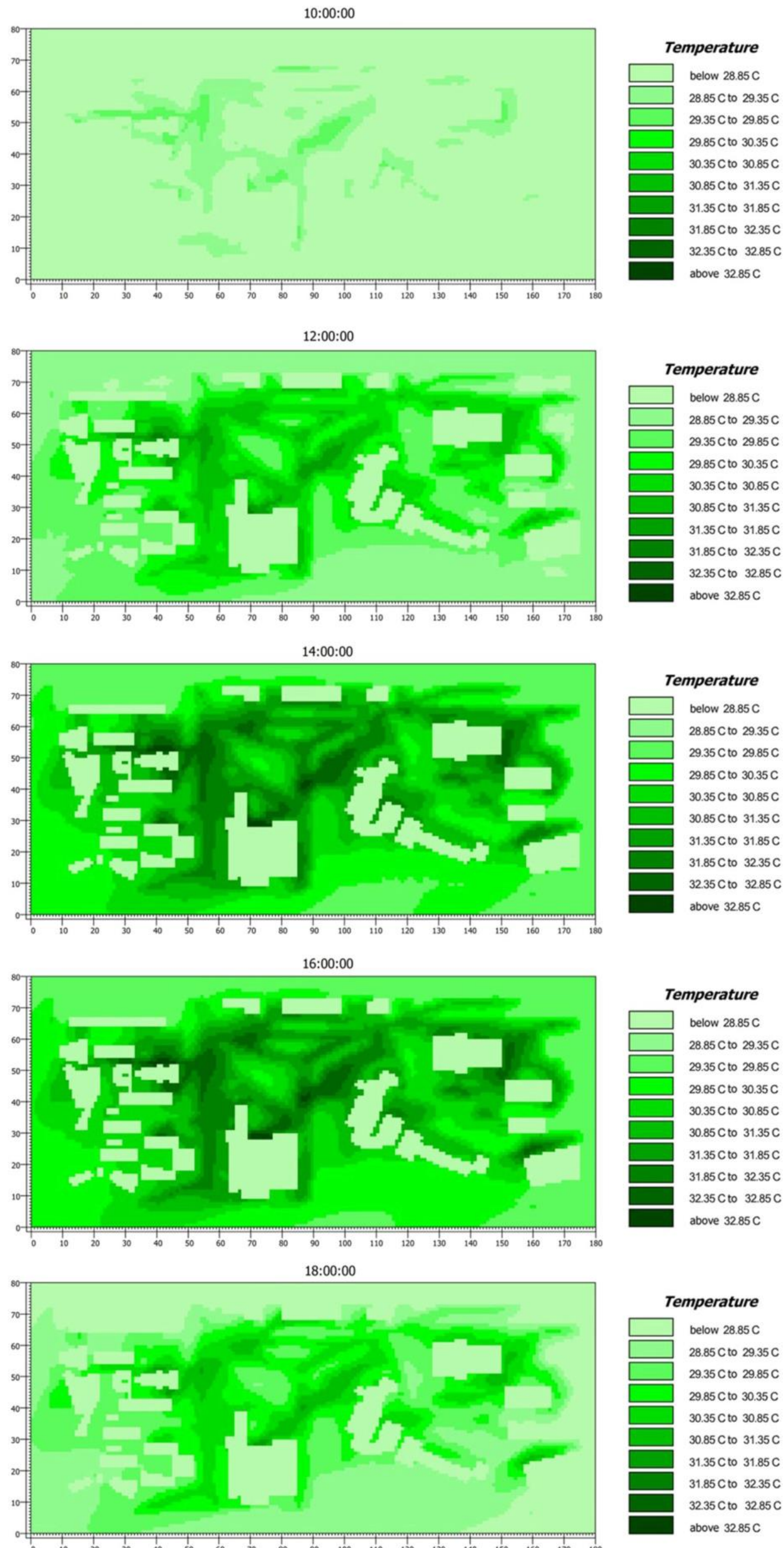

Fig. 8. Spatial representation of air temperature in the UM campus model.

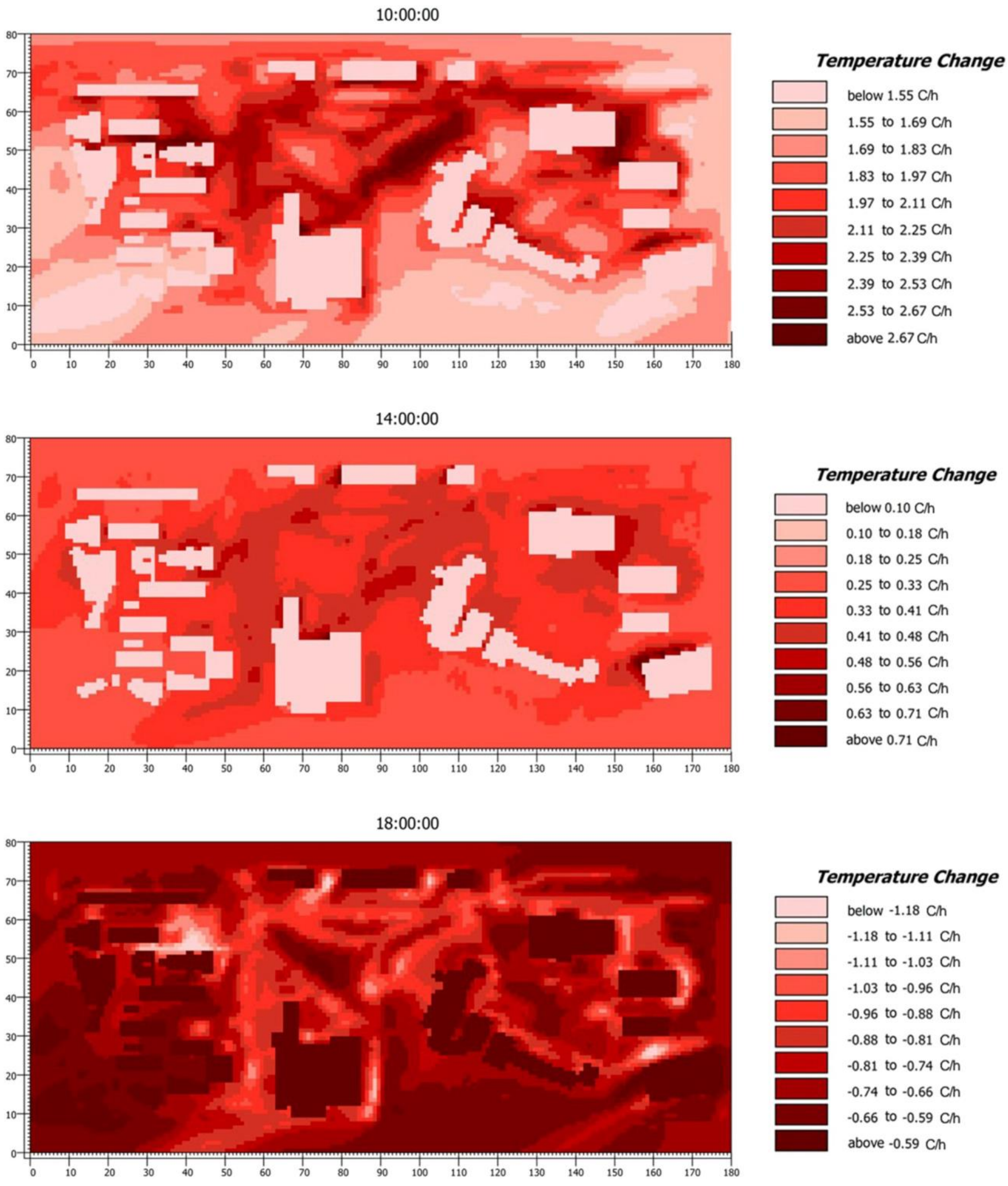

Fig. 9. Comparison of spatial variation of temperature changes within the UM campus model.

contrary, it is worthy to note that besides these areas with high exposure to solar radiation at both times, there are other spatial areas that are less exposed to solar radiations (approximately from 200 to 400 W/m^2). After comparing the different levels of exposure to solar radiation at the site with the aerial map, it can be expressed that these lo- cations, with considerably low levels of solar radiation, are mostly covered by greeneries confirming the strong influence of vegetation. On the other side, with view to mean radiant temperature changes, simulations demonstrate that the highlighted zones showing high PMV values (above 4), similarly have higher mean radiant temperature levels in contrast to their adjacent spaces. Looking at the thermally uncomfortable areas, mean radiant temperature generally falls between 61.8 and 65.8 °C and in some cases, even goes beyond this range. However, in other parts of the site, mean radiant temperature goes down to 33.8 °C and even less. Overall, it is apparent that the spatial distribution of both solar radiation and mean radiant temperature are in general agreement.

Fig. 10 displays the spatial representation of PMV values at various times of the day for a male person walking on the site and in general, clearly indicates that the lowest PMV values across the entire spaces

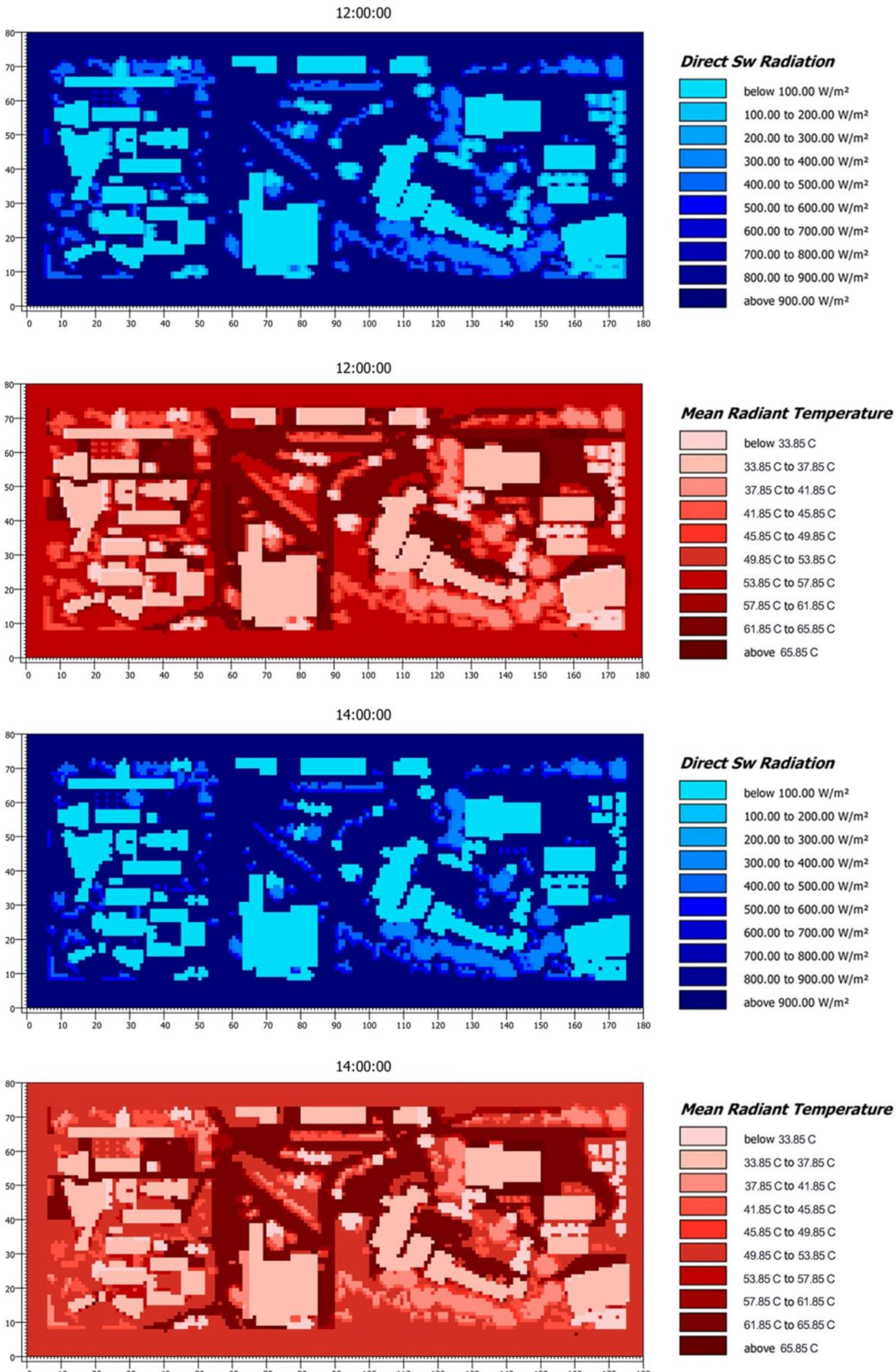

Fig. 10. Comparative illustration of the spatial representation of mean radiant temperature and direct solar radiation in the UM campus model.

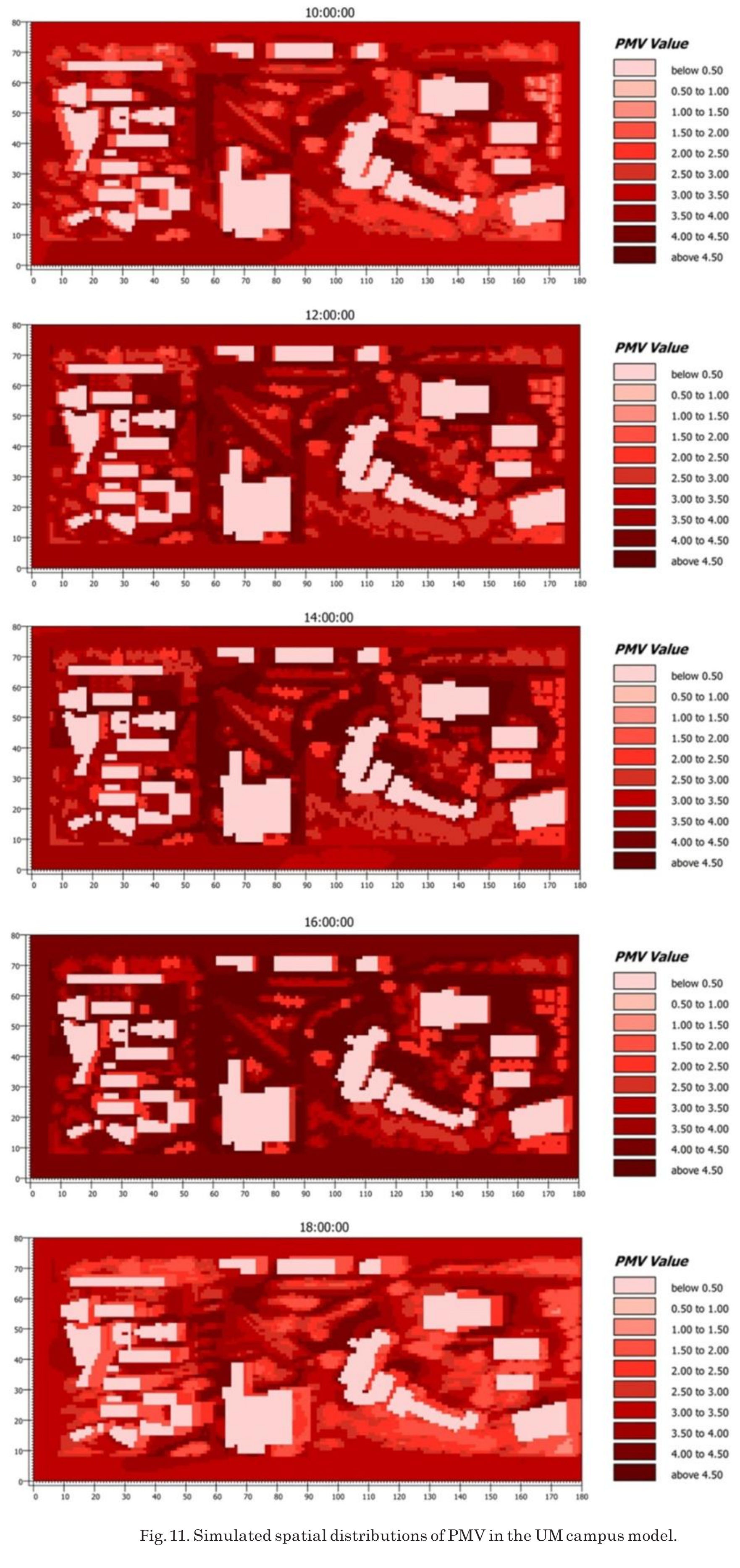

Fig. 11. Simulated spatial distributions of PMV in the UM campus model.

are observed at 16:00 followed by 10:00. However, even during these times, there are various spots with high levels of PMV reaching up to 4 as the evidence of thermal discomfort. On the other hand, the extremely high values of PMV, reaching 4 and beyond indicating very hot conditions, occur at 12:00, 14:00 and 16:00 when the sun is almost above the spaces and results in an excessive level of solar radiation. At these critical times, a huge portion of the campus is thermally uncomfortable for the occupants according to the large coverage of the site of dark color. Nevertheless, interestingly, regardless of the solar radiation intensity, the areas that are fully protected by large trees and are surrounded by green areas (referring to points covered by light color in Fig. 11) generally result in acceptable level of PMV values, ranging between 0.5 and 1.5 as the neutral or slightly hot zone, even during the critical periods of daytime.

It is demonstrated that the majority of buildings provide shading for their west side at 10:00 and in return, they provide shading for their east side at 16:00. Hence, in general, during these periods, one side of the buildings has low PMV values owing to the shading effects and the opposite side has high PMV values, unless additional shading options are utilized such as the use of tall and dense trees. This presents the important role of building masses for blocking the direct solar radiation and providing optimized levels of outdoor thermal comfort.

Lastly, the study further investigates extremely hot spots. As portrayed in Fig. 12, five main zones of thermal discomfort with PMV values of 4 to 4.5 are identified. All of these zones are consistently thermally uncomfortable throughout the daytime. As previously discussed, the analysis of microclimatic spatial variations reveals that in the thermal discomfort zones, mean radiant temperature is similarly high and the high level of direct solar radiations is similarly shown. Looking into details, among these, two zones are open parking lots (A and C), one zone is a main wide street (B), and the other two are vast open spaces adjacent to building blocks (D and E). In all of these hot zones, there is a lack of sufficient trees and vegetation while the existing green areas are relatively far from these spaces. Their surface materials are asphalt for three of the zones (A, B, and C) and dark mosaic covers the surface of the other two zones (D and E). Finally, there is no available shading option for protecting these spaces from the intensified solar radiations. Accordingly, based on these elaborations, technical guidelines, and concluding remarks are proposed for the amelioration of the outdoor thermal comfort conditions in such zones.

3.3. Output of urban canopy model: IES-VE

IES-VE simulations were then used to assess the microclimate conditions and to explore the urban canopy layer (UCL) for validating the results that obtained from field measurements and from the out- puts of ENVI-met simulation to enhance its reliability. Therefore, the IES-VE simulations assessed the urban climatology by investigating wind velocity and solar radiation loads in the focused area of the UM campus based on a developed model from the open street map (OSM). OSM tool imports surrounding buildings, landscaping and roads directly into IES-VE Project. The study developed the imported model and validated its parameters based on site visit and information obtained from the management of UM campus in Table 2. First, using CFD analysis, the study explored the condition of wind speed in the created IES-VE model from various directions. The reason behind evaluating the obtained model from different directions is owing to the highly diverse records of wind directions derived from both on-site measurements and the weather data file of Subang International Airport.

The simulated CFD model applied on the site area was run at the height of 1.5 m from the ground based on Blocken et al. (2016), Han et al. (2014) and Yang and Sekhar (2014). Fig. 13 shows the wind speeds from four directions. The findings showed that there is no constancy with wind movement. The readings from North direction (0°) showed that space 1 ranged between 0.1 and 0.2 m/s, space 2 ranged 0.3 and 0.4 m/s, space 3 varied from 0.7 and 0.8 m/s, space 4 varied from 0.2 and 0.3 m/s, space 5 varied from 0.7 and 0.8 m/s and space 6 varied from 0.8 and 0.9 m/s.

Fig. 14 shows the readings from three different outputs as field measurements, ENVI-met simulation and IES-VE simulation. The outputs from field measurements with ENVI-met and IES-VE show high

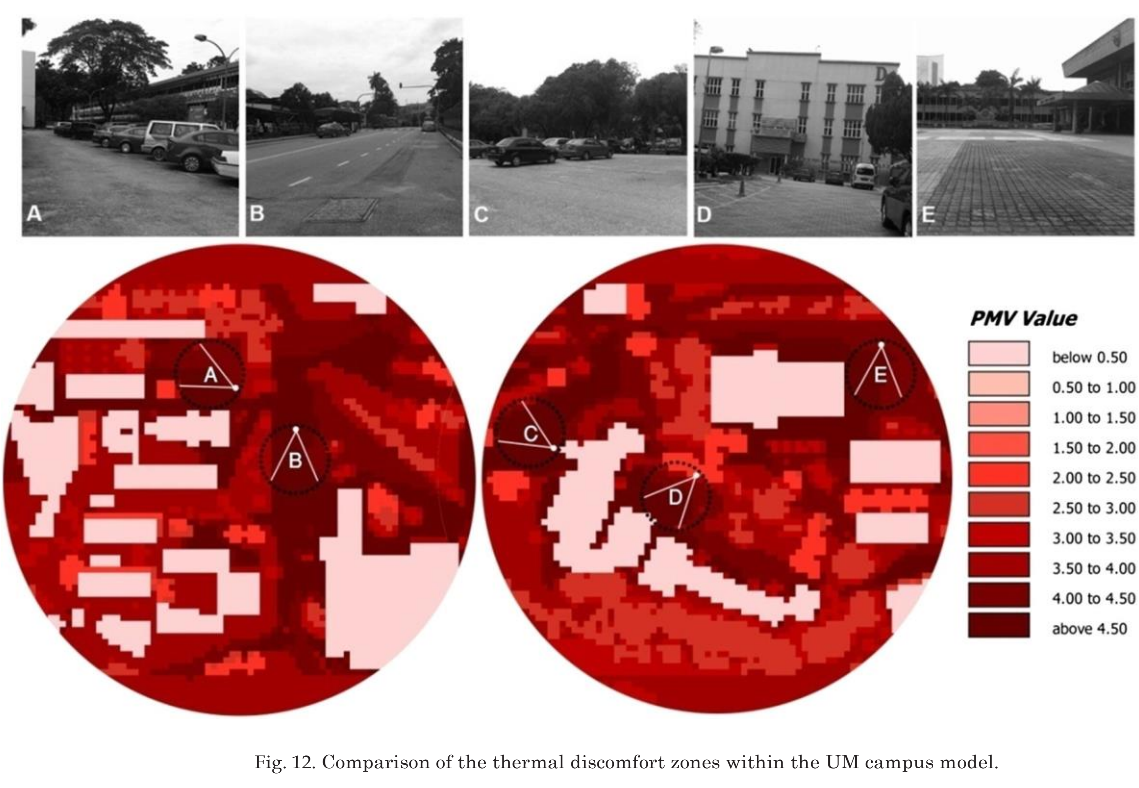

Fig. 12. Comparison of the thermal discomfort zones within the UM campus model.

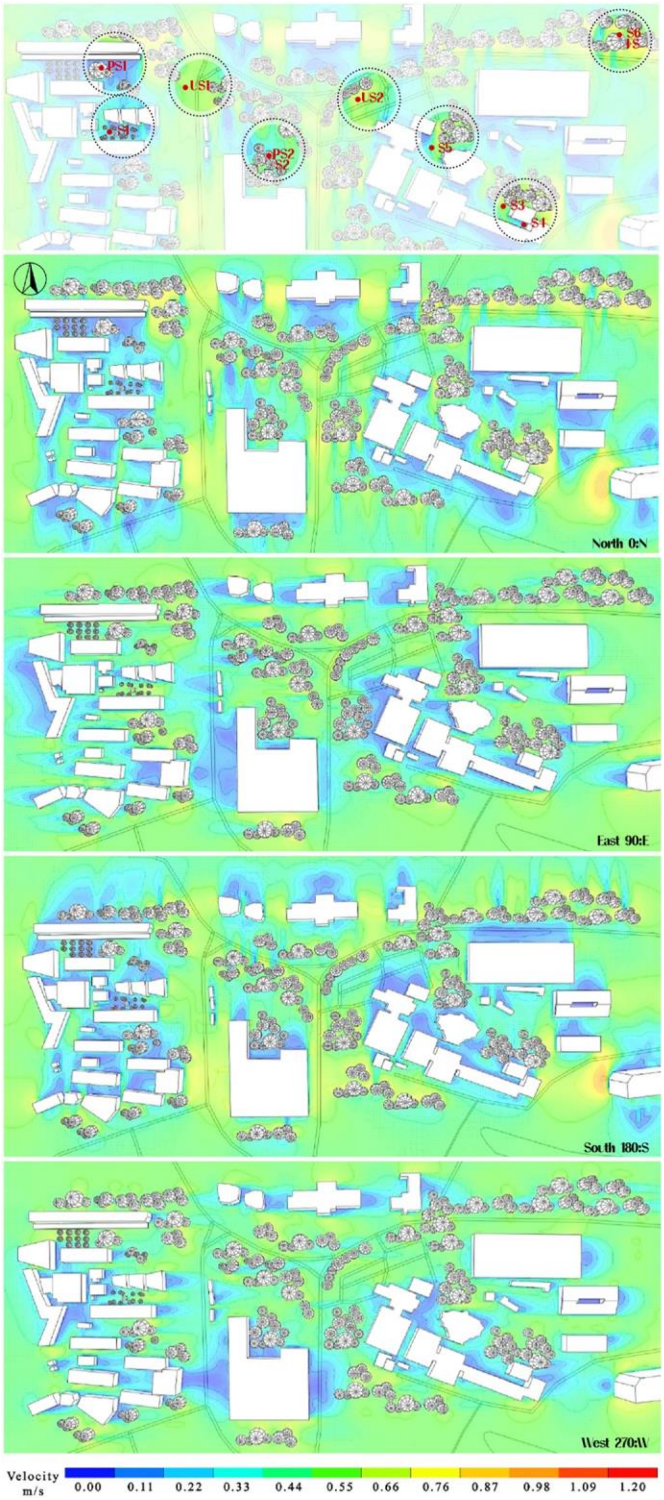

Fig. 13. Results of simulated wind velocity in UM campus from 4 directions (0:North, 90:East, 180:South, 270:West) with speed of 1.1 m/s (PS1-2: partially shaded 1-2, US1-2: unshaded 1-2, FS: fully shaded, S1-6: space 1-6).

similarities. In fact, the readings from field measurements show the actual scenario where wind variations could fall down to 0 m/s or go be- yond 0.8 m/s in the site with different wind directions in short period, but the average readings compared to two simulations gives more reliability as shown in the validation comparison in Fig. 3 due to set a fixed value of wind velocity with 1.1 m/s. Comparing the results in ENVI-met with IES-VE indicates a higher level of compatibility. The comparison between fully shaded in both simulations showed an average result between 0.6 and 0.7 m/s, partially shaded 1 ranged between 0.5 and 0.6 m/s, partially shaded 2 showed an average results between 0.5 and 0.6 m/s, unshaded 1 and unshaded 2 varied from 0.6 and 0.7 m/s. As a result, this comparison demonstrates the similarity of simulation inputs compared to the field measurements.

From another angle, investigating the impact of solar radiation loads on the site was compared with field measurement data for assessing the load of solar exposure during the peak period of the year. The input data for IES-VE was based on a weather file collected from Subang International Airport. The study further its investigations on 6 March on the UM campus and identify the level of solar exposure on several locations as fully shaded, partially shaded and unshaded. Fig. 15 shows the impact of solar loads on the site during 10:00 am, 14:00 pm and 18:00 pm. The readings at 10:00 am show that the maximum irradiation value was 0.34 kWh/m^2 for unshaded, at 14:00 pm the maximum area hit nearly 600 kWh/m^2 where during 18:00 pm the maximum reading was 0.17 kWh/m^2.

In addition, the effects of shadows of buildings are significantly noticeable which provide acceptable shaded areas, however, the urban model still has many large areas fall into unshaded zones that could affect thermal comfort. Fig. 16 demonstrates the comparison of different types of shading condition from 10:00 until 18:00. The IES-VE simulation showed that for a gazebo space (fully shaded), the maximum reading was 50.54 W/m^2, average 41.80 W/m^2 and minimum 24.60 W/m^2. Partially shaded 1, the maximum reading was 429.74 W/m^2, average 303.10 W/m^2 and minimum 147.73 W/m^2. Partially shaded 2, the maximum reading was 325.11 W/m^2, average 236.71 W/m^2 and minimum 115.22 W/m^2. Finally, unshaded, the maximum reading was nearly 600 W/m^2, average 437.43 W/m^2 and minimum 226.36 W/m^2.

3.4. Thermal comfort assessment

Finally, the study compares the thermal performance characteristics of various outdoor spots on the UM campus in order to explore the impacts of shading, provided by the existing trees, on their thermal comfort conditions. Utilizing RayMan model (Matzarakis et al., 2007, 2010) based on the output of Envi-met simulations, the study scrutinizes the obtained T_{mrt} and PET values at fully shaded, partially shaded and unshaded outdoor spots in the campus model.

Looking at the variations of the obtained T_{mrt} values and the significant differences between them at the studied spots shaded or un- shaded as shown in Table 4, it is evident that the fully shaded area has considerably lower T_{mrt} values followed by the partially shaded areas while the two unshaded areas have noticeably higher T_{mrt} ranges reaching 69.85 °C (unshaded 1) and 71.13 °C (unshaded 2). The T_{mrt} difference between the fully shaded and unshaded areas at 10:00, 12:00, 14:00 and 16:00 are approximately 32 °C, 25 °C, 24 °C, and 26 °C respectively.

Looking at the calculated PET values for a person (height: 1.75 m, weight: 75 kg) standing at the above outdoor spots with work metabolism of 80 W (representing light activity), and clo value of 0.6, the study clearly presents the crucial role of shading and its potentials for optimizing the thermal comfort conditions. As illustrated in Fig. 17, both unshaded spots fall under the category of very hot condition representing high level of thermal discomfort. On the other hand, the fully shaded spot constantly falls under slightly warm condition. Like- wise, the partially shaded areas have highly variable comfort conditions ranging from very hot to slightly warm and neutral. This comparison shows that the unshaded outdoor spaces on the campus are not sufficiently comfortable to be used by the staff/students. It also demonstrates that limited use of trees for the purpose of shading (resulting in unshaded and/or partially shaded spaces) has insignificant impact on the improvement of thermal comfort (increased PET for approximately 10 to 15°).

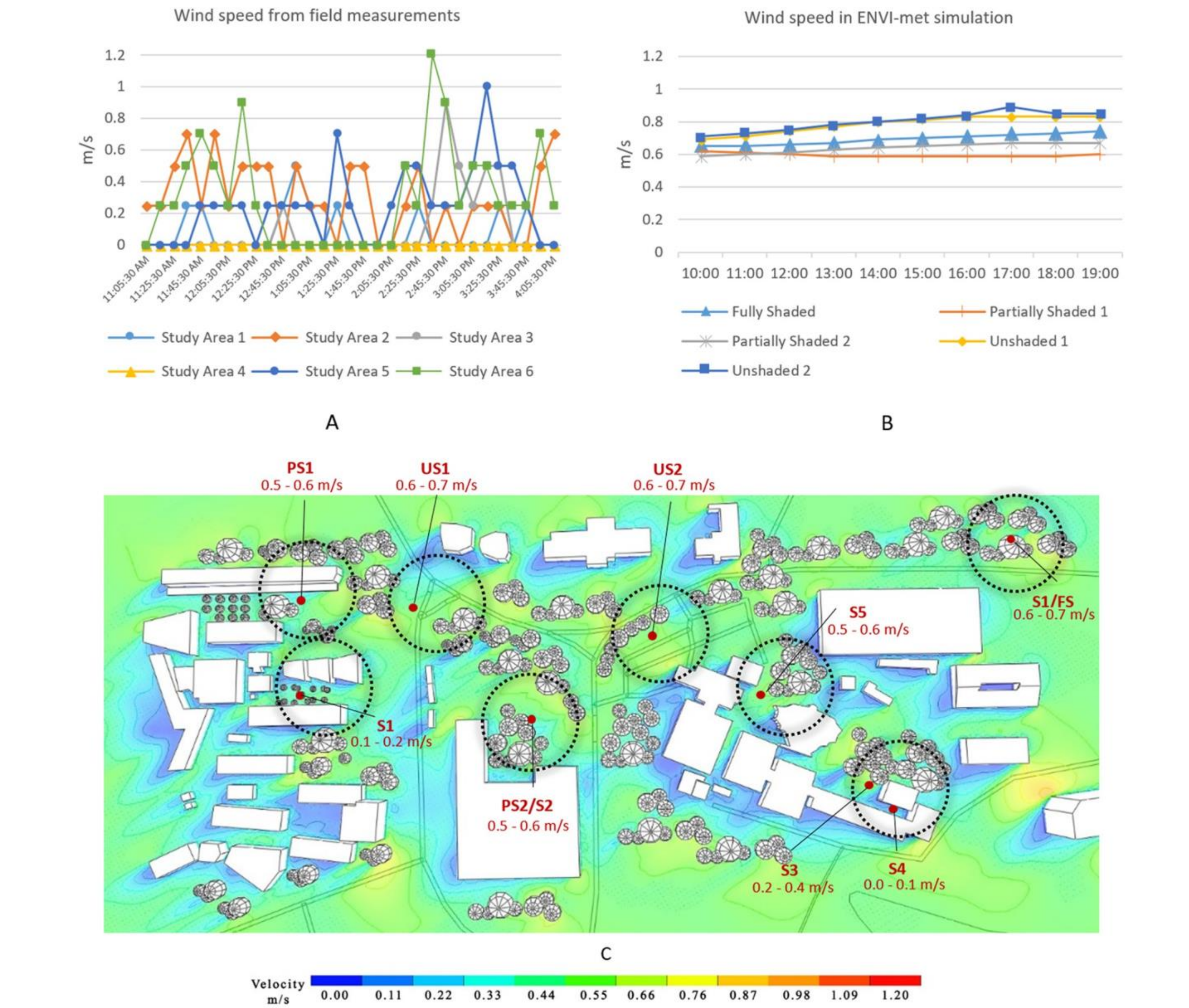

Fig. 14. A: wind velocity from field measurement in the site with different wind directions and wind speeds, B: wind velocity from ENVI-met simulation with one direction (60°) and C: Wind speed in IES-VE with one direction (60°) with a fixed value of wind velocity at 1.1 m/s.

From thermal adaptation and acclimatization viewpoints, as fully discussed and recommended in two relevant previous studies in Malaysia and Taiwan (Makaremi et al., 2012; Lin and Matzarakis, 2008), for the classification of PET values shown in Fig. 17, the study utilizes the thermal perception classification of tropical regions (See Table 5).

Looking at the average PET values for the shaded and unshaded areas, it is similarly found that there is a difference among the thermal comfort values during the day while from 17:00, this difference gradually decreases. It is important to denote that while the average of partially shaded and fully shaded areas results in PET values above the thermally comfort zone range (26-30 °C) and widened thermal comfort range (22-34 °C - considering the adaptation and acclimatization towards PET classification for tropical region), the gap between the two graph lines still attracts the attention towards shadings outdoor spaces in the tropics.

Likewise, the study explores the percentages of the thermal comfort conditions throughout the entire period of simulation in order to further investigate the thermal comfort status of the selected outdoor spots. As shown in Fig. 18, the fully shaded area can be used by the users for 80% of the above period. Nevertheless, the unshaded spots embrace an extremely high level of thermal discomfort for N80% of the time. The partially shaded areas are only slightly better than the unshaded spots in terms of providing comfortable outdoor spaces with 30% of thermal comfort condition.

4. Discussion and conclusions

It has been highlighted that the increased ambient air temperature in urbanized areas, particularly in the tropical climates, can result in enormous negative impacts on the social and environmental dimensions of cities (Aflaki et al., 2017). Nevertheless, there have been very limited studies in tropical contexts focusing on outdoor thermal comfort using heat mitigation strategies. Among these limited studies, the most effective cooling approaches include the utilization of materials with high albedo, trees, and vegetation, as well as shading (Al-Obaidi et al., 2014a, 2014b). The inclusion of greeneries and vegetated spaces is of significant importance and considered highly promising.

In the tropical context of Kuala Lumpur in Malaysia, due to the intensified sun radiation, high level of air temperature and relative humidity

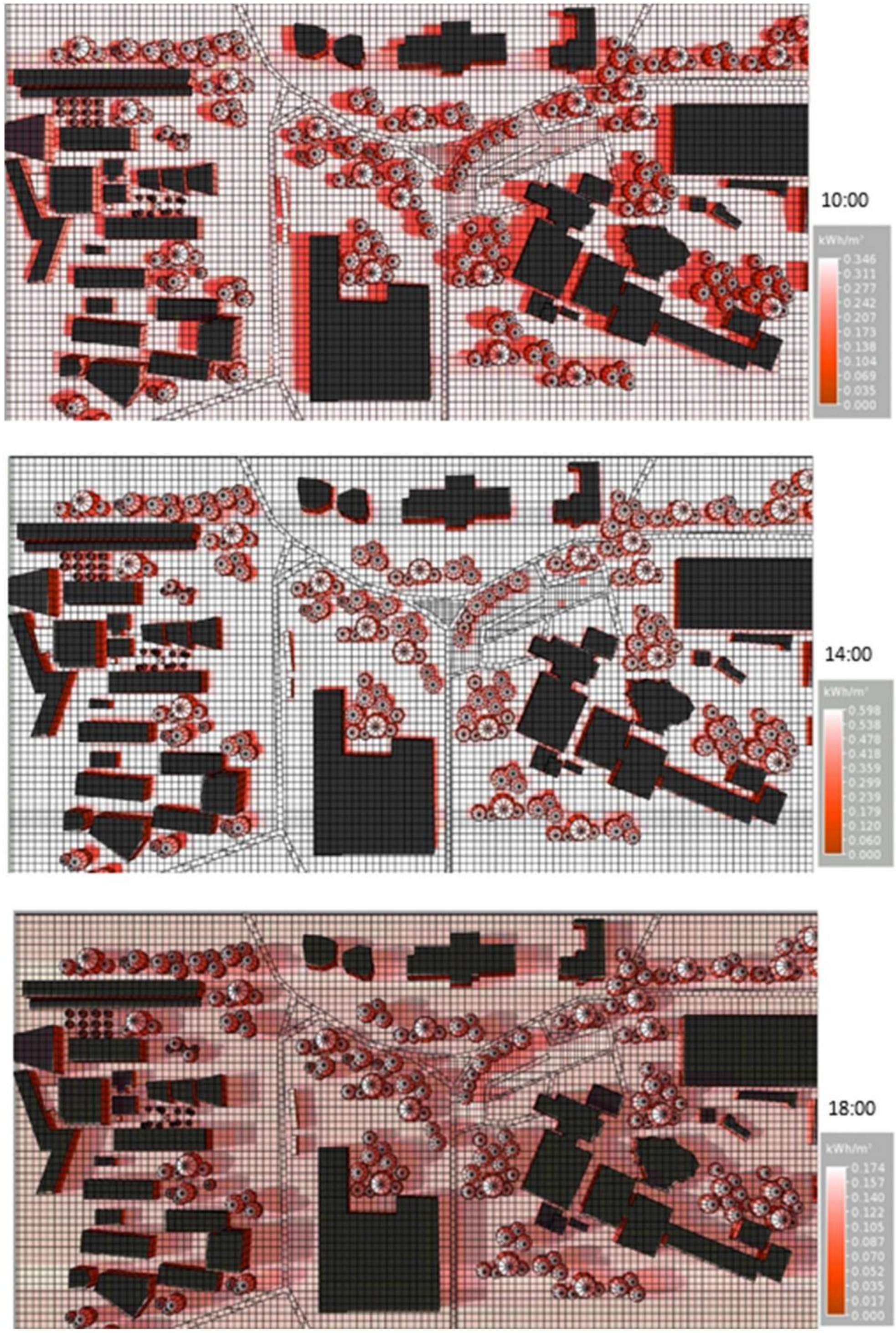

Fig. 15. Irradiation levels in UM campus on 6 March at 10 am, 14 pm and 18 pm.

and weak wind velocity, many of the outdoor environments are not practically usable due to their thermally uncomfortable condition. These aspects affect the expectations of university students and staff to have campuses with thermally comfortable outdoor environments to enjoy walking, cycling, and have outdoor social interaction and other recreational activities.

In this study, outdoor thermal comfort conditions have been evaluated using on-site measurements and parametric simulations in Kuala Lumpur, Malaysia. To further reinforce the existing body of knowledge in thermal comfort studies in Malaysia, this study presented the existing thermal performance characteristics of outdoor spaces with different design configurations and surroundings within a university campus. Findings explicitly proved the need for use of heat mitigation techniques towards cooling down the spaces for more usability. The overall finding suggests that within this tropical condition, the outdoor spaces that are not efficiently designed in accordance with heat mitigation strategies and for providing shading derived from vegetation and surrounded buildings will have limited potentials for attracting users even during partially cloudy sky conditions.

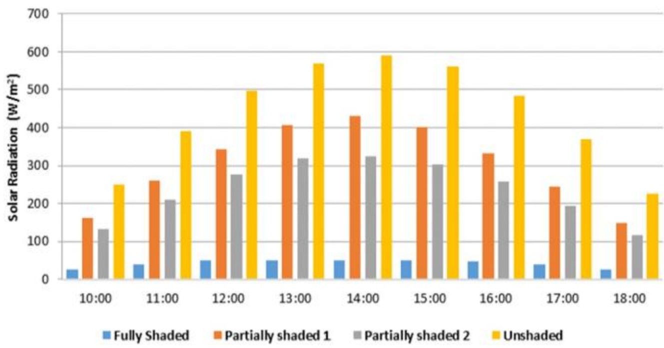

Fig. 16. Irradiance levels of four different types of shading areas in the UM campus in Kuala Lumpur.

Table 4
The obtained T_{mrt} values for the fully shaded, partially shaded and unshaded areas on the UM campus.

Time	T_{mrt} values (°C) obtained for the studied outdoor spots				
	Fully shaded	Partially shaded 1	Partially shaded 2	Unshaded 1	Unshaded 2
10:00	34.2	43.2	59.4	66.1	66.1
11:00	38.8	40.3	58.5	67.7	67.8
12:00	39.4	40.6	51.0	65.0	65.1
13:00	37.8	39.0	41.2	60.5	59.6
14:00	38.6	42.4	41.9	62.0	62.1
15:00	40.6	46.7	45.0	67.8	67.9
16:00	44.4	54.1	45.3	69.8	71.1
17:00	40.3	53.4	34.4	55.6	69.7
18:00	29.6	45.3	27.1	40.5	51.0
19:00	19.7	19.4	19.7	23.7	24.1

Table 5
Thermal perception classification for tropical regions.

Thermal perception	TPC for (sub)tropical region[a] (°C PET)	TPC for temperate region[b] (°C PET)
Very cold	b14	b4
Cold	14–18	4–8
Cool	18–22	8–13
Slightly cool	22–26	13–18
Neutral	26–30	18–23
Slightly warm	30–34	23–29
Warm	34–38	29–35
Hot	38–42	35–41
Very hot	b42	b41

[a] Lin and Matzarakis, 2008.
[b] Matzarakis and Mayer, 1996.

For further enhancement of the thermal comfort condition of outdoor spaces in the tropical climate of Kuala Lumpur, the study draws attention to the following concluding remarks:

- In the tropics, sky conditions radically affect the thermal characteristics of outdoor spaces: i.e. field studies showed that while air temperature reached 34 °C and above during noon time, it can significantly drop to 24 °C or lower as a result of cloudy and rainy conditions. Likewise, findings showed that the impact of solar loads on the site from 10:00 am to 16:00 pm is soaring and air temperature constantly increased from 11:00 to 16:00 regardless of the existence or unavailability of the heat mitigation strategies;
- In the tropical contexts, lack of outdoor thermal comfort significantly affects the level of social interaction in outdoor settings as a result of extremely low intensity of spatial use. However, many outdoor and semi-outdoor spaces in the university campus are not carefully designed in order to respond to the microclimatic characteristics, and they fail to provide highly comfortable outdoor environments even under partly cloudy sky conditions: looking at the period of 10:00 to 19:00, poorly designed outdoor spaces on the UM campus are thermally comfortable for 10% to 30% of the time;
- The findings indicated that approximately 30–40% of the study areas were shaded during low sun altitude especially morning and evening, however, during midday most of the site was not well shaded where buildings and trees did not provide enough shades to shade the surroundings. During this period, the solar impact could exceed 500 W/m² from 12:00 pm until 16:00. Therefore, redesigning urban blocks and providing shaded walkways are more important than relying on scattered trees and scattered buildings;
- Greeneries such as trees do not guarantee a sufficient effect on the outdoor thermal performance characteristics, unless their number, type, size, and location are efficiently designed to provide sufficient shading;
- It is evident that the fully shaded area has considerably lower Tmrt values followed by the partially shaded areas while unshaded areas have noticeably higher Tmrt ranges reaching 69.85 °C (unshaded 1) and 71.13 °C (unshaded 2). The Tmrt difference between the fully shaded and unshaded areas at 10:00, 12:00, 14:00 and 16:00 are approximately 32 °C, 25 °C, 24 °C, and 26 °C respectively;
- Simulations present that the outdoor spaces that encompass shading potentials due to the existence of trees and adjacent building blocks provide more acceptable thermal comfort conditions during the critical period of day: fully shaded outdoor spaces of the UM campus can provide thermally comfortable environments for over 90% of the period from 10:00 to 19:00;
- The majority of outdoor spaces with the highest temperatures and PMV/PET values embrace very similar characteristics, i.e. openness to the sky with no possibility of shading, relatively far from the surrounded trees and considerably less vegetated, and covered by low albedo surface materials such as asphalt;
- Due to the extremely low and negligible values of wind speed, it is essential to propose new design strategies for accelerating wind

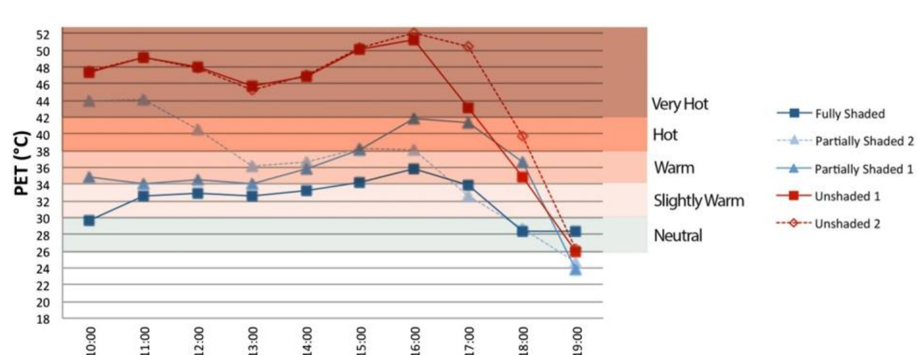

Fig. 17. Comparison of the PET values of the fully shaded, partially shaded and unshaded areas on the UM campus based on thermal perception classification for tropical regions as shown in Table 5.

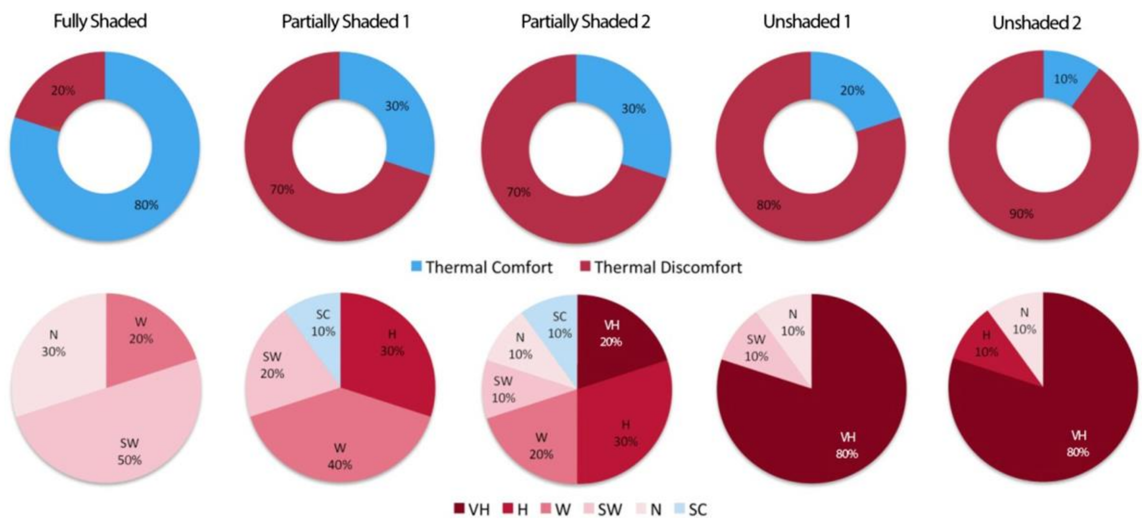

Fig. 18. Comparison of the percentages of thermal comfort conditions at the fully shaded, partially shaded and unshaded areas in the UM campus (VH: very hot, H: hot, W: warm, SW: slightly warm, N: neutral, SC: slightly cool).

velocity: the majority of recent studies in tropical regions predominantly concentrate on the impact of shading and greeneries, thus, the potential benefits of wind is commonly neglected;

- Unpredictable wind direction and weak wind velocity showed that different spaces in the urban model have unsteady wind velocity levels. The study identified the need for use of heat mitigation techniques based on accelerating wind velocity to cool down the spaces for more usability. It is realized that considering various attributes such as soft/hard landscape, trees type/location and height, forms of trees canopy, buildings forms and height, albedo of façades and roofs as well as the shapes and the arrangements of urban pockets are important to maintain an acceptable wind velocity;
- The investigation showed that the effect of buildings and trees in urban canopy model is significantly noticeable to provide well-shaded areas, however, the urban model still has many large areas falling into unshaded zones that affect thermal comfort and increase the level of mean radiant temperature;
- Likewise, in future re-design of outdoor settings in hot and humid climates, it is important to draw adequate attention to the changing behaviour and preferences of campus users, with regards to the spatial characteristics of locations, based on variable sky conditions and the changing level of exposure to direct sun or shade: i.e. the preference for more shading during direct exposure to sunlight under clear sky condition and the desire for a cold breeze under overcast sky condition with high level of relative humidity.

Finally, future possible studies could be expanded to cover the circumstances of optimizing the thermal performance of these outdoor spaces using versatile heat mitigation strategies by connecting physically and socially the people with buildings and outdoor spaces in the campus. The improved design should understand the integration of three levels which are semi-open spaces (within buildings) + semi- outdoor spaces (between buildings) with outdoor spaces. This connection would help to minimise the current separation that exists due to bitumen surfaces in main roads and car parking areas which considerably affect the outdoor thermal comfort conditions.

This study stresses that the increased urban air temperature and its intensifying negative impacts are severe public health concerns. Likewise, the liveability and successfulness of urban outdoor environments including the university campuses, particularly in the tropics, largely depend on their frequency of use, which can be highly altered by the level of outdoor thermal comfort. Hence, future studies are recommended to look into the circumstances of optimizing the thermal performance of these outdoor spaces using versatile heat mitigation strategies.

References

Aflaki, A., Mirnezhad, M., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Omrany, H., Wang, Z.H., Akbari, H., 2017. Urban heat island mitigation strategies: a state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong. Cities 62, 131-145.

Ahmed, K.S., 2003. Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. Energy Build. 35 (1), 103-110.

Al-Obaidi, K.M., Ismail, M., Rahman, A.M.A., 2014a. Passive cooling techniques through reflective and radiative roofs in tropical houses in Southeast Asia: a literature review. Front. Archit. Res. 3 (3), 283-297.

Al-Obaidi, K.M., Ismail, M., Rahman, A.M.A., 2014b. Design and performance of a novel innovative roofing system for tropical landed houses. Energy Convers. Manag. 85, 488-504.

Berardi, U., 2016. The outdoor microclimate benefits and energy saving resulting from green roofs retrofits. Energy Build. 121, 217-229.

Berkovic, S., Yezioro, A., Bitan, A., 2012. Study of thermal comfort in courtyards in a hot arid climate. Sol. Energy 86 (5), 1173-1186.

Blocken, B., Stathopoulos, T., Van Beeck, J.P.A.J., 2016. Pedestrian-level wind conditions around buildings: review of wind-tunnel and CFD techniques and their accuracy for wind comfort assessment. Build. Environ. 100, 50-81.

Brown, R.D., Vanos, J., Kenny, N., Lenzholzer, S., 2015. Designing urban parks that ameliorate the effects of climate change. Landsc. Urban Plan. 138, 118-131.

Chatzidimitriou, A., Yannas, S., 2016. Microclimate design for open spaces: ranking urban design effects on pedestrian thermal comfort in summer. Sustain. Cities Soc. 26, 27-47.

Del Carpio, J.A.V., Marinoski, D.L., Trichês, G., Lamberts, R., de Melo, J.V.S., 2016. Urban pavements used in Brazil: characterization of solar reflectance and temperature verification in the field. Sol. Energy 134, 72-81.

Fabbri, K., Canuti, G., Ugolini, A., 2017. A methodology to evaluate outdoor microclimate of the archaeological site and vegetation role: a case study of the Roman Villa in Russi (Italy). Sustain. Cities Soc. 35, 107-133.

Gartland, L.M., 2012. Heat Islands: Understanding and Mitigating Heat in Urban Areas. Routledge.

Ghaffarianhoseini, A., Berardi, U., Ghaffarianhoseini, A., 2015. Thermal performance characteristics of unshaded courtyards in hot and humid climates. Build. Environ. 87, 154-168.

Han, Z., Weng, W., Huang, Q., 2014. Numerical and experimental investigation on the dynamic airflow of human movement in a full-scale cabin. HVAC&R Res. 20 (4), 444-457.

Jamei, E., Rajagopalan, P., Seyedmahmoudian, M., Jamei, Y., 2016. Review on the impact of urban geometry and pedestrian level greening on outdoor thermal comfort. Renew. Sust. Energ. Rev. 54, 1002-1017.

Lin, T.P., Matzarakis, A., 2008. Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. Int. J. Biometeorol. 52, 281-290.

Lobaccaro, G., Acero, J.A., 2015. Comparative analysis of green actions to improve outdoor thermal comfort inside typical urban street canyons. Urban Clim. 14, 251-267.

Lu, J., Li, Q., Zeng, L., Chen, J., Liu, G., Li, Y., ... Huang, K., 2017. A micro-climatic study on cooling effect of an urban park in a hot and humid climate. Sustain. Cities Soc. 32, 513-522.

Makaremi, N., Salleh, E., Jaafar, M.Z., GhaffarianHoseini, A., 2012. Thermal comfort conditions of shaded outdoor spaces in hot and humid climate of Malaysia. Build. Environ. 48, 7-14.

Martins, T.A., Adolphe, L., Bonhomme, M., Bonneaud, F., Faraut, S., Ginestet, S., ... Guyard, W., 2016. Impact of Urban Cool Island measures on outdoor climate and pedestrian comfort: simulations for a new district of Toulouse, France. Sustain. Cities Soc. 26, 9-26.

Matzarakis, A., Mayer, H., 1996. Another kind of environmental stress: thermal stress. WHO collaborating centre for air quality management and air pollution control. Newsletter 18, 7-10.

Matzarakis, A., Rutz, F., Mayer, H., 2007. Modelling radiation fluxes in simple and complex environments - application of the RayMan model. Int. J. Biometeorol. 51 (4), 323-334.

Matzarakis, A., Rutz, F., Mayer, H., 2010. Modelling radiation fluxes in simple and complex environments - basics of the RayMan model. Int. J. Biometeorol. 54, 131-139.

MMD, 2018. Malaysian Meteorological Department. Retrieved at www.met.gov.my.

Morckel, V., 2015. Community gardens or vacant lots?: rethinking the attractiveness and seasonality of green land uses in distressed neighborhoods. Urban For. Urban Green. 14 (3), 714-721.

Niu, J., Liu, J., Lee, T.C., Lin, Z.J., Mak, C., Tse, K.T., Kwok, K.C., 2015. A new method to assess spatial variations of outdoor thermal comfort: onsite monitoring results and implications for precinct planning. Build. Environ. 91, 263-270.

O'Malley, C., Piroozfar, P., Farr, E.R., Pomponi, F., 2015. Urban Heat Island (UHI) mitigating strategies: a case-based comparative analysis. Sustain. Cities Soc. 19, 222-235.

Piselli, C., Castaldo, V.L., Pigliautile, I., Pisello, A.L., Cotana, F., 2018. Outdoor comfort conditions in urban areas: on citizens' perspective about microclimate mitigation of urban transit areas. Sustain. Cities Soc. 39, 16-36.

Ruiz, M.A., Correa, E.N., 2015. Adaptive model for outdoor thermal comfort assessment in an Oasis city of arid climate. Build. Environ. 85, 40-51.

Sailor, D.J., 2014. A holistic view of the effects of urban heat island mitigation. Low Carbon Cities Transf. Urban Syst. 270-281.

Sailor, D.J., Dietsch, N., 2007. The urban heat island mitigation impact screening tool (MIST). Environ. Model. Softw. 22 (10), 1529-1541.

Salata, F., Golasi, I., de Lieto Vollaro, R., de Lieto Vollaro, A., 2016. Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data. Sustain. Cities Soc. 26, 318-343.

Salata, F., Golasi, I., Petitti, D., de Lieto Vollaro, E., Coppi, M., de Lieto Vollaro, A., 2017. Relating microclimate, human thermal comfort and health during heat waves: an analysis of heat island mitigation strategies through a case study in an urban outdoor environment. Sustain. Cities Soc. 30, 79-96.

Santamouris, M., 2014. Cooling the cities-a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Sol. Energy 103, 682-703.

Santamouris, M., Ding, L., Fiorito, F., Oldfield, P., Osmond, P., Paolini, R., ... Synnefa, A., 2017. Passive and active cooling for the outdoor built environment - analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. Sol. Energy 154, 14-33.

Saran, S., Wate, P., Srivastav, S.K., Krishna Murthy, Y.V.N., 2015. CityGML at semantic level for urban energy conservation strategies. Ann. GIS 21 (1), 27-41.

Sharmin, T., Steemers, K., Matzarakis, A., 2017. Microclimatic modelling in assessing the impact of urban geometry on urban thermal environment. Sustain. Cities Soc. 34, 293-308.

Taleb, H.M., 2014. Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in UAE buildings. Front. Archit. Res. 3 (2), 154-165.

Taleghani, M., Sailor, D.J., Tenpierik, M., van den Dobbelsteen, A., 2014. Thermal assessment of heat mitigation strategies: the case of Portland State University, Oregon, USA. Build. Environ. 73, 138-150.

Taleghani, M., Tenpierik, M., van den Dobbelsteen, A., Sailor, D.J., 2014b. Heat mitigation strategies in winter and summer: field measurements in temperate climates. Build. Environ. 81, 309-319.

Wang, Y., Berardi, U., Akbari, H., 2016. Comparing the effects of urban heat island mitigation strategies for Toronto, Canada. Energy Build. 114, 2-19.

Yang, B., Sekhar, C., 2014. Interaction of dynamic indoor environment with moving person and performance of ceiling mounted personalized ventilation system. Indoor Built Environ. 23 (7), 920-932.

Zhao, T.F., Fong, K.F., 2017. Characterization of different heat mitigation strategies in landscape to fight against heat island and improve thermal comfort in hot-humid climate (part I): measurement and modelling. Sustain. Cities Soc. 32, 523-531.

Zinzi, M., 2016. Exploring the potentialities of cool facades to improve the thermal response of Mediterranean residential buildings. Sol. Energy 135, 386-397.