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EFFECT OF WATER FEATURES ON THE MICROCLIMATE OF RESIDENTIAL PROJECTS IN A HOT-ARID CLIMATE: A COMPARATIVE ANALYSIS

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ABSTRACT

This paper investigated the effect of water features on thermal comfort in a central open space of a residential project in a hot-arid climate. A crowded urbanized area in Baghdad was chosen as a case study a city. The methodology relied on a simulation method using ENVI-met 4.4.5 software to create a model of a residential project and obtain the levels of the predicted mean vote as well as four parameters associated with it. These parameters included, air temperature, mean radiant temperature, horizontal wind speed, and relative humidity. For the purpose of comparative analysis, four types of surfaces were modelled, a surface with a water feature, a vegetated surface, a concrete surface, and a combination of green and blue surfaces. The simulation results showed that a water feature can significantly decrease the levels of the predicted mean vote (PMV) index. It was even more effective than a vegetated surface in increasing thermal comfort levels in the microclimate of a residential project in a hot-arid climate.

Keywords: water feature, vegetated surface, residential projects, thermal comfort, ENVI-met, hot-arid climate

INTRODUCTION

The presence of water in its various forms plays an important role in enhancing the quality of the physical environment, and the socio-economic environment during the expansion process in cities (Bindu & Mohamed, 2016). This process is one of the most important reasons behind the change in the land cover which could cause the phenomenon of urban heat island (UHI) (Hyader & Hassan, 2020). According to the results of previous literature on UHI, one of the factors affecting this phenomenon is the mineralization of cities and the reduction of evaporation from urban green surfaces due to the replacement of vegetation cover with concrete and asphalt (Ballout et al., 2015). Therefore, the addition and inclusion of vegetation and water bodies within the urban fabric can improve thermal comfort. Trees act as a source of moisture, a temperature regulator, and an effective barrier that protects against sun radiation, wind (Hassan et al., 2019). In addition to plants, and tree shade, the effects of UHI can be

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minimized by evaporation from water bodies (rivers, lakes, ponds, etc.) which have higher evaporation rate as compared to vegetation and can thus enhance outdoor comfort and reduce energy consumption (Manteghi et al., 2016; Syafii et al., 2017).

Literatures on the importance of water features in the mitigation of UHI effects are few. A number of them argued that the presence of water bodies is the strongest cooling element in cities on hot summer days (Manteghi et al., 2015). In general, the high availability of water enhances evaporation, especially during the daytime, which leads to a decrease in air temperature in areas over or near water bodies (Du et al., 2016). It is believed that water bodies are the best absorbers of radiation, but on the other hand, their thermal response is limited due to the high heat capacity of water (Manteghi et al., 2015). This is because, it takes about three times the heat to raise one unit of water volume compared to soil, and thus, planners and architects tend to include water features in their designs (Manteghi et al., 2015). In previous research on water bodies concerning thermal comfort, it was found that there is a difference of 1 to 3°C between a river and an urban canyon inside the city on a hot day in Japan (Syafii et al., 2017). It was also found that a small river in the United Kingdom can reduce the temperature by approximately 1°C when the temperatures are higher than 20°C (Syafii et al., 2017). A small urban lake in Singapore, which has a hot and humid climate, led to a decrease of 1.3°C between the near and far regions of it (Ichinose, 2017). Moreover, a pond in Fukuoka in Japan has a 3°C effect extending up to 400 meters, and the effect of the Ota River in Hiroshima reaches 5°C above the river and it spreads 100 meters on the banks of the river, and another research revealed that the pond, which has an area of 4 square meters, is able to reduce the temperature of its surroundings (Robitu et al., 2004). However, the climatic effects of a water body depend on the direction and speed of the prevailing winds, the area of the water surface, and the design of the areas surrounding water bodies (Syafii et al., 2017).

For instance, when relatively small bodies of water are evenly distributed over an urban area, the reduction in temperature is more than that of one body of water of the same total volume (Gunawardena, 2017). The shape of water features is also important in distributing the cooling effect. The simpler or more regular shapes provide higher efficiency than the irregular shapes (Lee et al., 2016; Gunawardena, 2017; Mostofa & Manteghi, 2019) and the local thermal effect of water is higher during the daytime on hot days as compared to nighttime, especially at the end of summer, it may not have any effect (Gunawardena, 2017). Nonetheless, green spaces can also be used to reduce temperatures in hot climates through the reduction in radiation exchange on the surface of the earth. Field studies support the theory that the lack of plants in a city can lead to higher temperatures and increase the impact of UHI in the built environment. Given the positive effect of plants, designers must understand the interaction between the basic components (climate, buildings, plants) to reduce temperatures (Duarte et al., 2015). Vegetation affects the balance of thermal energy in cities, directly and indirectly. Directly by reducing air temperatures near the ground surface. It also modifies it indirectly by reducing the transfer of heat to occupied places, and thus reducing mechanical cooling loads and any thermal emissions from the urban fabric. The most discussed plant-based cooling process is transpiration, in which the water through the plant is evaporated by absorbing energy from solar radiation, which keeps tree leaves and the temperature of the surrounding atmosphere relatively cooler.

A review of previous studies on the effect of water bodies on UHI mentioned above in table 1 indicates that the main way in which blue and green surfaces affect the microclimate is based on evaporation, yet, the cooling effect of blue surfaces is more during the daytime as compared to nighttime. Therefore, both surfaces should be used together and included in future urban growth strategies, especially in countries experiencing high summer temperatures and rapid urbanization (Gunawardena, 2017). Although a large number of scholarly articles have pointed out the advantage of water bodies as the best means of passive cooling, they may not work perfectly

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Table 1. A summary of previous literature on the effect of water features on thermal comfort

Findings	Methodology	Reference
During hot summer day, a waterbody can effectively improve human comfort. Landscaping can improve human comfort	On-site measurements on hot summer days	(Xu et al., 2010)
Due to relatively high humidity, evaporative cooling may not be effective in a hot-humid tropical climate	Field measurements and calculations	(Wong et al., 2012)
The cool island effect of parks was greater than that of the lake	Using on-site measurements and regression analysis	(Li & Yu, 2014)
The larger the water areas, the more positive effects they have with a simplified shape	Using GIS software	(Lee et al., 2016)
The use of vegetation and water features, such as fountains, can improve thermal comfort, thus reduce the heat island. They also have good psychological effect on humans	Using ENVI-met software	(Ballout et al., 2015)
Traditional and innovative techniques using water features can create and improve passive cooling	A review of existing literature on passive cooling techniques	(De Joanna et al., 2016)
The thermal effects of lakes are stronger than the effect of rivers. Vegetation has a positive effect when combined with water features. Also, the geometry of the water body must be simple	Using satellite data of eighteen lakes and three rivers in a ring road in Shanghai, China	(Du et al., 2016)
The larger the water bodies, the greater the cooling effect, especially if it paralleled the direction of the wind. It might increase the absolute humidity, which may negatively affect pedestrians	Creating a miniature model of the urban environment formations with different formations of water bodies	(Syafii et al., 2017)
Centralized water can regulate the microclimate of residential district. Scattered water can improve the uniformity of microclimate. Water should be arranged parallel to prevailing wind direction	Using ENVI-met software	(Jin et al., 2017)
Water evaporation, shading and ventilation can reduce daytime PET of surroundings	Using ENVI-met software	(Cortesão et al., 2018)
Water features (waterfalls, fountains, and water curtains) might increase humidity beyond the comfort level, thus ventilation is necessary to maintain thermal balance	Furthermore, Computational Fluid Dynamics (CFD) is employed to process the data	(Seputra, 2018)
Vegetation, and water bodies improved the thermal environment in hot-dry climates. Yet, provided less cooling in compact urban spaces than in open areas	Reviewing existing literature on the mechanisms and cooling effects of four major mitigation strategies	(Lai et al., 2019)
The temperature is slightly lower near the lake and PET level showed a maximum decrease of 1.44°C	Field Measurements of four sites around Lake Kankaria using hand-held devices	(Gajjar & Devi, 2019)
increasing the size of water body with very simplified shape can have appositive impact on air temperature levels and thus, thermal comfort	Reviewing existing literature on water bodies' cooling effect	(Mostofa & Manteghi, 2019)
Thermal effects of small water bodies can be considered negligible in design practice. Shading, and natural ventilation can make the immediate surroundings of small water bodies cooler	Using ENVI-met 4.1.3 software	(Jacobs et al., 2020)

Source: own preparation.

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in hot and humid regions. Evaporation from water features, such as artificial waterfalls, water curtains, and fountains if applied in a warm humid climate, might increase air humidity beyond the comfort level (Seputra & Wong, 2012).

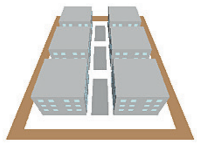
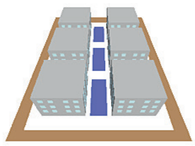
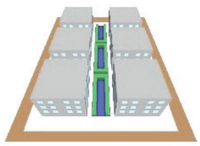
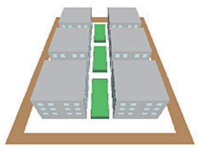
Therefore, the impact of relatively smaller water bodies represented in water features, such as large fountains and swimming pools, needs further research to measure the effect of a water feature upon its thermal condition. In response, this research investigates the impact of water feature's evaporative cooling on outdoor thermal comfort in urban canyons of residential projects, as compared to other surfaces such as a vegetated surface and a concrete pavement, in a hot arid climate. Psychological parameters associated with individual expectations affect thermal comfort. According to Fanger, this thermo-physiological comfort encompasses indexes such as physiological equivalent temperature (PET) and predicted mean vote (PMV) (Fanger, 1970). Here (PMV) is considered the most recognized thermal comfort model. It was developed by Fanger using and empirical studies to define comfort using experimental data about skin temperature obtained in a controlled climate chamber and principles of heat-balance equations. According to de Dear and Brager (1998) the main factors that determine heat loss and heat gain and influence thermal comfort include clothing insulation, air temperature, mean radiant temperature, metabolic rate, wind speed, and relative humidity (Dear & Brager, 1998).

In order to study these parameters and perform a comparative analysis, the methodology of this research relies on ENVI-met 4.4.5 software with an emphasis on the levels of PMV as well as four parameters associated with it. These parameters include air temperature, mean radiant temperature, horizontal wind speed, and relative humidity. The analysis in this software employs Fanger's equations to calculate the PMV of a group of people for a particular combination of the aforementioned parameters. Thermal neutrality is achieved when PMV equals zero, while the recommended limits of PMV to be within the comfort zone is within (-0.5<PMV<+0.5).

METHODOLOGY

In order to investigate the influence of water feature's evaporative cooling on urban canyons in residential projects, ENVI-met 4.4.5 software was used. For the purpose of comparative analysis, four scenarios of simulation modeling were used. See table 2 below for details.

Table 2. Simulation modeling scenarios

Simulation scenarios	Urban canyon surface type	ENVI-met model
Scenario no. 1	A residential project with a central space covered by concrete paving surface.	
Scenario no. 2	A residential project with a central space covered by water features (rectangular swimming pools).	
Scenario no. 3	A residential project with a central space covered by a combination of 50% water features (rectangular swimming pools) and 50% vegetated surfaces (dense hedge 2m).	
Scenario no. 4	A residential project with a central space covered by vegetated surfaces (dense hedge 2m).	

Source: own preparation.

A simple rectangular shape was chosen for the geometry of all proposed surfaces. These surfaces were modeled in a central open space which represents the urban canyon (12 m wide, 72 m long) surrounded by residential buildings (20 m × 20 m each) on both sides. Each of the four types of urban canyons was analyzed in three simulation models in which the urban canyon is flanked by:
– Low-rise residential buildings (3 stories, with a height of 10 m);

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– Mid-rise residential buildings (6 stories, with a height of 18 m);
– High-rise residential buildings (10 stories, with a height of 30 m).

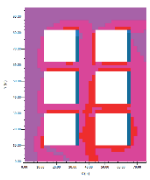
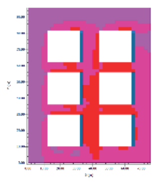
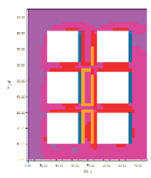
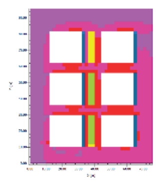
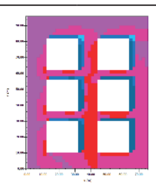
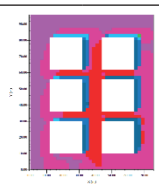
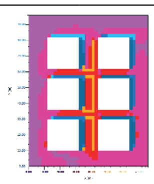
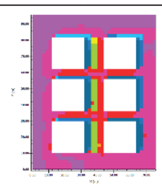
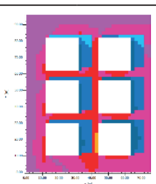
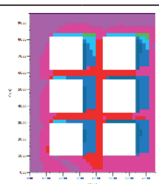
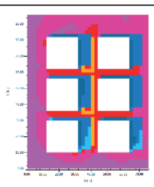
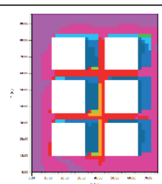
Therefore, the total number of simulations included 12 model output files in ENVI-met. Data were then collected and processed using Biomet which is a post-processor tool used for calculating Indices for human thermal comfort based on the output files. In terms of the location, a crowded urban area was chosen in Baghdad which is known for its hot-arid climate with extremely prolonged hot, dry summers and mild to cool short winters. Summer lasts for nearly 8 months. Therefore, high temperature is a major issue in Baghdad. The average maximum temperature from June through August is as high as 44°C (111°F). Even at night, temperatures in summer are rarely below 24°C (75°F) and the highest could reach up to 52°C (125°F). Humidity is typically under 50% in summer. Therefore, for the purpose of simulation, the temperature was set to range from 23°C to 50°C. One of the hottest days in summer was chosen, the 21st of July.

RESULTS AND DISCUSSION

Table 3 and table 4 below list the results obtained from a comparative analysis of 12 model output files of four types of urban canyons: A concrete surface, a surface containing a water feature, a combination of green and blue surfaces (50% each), and vegetated surface, in terms of PMV and four parameters associated with it in a central open space of three types of residential projects: low-rise, mid-rise, and high-rise buildings.

The levels of PMV for all four types of urban canyons are shown in figure 1. The peak of all four thermal comfort parameters associated with PMV

Table 3. A comparison among four types of surfaces in terms of PMV value

Surface type	Concrete surface Scenario no. 1		Water feature Scenario no. 2		Blue and green surfaces Scenario no. 3		Vegetated surface Scenario no. 4	
	Min	Max	Min	Max	Min	Max	Min	Max
PMV value	6.27	8.19	5.76	7.77	5.81	7.81	5.84	7.84
Low-rise residential buildings 3 stories								
PMV value	6.03	8.02	5.51	7.65	5.56	7.68	5.59	7.71
Mid-rise residential buildings 6 stories								
PMV value	5.81	7.88	5.38	7.57	5.39	7.60	5.45	7.62
High-rise residential buildings 10 stories								

Source: own preparation.

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Table 4. A comparison among four types of surfaces in terms of thermal comfort parameters (air temperature, humidity, mean radiant temperature (MRT), and wind speed) in a central open space of three residential projects: Low-rise, mid-rise, and high-rise

Residential Buildings type	Parameter	Concrete surface Scenario no. 1		Water feature Scenario no. 2		Blue and green surfaces Scenario no. 3		Vegetated surface Scenario no. 4	
		Min	Max	Min	Max	Min	Max	Min	Max
Low-rise buildings (LR) 3 stories	Air temp. (°C)	43.57	45.92	43.58	45.93	43.62	45.93	43.66	45.93
	MRT (°C)	57.25	77.37	50.39	71.95	50.43	72.53	50.90	72.82
	Wind speed (MPF)	0.21	2.05	0.19	2.02	0.19	2.02	0.20	2.02
	Relative humidity %	53.95	57.92	53.97	58.19	53.97	58.12	53.98	58.05
Mid-rise buildings (MR) 6 stories	Air temp. (°C)	43.49	45.92	43.49	45.93	43.52	45.93	43.55	45.93
	MRT (°C)	54.11	75.25	47.80	70.45	48.14	70.90	48.46	71.17
	Wind speed (MPF)	0.03	2.43	0.02	2.40	0.02	2.40	0.02	2.40
	Relative humidity %	53.94	58.23	53.96	58.49	53.97	58.48	53.97	58.42
High-rise buildings (HR) 10 stories	Air temp. (°C)	43.34	45.92	43.35	45.92	43.44	45.93	43.38	45.93
	MRT (°C)	51.82	73.60	46.63	69.52	46.84	69.90	46.82	70.11
	Wind speed (MPF)	0.03	2.91	0.03	2.88	0.03	2.80	0.03	2.88
	Relative humidity %	53.94	58.80	53.96	58.95	53.96	58.71	53.96	59.00

Source: own preparation.

is shown in figures 2, 3, and 4 below. The results can be described as follows:

– In scenario 1, concrete paving was used as a surface for the urban canyon. As compared to other surfaces, it had the highest indices in terms of PMV, and MRT. The results are most significant in the case of low-rise residential buildings and are nonsignificant in the case of mid-rise and high-rise residential buildings.

– In scenario 2, the concrete paving was replaced by water features (swimming pools). As compared to scenario 1, it caused a decrease in MRT average value of (6.14, 5.55, 4.63) °C, as well as a decrease in PMV level of (0.46, 0.44, 0.37) in the cases of low-rise (LR), mid-rise (MR), and high-rise (HR) buildings, respectively. Yet, there was a slight, nonsignificant increase in relative humidity of about 0.02%. The change in the rest of the analyzed parameters (wind speed and air temperature) was nonsignificant. Nonetheless, it can be stated that this scenario is the best among the four scenarios, and it is most visible in the case of low-rise residential buildings. See figures 2, 3, and 4 below for the average values of analyzed parameters.

– In scenario 3, a combination of green and blue surfaces (50% each) was used. Here, the results are very close to scenario 2 in terms the decrease in MRT. Yet, the PMV level was slightly higher. When compared to scenario 1. There was a decrease of (0.42, 0.4, 0.35) in PMV average level, and a decrease of (6.14, 5.55, 4.63) °C in the average MRT in the cases of low-rise (LR), mid-rise (MR), and high-rise (HR) buildings, respectively.

– In scenario 4, a vegetated surface was used. When compared to scenario 1, there was a decrease of (0.4, 0.37, 0.31) in PMV average level, and a decrease of (5.45, 4.87, 4.24) °C in the average MRT in the cases of low-rise (LR), mid-rise (MR), and high-rise (HR) buildings, respectively. Yet, scenario 4 indicated slightly higher indices when compared to scenarios 2 and 3.

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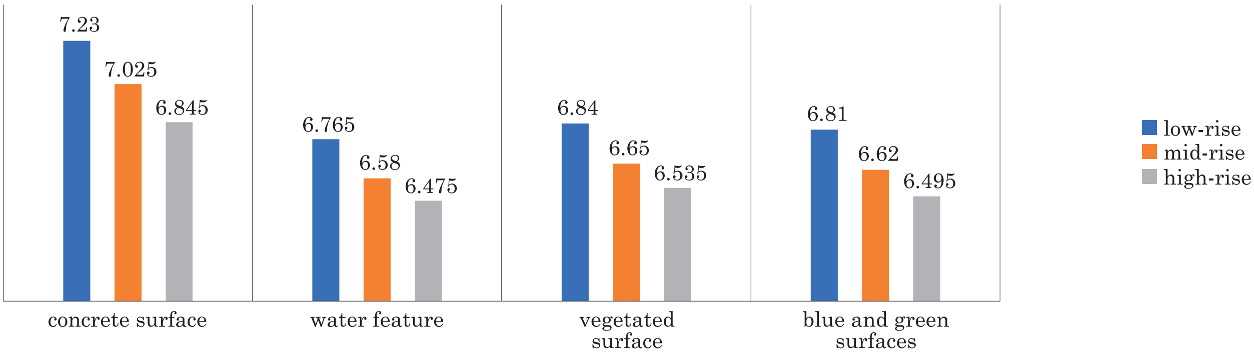

Fig. 1. Average PMV levels of four types of urban canyons flanked by of low-rise, mid-rise, and high-rise residential buildings, respectively
Source: own preparation based on Author.

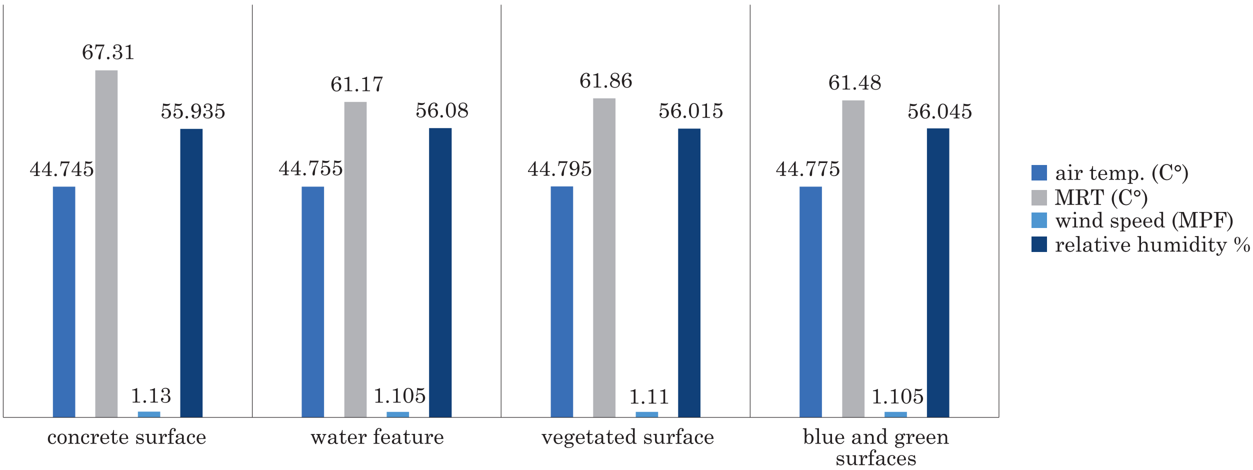

Fig. 2. Average levels of four thermal comfort parameters processed in an urban canyon flanked by low-rise residential buildings
Source: own preparation based on Author.

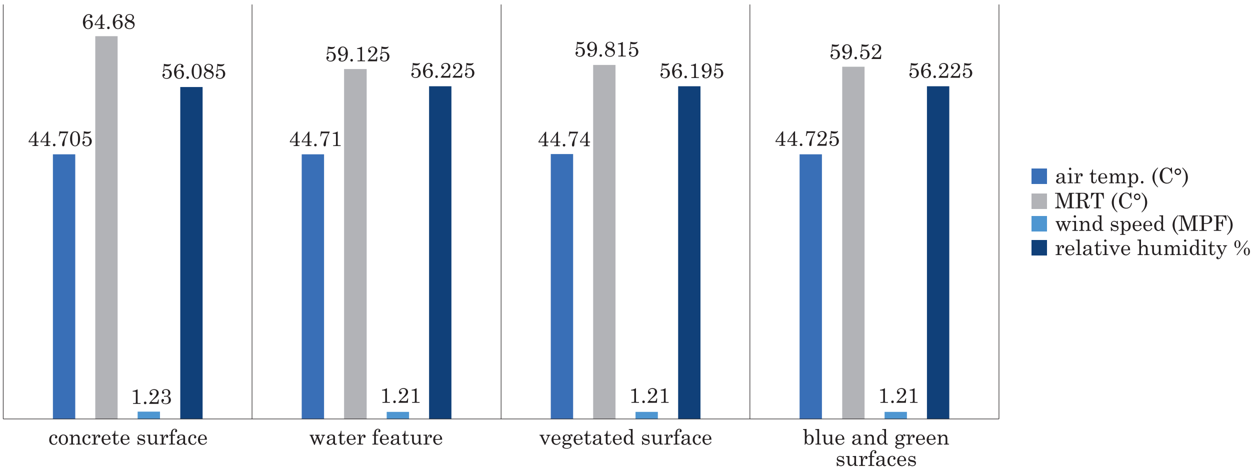

Fig. 3. Average levels of four thermal comfort parameters processed in an urban canyon flanked by mid-rise residential buildings
Source: own preparation based on Author.

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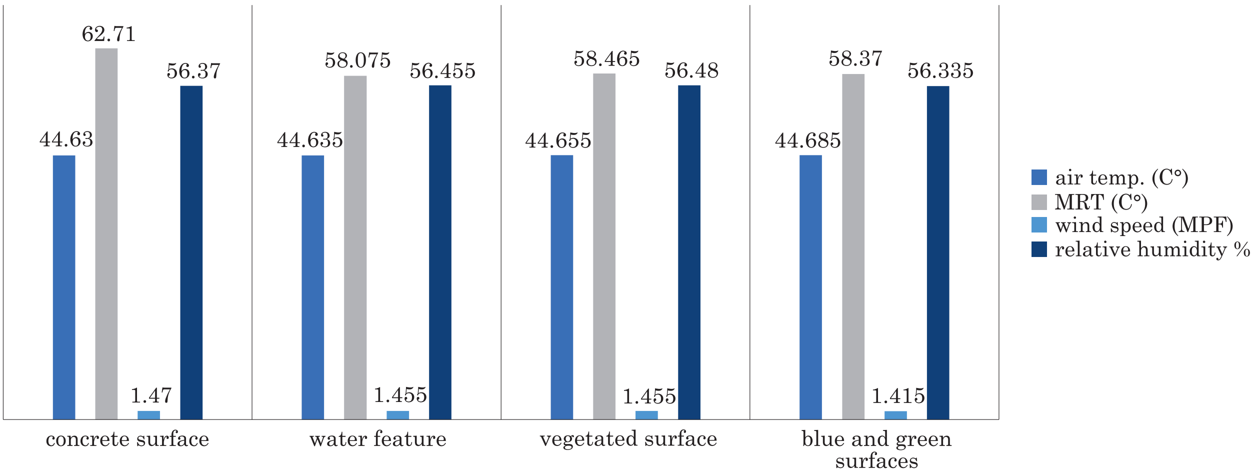

Fig. 4. Average levels of four thermal comfort parameters processed in an urban canyon flanked by high-rise residential buildings
Source: own preparation based on Author

CONCLUSIONS

It was observed that the use of the vegetated surface, as compared to a concrete surface, has improved the level of PMV, yet, when the vegetated surfaces were combined with water features, represented in the rectangular swimming pools, 50% for each type of surfaces, PMV levels showed further improvement. However, the most significant improvement in these levels was obtained in the second scenario in which the central open space in the residential project consisted of swimming pools with no vegetation. These results were most visible in the case of an urban canyon flanked by low-rise residential buildings. Based on the findings, this research recommends replacing paved open spaces within residential projects in a hot-arid climate with water features such as large swimming pools of simple geometric shape. Even though some previous literature suggested that water features might increase humidity levels beyond comfort, the results of this research using ENVI-met indicated that humidity levels slightly increased due to evaporation from the water feature. This increase was nonsignificant and could be considered negligible in designing residential projects. This difference in findings could be because humidity levels can vary according to variables, such as the size and shape of the water feature. This research aimed at measuring the exact influence of relatively small water bodies on the microclimate of urban canyons.

Predicting the thermal sensation of a population using simulation software is an important step in identifying the comfortable conditions in a particular setting during the design process of a residential project. Nonetheless, thermal comfort is a feeling and a state of mind which represents satisfaction with the surrounding thermal environment. Therefore, further research which relies on surveys and on-site measurements in urban canyons of residential districts in hot-arid climate would perhaps be needed to support the findings of this research.

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