Nakhara: Journal of Environmental Design and Planning (2023)
Volume 22(3), Article 319
DOI: https://doi.org/10.54028/NJ202322319
Article Type: Research Article

The Concurrent Effect of Building Height Diversity and Cool Pavement Materials on Air Temperature Near the Surface of an Urban Facade: A Case Study of Shahriar Street In Esfahan, Iran

Zahra Gholami[1], Samaneh Jalilisadrabad[2,*]

[1] Urban Design, School of Architecture and Environmental Design, Iran University of Science & Technology, Tehran, Iran

[2] Urban Planning, School of Architecture and Environmental Design, Iran University of Science and Technology, Tehran, Iran

*Corresponding e-mail: s_jalili@iust.ac.ir

Received 2023-04-02; Revised 2023-09-14; Accepted 2023-09-21

ABSTRACT

The rise in urban temperatures is a significant threat to the urban heat island effect, increasing building energy demand. This increase is worrisome because the supply of renewable energy is a big challenge. The approach to improving the urban microclimate offers a promising solution. This research investigates the concurrent effect of urban morphological parameters and physical characteristics of urban surfaces, such as cool materials, on the urban microclimate near the building's facades in an urban street. This evaluation was conducted by ENVI-met(v_4). The results show that the concurrent effects of increasing building height diversity and by using cool pavement materials are more helpful in reducing the average air temperature of an urban street. Because the amount of shade and wind speed increased as building height variety increased, the absorption of solar radiation decreased as pavement material albedo increased. As a result, these two parameters reduced air temperature by 0.8 °C. Also in the combined scenario of increasing building height diversity and by using cool pavement materials, the air temperature near the building's facades was reduced by 1°C on the first and second floors and by approximately 0.5°C on the upper floors.

Keywords: standard deviation height, cool pavement material, urban facade surface, urban microclimate, air temperature

INTRODUCTION

Global energy consumption in cities accounts for 75%, which leads to the emission of about 60% of all greenhouse gases (Oliveira & Silva, 2017). The energy consumed by buildings accounts for 40% of the total energy consumption, which is directly influenced by the urban context and microclimate in which buildings are located (Piselli et al., 2018). The heat island phenomenon is exacerbated by an increase in air temperature in the urban environment and leads to a rise in the energy consumption demand of buildings for cooling. Also, it imposes extra pressure, especially during peak energy consumption hours. Previous studies show that with the increase in global warming from 1970-2010, the use of cooling energy has increased by approximately 23% (Allegrini et al., 2012; Lee et al., 2016).

Buildings in urban environments may experience more heat load due to the high air temperature of the urban space, as research shows that the heat island effect in urban spaces may increase energy demand for cooling by between 15% and 200% (Palme et al., 2017). On the one hand, the energy crisis has become a significant concern due to constrained energy supply sources. On the other hand, a large portion of energy in cities is provided by fossil fuels, which has increased greenhouse gas emissions. In response to the issues above, numerous urban planning movements have emerged that emphasize the significance and necessity of giving attention to environmental aspects in cities, such as the energy consumption used. In other words, if the thermal environment and microclimate elements are considered throughout the urban planning and design process, city buildings' dependence on non-renewable energy may be significantly decreased, as can their consumption.

There are several approaches for reducing building energy consumption by changing the urban microclimate. Energy-based urban designs, for instance, represent urban morphology that reduces energy demand while providing a high level of comfort for users (Shi, 2020). Previous research has found that some urban morphological parameters, such as building height and density, could help to reduce the building's energy consumption. The cooling demand is lowered in urban environments with high buildings and associated self-shading (Natanian et al., 2019). The structure of the buildings mainly characterizes microclimates; they change wind flow, create shade, and change radiation and energy levels through processes such as heat storage, reflection, or modified sky view factor.

However, buildings not only impact the microclimate, but the internal air and the need to regulate it (heating and cooling demand) are highly dependent on the outdoor microclimate (Sun et al., 2014). The analysis of fifteen studies that examined the effect of urban environment air temperature (as a microclimate parameter) on the total building electricity consumption showed that the actual increase in electricity demand for each degree of urban environment temperature increase is between 0.5% and 8.5% (Santamouris et al., 2015). In addition to the beneficial effects of urban morphological changes on reducing the energy consumption of buildings, studies have shown that using cool materials in paving urban surfaces can also help reduce the energy consumption of buildings. Cool material is reflective and therefore absorbs less radiation and cools the surface (Nasrollahi et al., 2017; Salata et al., 2016).

This study aims to answer the question, what is the impact of the concurrent effect of the building's height diversity (as an urban morphology index) and cool pavement materials on the air temperature near the facade surfaces. Previous research has not investigated the concurrent effect of these two themes on reducing the air temperature. This paper focuses on the air temperature near the surface of the urban façade since building facades play a significant role in transferring heat from inside to outside and vice versa. So, as a result, changes in the microclimate of the space near the façade could cause changes in energy consumption in buildings.

LITERATURE REVIEW

Many studies have investigated the impact of various urban morphological parameters (such as building height diversity) on reducing the building's energy consumption. Much research has also been conducted to examine the effect of cooling materials on pavement surfaces and urban facades. It has been demonstrated that these materials lead to the cooling of urban surfaces and are effective at reducing the temperature inside buildings.

Urban Morphology

The implications of urban morphology on energy have long been discussed in global forums. Also, many studies have shown that energy-based urban designs can affect the urban microclimate and energy demand. Meanwhile, the urban researcher has investigated the effect of the street aspect ratio (ratio of building height to street width H/W), building's orientation and urban surface coverings (Deng & Wong, 2020; Xu et al., 2020). The results of some of these studies have shown that urban canyons with a higher aspect ratio provide more shade, and the air temperature decreases by about 6 °C (Kakon et al., 2009). Furthermore, street orientation may significantly improve urban air temperature (Srivanit & Jareemit, 2020). East-west streets reduce energy consumption. The more shade there is in these streets, the better the thermal comfort and energy-efficient design may be (Yahia et al., 2018).

Urban morphology is regarded as an inevitable tendency in urban construction, and it plays a significant role in increasing human quality of life, supporting healthy urban development, and lessening energy consumption (Bardhan et al., 2015; Habitzreuter et al., 2019). According to some research, urban construction has affected the urban morphology on the earth's surface and the urban microclimate (e.g., air temperature and surface temperature), impacting heat conduction and convection of near-surface air. The vertical spatial layout (i.e., building height, density, and amount of green open space) significantly affects the urban heat island effect in built-up regions (Chen et al., 2006; Yin et al., 2018).

The diversity in building height impacts the sunlight and shadows inside street blocks, changing the urban near-surface temperature (Giridharan et al., 2007). Some researchers believe that the detrimental impacts of urban thermal environments can be mitigated by modifying urban morphological elements (Stone et al., 2010). According to prior research findings, building density and height variables constitute the character of urban morphology, which can describe the condition of the urban environment. The building density and height factors have a strong relationship with the variables of outdoor thermal comfort. The height of a building has a significant impact on the microclimate (Wei et al., 2016).

Cool Materials

The physical properties of urban surfaces could impact the air temperature of urban space and energy consumption. Cool materials with high albedo in urban environments can reduce ambient air temperature (Piselli et al., 2018). One of the most important reduction strategies to balance a city heat load is by using cool materials on urban surfaces. Since 1970, many studies have been conducted on the optical characteristics of materials, and the results of these studies have led to the use of reflective materials (cool materials) because these materials can significantly reduce surface temperature. Meanwhile, materials with a high albedo, such as white materials (white asphalt and white concrete), have received much attention (Pisello, 2017; Akbari et al., 2017; Nasrollahi et al., 2017; Salata et al., 2016).

Using cool materials during the day reduces the temperature of urban surfaces such as facades and pavements, because cool materials absorb less solar radiation (Akbari et al., 2016). Urban surfaces with high albedo absorb less solar radiation and have lower temperatures than urban surfaces with low albedo. If used in homes and buildings in hot climates, surfaces with high solar reflectance can lessen the cooling energy used in buildings (Akbari et al., 2007). An experimental study investigated the thermal effect of pavement with high albedo in several large urban parks. Their study is one of the most extensive samples of practical cases (combination of 4500 square meters of bright yellow concrete tiles with 3700 square meters of yellow asphalt and white concrete). Their outcomes demonstrated that employing cool pavement materials reduced the air temperature of the urban environment by 1.9 degrees Celsius and the earth's surface temperature by 12 degrees Celsius (Santamouris et al., 2012).

METHODOLOGY

The main research aim is to investigate the concurrent effect of building height diversity and using cool materials on the air temperature near the urban surfaces of the building's facade and the pavement. Therefore, the simulations have been done using ENVI-met because it is a 3D grid-based microclimate model designed to simulate the complex interactions of air, surfaces and covers in an urban environment. It is a powerful tool used to evaluate air temperature as an important parameter of urban microclimate Figure 1.

Isfahan is a historical and semi-desert city located in the center of Iran. The height of Isfahan city is different from the general sea level in different parts of it; the height reaches 1550 meters on the Zayandehrood River banks and up to 1650 meters in the highest areas of the city (32° 38' 30" N and 51° 39' 40" E) Figure 2. The research site is a street called Shahryar in the Valiasr neighborhood (District 13 of Isfahan). Shahriar Street is east-west and is located southwest of Isfahan. Valiasr neighborhood has recently been developed, and Shahriar street is newly built, as satellite images show.

The main reason for choosing this area is that, as shown in Figure 2, land surface temperature, this street is located in the core of the thermal islands of Isfahan city. As a result, the air temperature in this location is high, and the energy consumption to reduce the air temperature inside buildings is also high. Therefore, reducing the air temperature of this area's urban space can help reduce the air temperature inside the buildings. This street is located in district 13 of Isfahan. District 13 is being developed dramatically, and with the increase in construction, there is a risk of increasing the air temperature in the urban space of this area.

Figure 1

Shows the Research Methodology

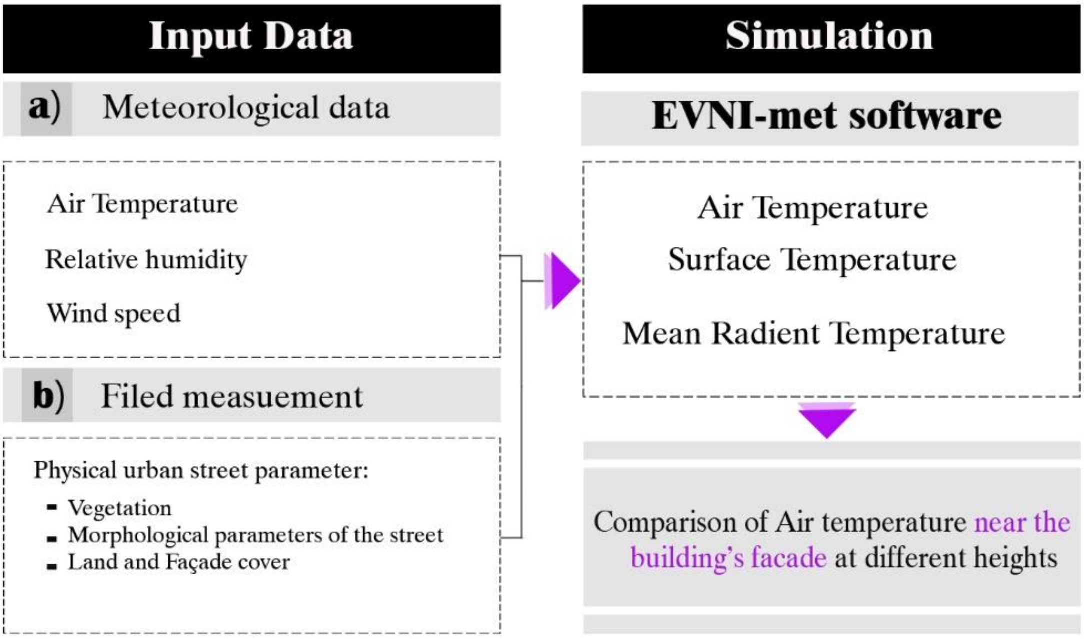
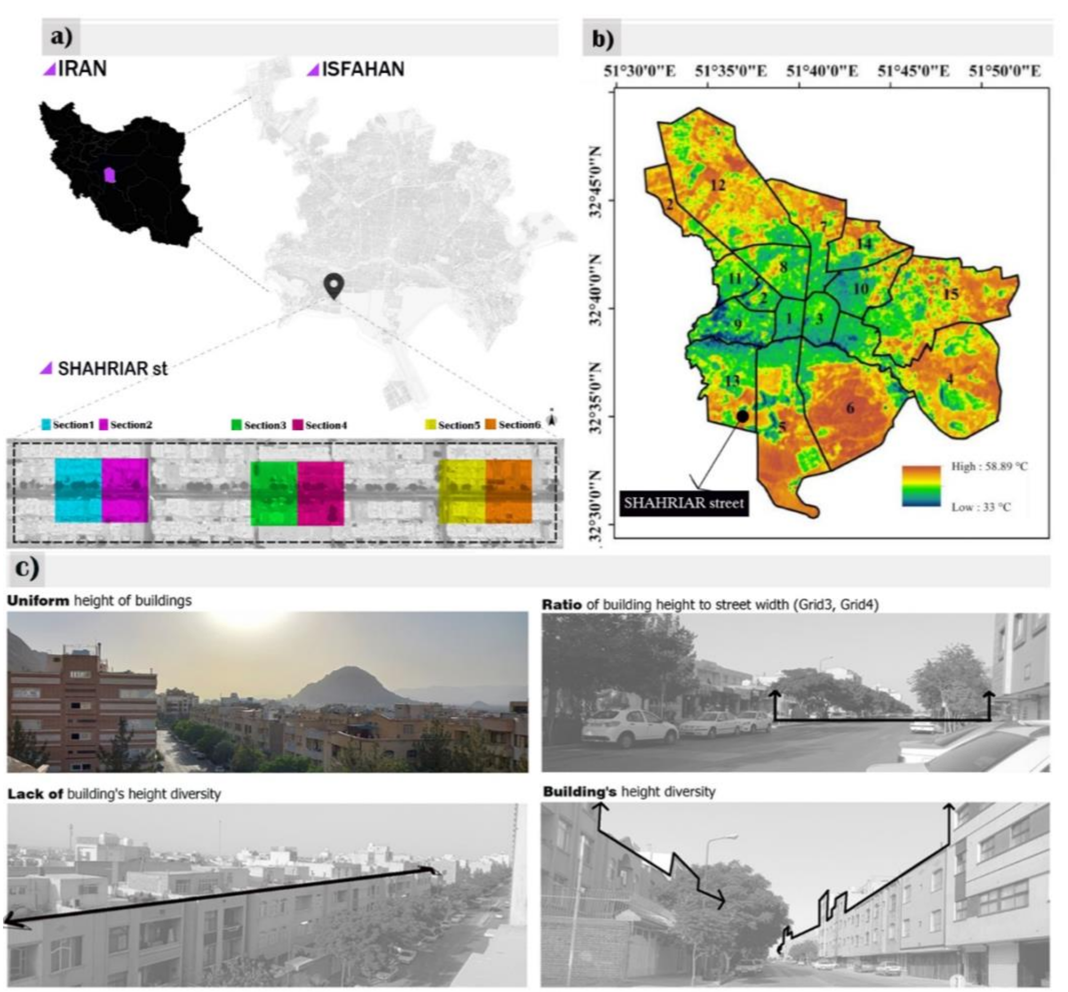


Figure 2

The Location of Shahriar Street of Isfahan (a), Map of Land Surface Temperature (b), Current Situation Pictures of the Study Area (c)



Note. Map of Land Surface Temperature from (Mirzaei et al., 2020)

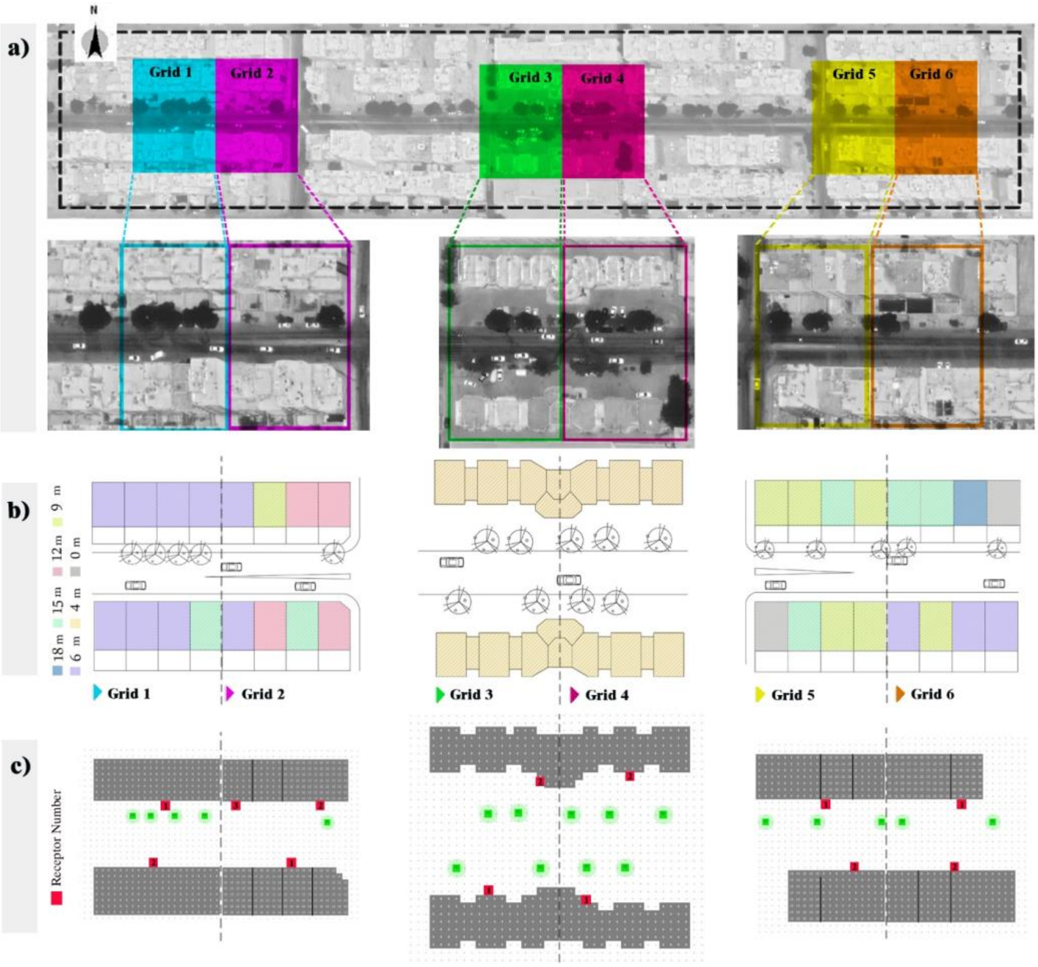
Simulation

The examined site is divided into six grids because of the limitations of the ENVI-met software. About 500 meters of Shahriar street's length have been simulated in Figure 3.

The meteorological station of Isfahan international airport has been selected to receive input data. The receptors were situated adjacent to the building's facade for the main research objective: to evaluate the air temperature in the space near the building's facade. The receptor's results at different heights were analyzed, and the air temperature distribution maps of the urban street at the height of 1.5 meters were obtained. The average annual temperature and precipitation in Isfahan are shown in Figure 4. July in Isfahan, Iran, is a sweltering summer month, with an average temperature fluctuating between 36.4°C and 21.5°C. July is the warmest month, with an average high temperature of 36.4°C and an average low temperature of 21.5°C. Based on meteorological data, July 20, 2022 is considered a hot day for simulation. The details of the simulation's input parameters are reported in Table1.

Figure 3

The 6 selected sections in Shahriar street for simulation.



Note. *Aerial satellite view (a), CAD map (b), ENVI met model (c)*

Figure 4

Mean and Maximum Temperature (a) and Mean Precipitation of Isfahan (b)

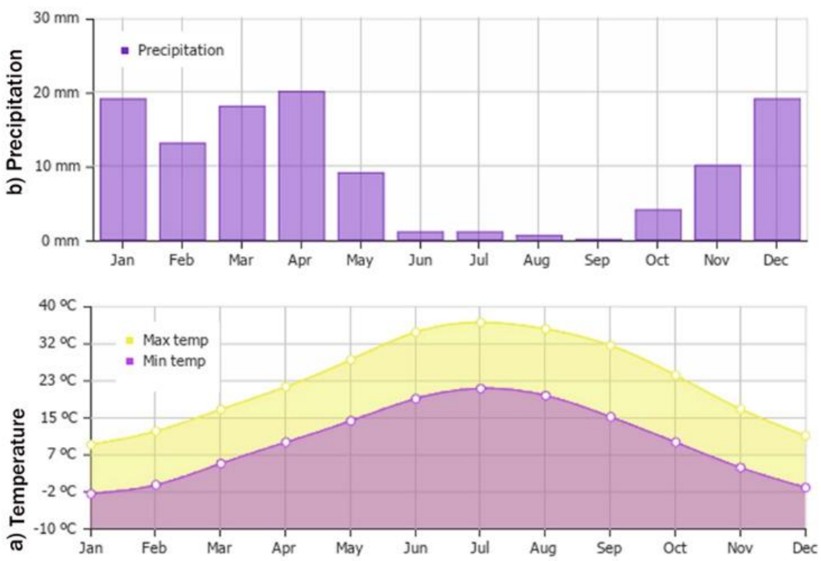


Table 1

ENVI-met Input Parameters for the Simulations

<table>
<tr><td colspan="9">Initiation and duration of modeling and meteorological conditions</td></tr>
<tr><td colspan="3">Simulation date</td><td colspan="3">July 20</td><td colspan="2">Wind speed in 10m</td><td>4.50</td></tr>
<tr><td colspan="3">Starting time</td><td colspan="3">06:00 Am</td><td colspan="2">Wind direction</td><td>East</td></tr>
<tr><td colspan="3">Total simulation time</td><td colspan="3">12 hrs.</td><td colspan="2">Roughness length at measurement site</td><td>0.010</td></tr>
<tr><td colspan="3">Maximum temperature (°C)</td><td colspan="3">40.00</td><td colspan="2">Maximum relative humidity (%)</td><td>17.00</td></tr>
<tr><td colspan="3">Minimum temperature (°C)</td><td colspan="3">18.88</td><td colspan="2">Minimum relative humidity (%)</td><td>4.00</td></tr>
<tr><td colspan="9">Model Zone</td></tr>
<tr><td rowspan="3">Model dimension</td><td>x axis station</td><td>40</td><td rowspan="3">Situation</td><td rowspan="2">Longitude</td><td rowspan="2">32.36</td><td rowspan="3">Size of grid</td><td>DX :dimensions of x axis station</td><td>2</td></tr>
<tr><td>y axis station</td><td>40</td><td>DY: dimensions of y axis station</td><td>2</td></tr>
<tr><td>z axis station</td><td>15</td><td>Latitude</td><td>51.37</td><td>DZ dimensions of z axis station</td><td>3</td></tr>
</table>

In this research, three models are simulated in ENVI-met software to evaluate the concurrent impact of building's height diversity and cool pavement materials on air temperature near the building's facade. Model B represents the current situation of the street, and two models, CBH and BHCP, are the proposed scenarios. The properties of each model are reported in Table 2. In ENVI-met software, creating and changing color in a material is done by changing a parameter called albedo (reflectivity for shortwave radiation). In this research, in order to create white asphalt and white concrete material, this parameter was altered in the Database section. ENVI-met software has a very powerful library of different materials. Due to Model B changing the albedo of asphalt and concrete materials in the profile, white asphalt and white concrete has been created. The purpose of this research is not to change the properties of asphalt and concrete materials; only the color of these materials is important for this study.

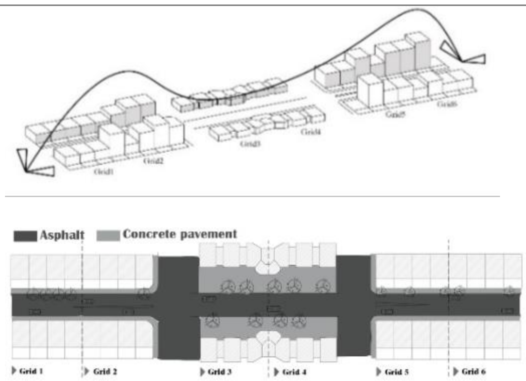
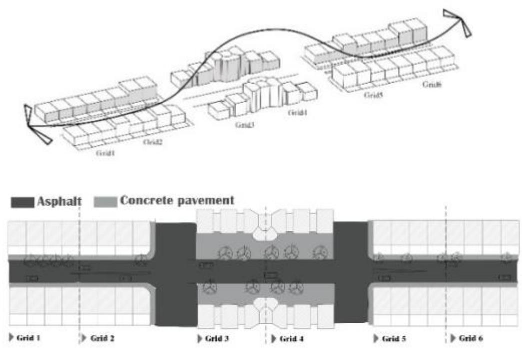
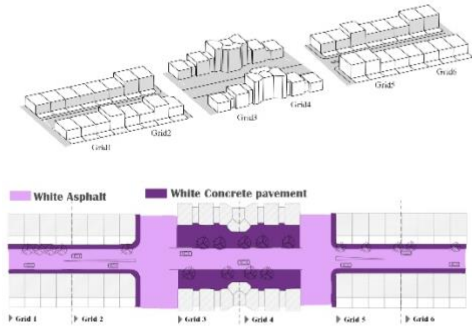
Validation of ENVI-met$_{V4}$ Results with Field Measurements

ENVI-met is an innovative 3D simulation software developed by Bruse and Fleer that can simulate the physical and microclimatic behavior of outdoor urban and rural regions based on climatic factors, vegetation, surface, soil, and built environment. This software can estimate air temperature, mean radiant temperature, relative humidity, global radiation, and thermal comfort using thermal comfort indicators such as PMV and PET. Previous studies (Nasrollahi et al., 2017; Taleghani et al., 2015) showed that ENVI-met simulates environmental conditions with reasonable accuracy. The results of ENVI-met software are slightly different when compared with the results of the field measurements. The unified values of material characteristics, inaccuracies in vegetation profiles (Krüger et al.,2011), restrictions for a detailed simulation of the morphological characteristics and constant solar radiation and atmospheric flow settings during simulation (Acero et al.,2015), could all be contributing factors to this difference.

In this examination, simulated and measured results were compared for validation. On-site monitoring was conducted precisely at the same hours simulated scenarios were investigated Figure 5. The air temperature data were measured by a data logger (Data logger model: GM1365, accuracy: ± 0.3 °C, range: −30 to 80 °C). The data show that the simulated results are approximately 1.56 °C higher than the measured results. Based on previous studies, the simulation results in this research have an acceptable level of accuracy. For statistical validation of the ENVI-met model results, coefficient of determination (R2) was calculated. The coefficient of determination is often used as the best suitable metric to describe the agreement between model projections and empirical observations.

Table 2

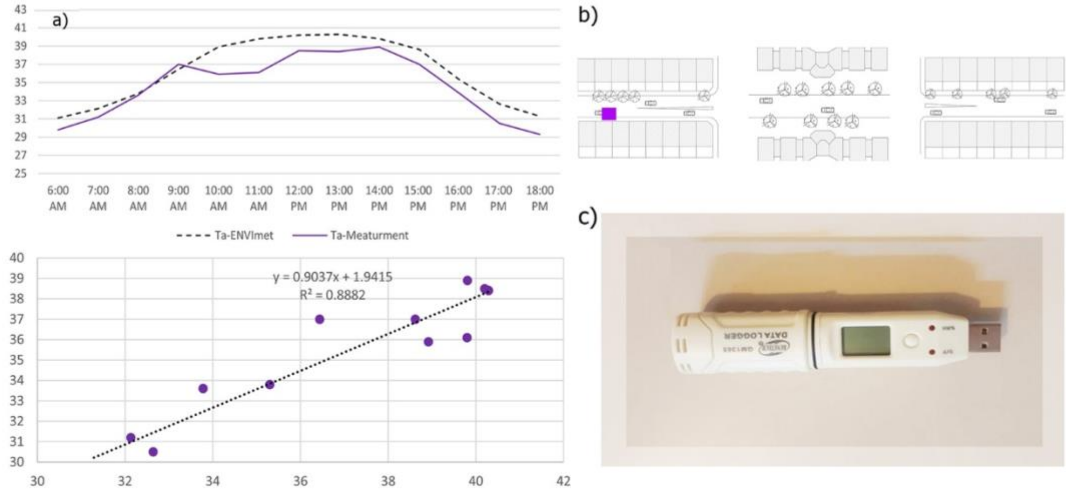
Proposed Models: Material Properties for the Base (a) , Material Properties for the CBH (b), Material Properties for the BHCP (c)

Model	Definition	3D Proposed Model	Material Properties		
			Pavement	Facade	Roof
a) Base Model (B)	This simulation shows the current situation of the Shahriar street		Asphalt (Albedo: 12.0), Concrete pavement (Albedo: 0.4)	Brick (Albedo: 0.4)	Moderate isolation
b) Changing Building Height (CBH)	This simulation shows the changing of a street's buildings height		Asphalt (Albedo: 12.0), Concrete pavement (Albedo: 0.4)	Brick (Albedo: 0.4)	Moderate isolation
c) Changing Building Height and Cool Pavement Model (**BHCP**)	This simulation shows the changing of street pavement materials with cool materials and changing buildings height		White Asphalt (Albedo: 0.33), White Concrete pavement (Albedo: 0.85)	Brick (Albedo: 0.4)	Moderate isolation

Note. From a) (www.envi-met.com), b) (www.envi-met.com), c) (9/23/2022: https://b2n.ir/f14802) (Nasrollahi 2017, Salata 2016)

Figure 5

Comparison of Simulation Results and Measurements (a), The location of Data Logger (b), Weather Data Logger Used for Measurement (c)



Analysis Parameters

The wind speed and air temperature are affected by the building's height changes. As the height changes, the wind is blocked at the top of the high buildings, before being directed downwards and reaches the ground level or flows around the high buildings (Chen et al., 2020).

The study aims to assess the concurrent impacts of building height diversity and cool pavement materials on the air temperature adjacent to a building façade. It is of importance since urban facades act as an intermediary between the outside and the inside buildings and are vital in lowering and increasing their energy consumption. A building height is one of the most effective morphological indicators. Some previous studies show that short buildings with uniform heights do not positively affect airflow patterns and wind speed increase. A lack of building height diversity does not have a positive effect on increasing the wind speed and improving the airflow, while an optimal height diversity significantly affects the wind speed Figure 6. Numerous research has been conducted to evaluate the impact of height changes as a morphological index in the urban environment. Some of these indexes are shown in Table 3.

This study used the building height diversity index (standard deviation of building height). The standard deviation of building height (SDBH) as an index to measure the height diversity of buildings is equal to (1): (H1 is the lowest building height, and H2 is the highest building height)

$$[\sigma = \frac{(H2-H1)}{(H2+H1)} \times 100]. \qquad (1)$$

The Standard deviation of building height (SDBH)

The following indexes are considered to analyze the effect of cool materials (materials with high albedo) on the pavement of urban open spaces: air temperature, mean radiant temperature (MRT), and surface temperature (Ts). ENVI-met can calculate MRT, TS, and potential air temperature with reasonable estimates and is calculated for each grid point in the simulation.

Figure 6

Comparison Between the Effect of a Lack of Building Height Diversity and Building Height Diversity

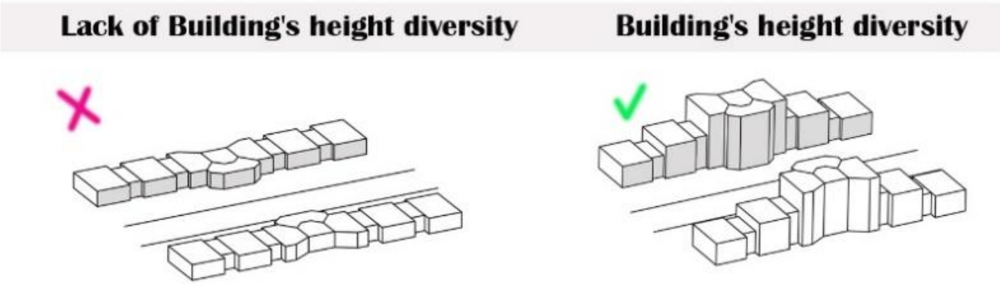


Table 3

Types of Indexes for Evaluating Height Changes

Types of indexes	Definition
Classification based on the number of floors	1-2 , 2-4, >4
Dividing the maximum building height by the minimum building height	Hmax / Hmin
Dividing uniform height into non-uniform height	uniform height/ non-uniform height
Classification based on the height of buildings in meter	0-150 m, 15-20m, >20m
Standard deviation of building height	$\sigma = \frac{(H2 - H1)}{(H2 + H1)} \times 100$
Low building height, medium building height, high building height	H, 2H, 4H

RESULTS AND DISCUSSION

The research results are presented in two parts. In the first part, air temperature distribution maps and ground surface temperature have been compared in all grids. In the second part, the results of receptors are compared with each other. In both sections, the results of the two proposed scenarios CBH, and BHCP, have been compared with the results of the base model B.

Analysis of Distribution Maps of Potential Air Temperature, Surface Temperature

Comparing the results of the potential air temperature distribution maps of the CBH and BHCP proposed scenarios with model B shows that the average potential air temperature decrease in the BHCP scenario is greater than in the CBH scenario .According to Figure 6, the average potential air temperature reduction near the building facades in the BHCP scenario, grids 3 and 4, is about 1.5 °C. The average potential air temperature next to the southern buildings' facades has decreased by a maximum of 0.5 °C in grids 5 and 6. Additionally, the maximum decrease in temperature near the southern facades in grids 1 and 2 is around 0.3°C. In the CBH scenario, grids 3 and 4 experience a maximum reduction in the average potential air temperature next to the building facades of about 0.6 °C. Therefore, the concurrent effect of the building's height diversity and using cool materials to reduce the average air temperature is better in the BHCP scenario. These results were analyzed at 14:00 at a 1.5 m.

Figure 6

Comparison of the Potential Air Temperature Distribution Maps at 14:00 Pm in Three Scenario

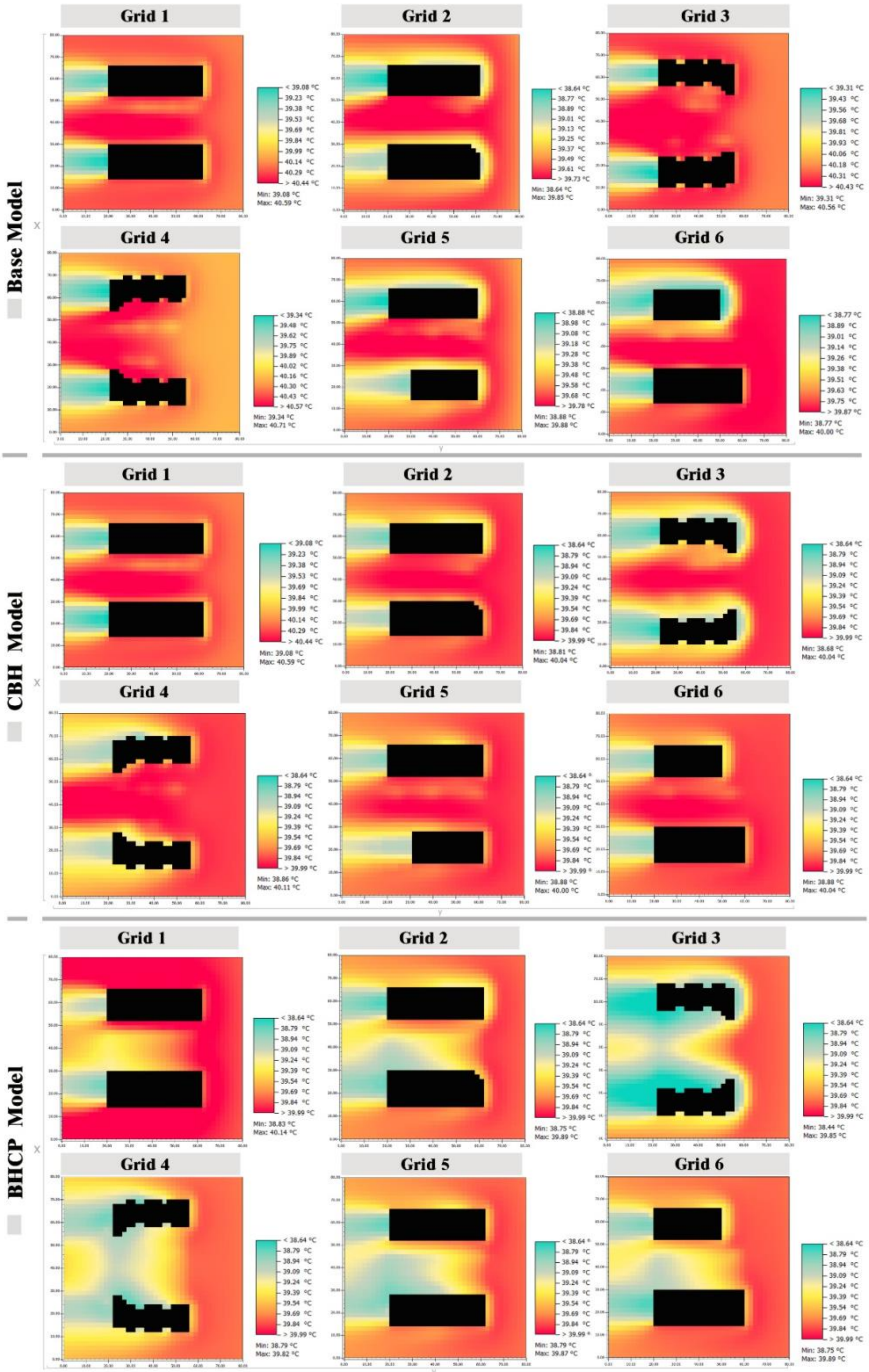


Figure 7 illustrates the street's surface temperature distribution map for grids 2 and 3. In the CBH scenario, in grid 3, the maximum decrease in ground surface temperature near the facade of the buildings is approximately 7 °C. This is because the height diversity of the buildings increased in grid 3, and the wind speed and the shade of the buildings increased. In the BHCP scenario, with the addition of cool materials to the street pavement, in grid 3, the maximum surface temperature reduction near the facade of the buildings is only approximately 14 °C.

In the CBH scenario, the building height diversity is reduced in grid 2. The low height of the buildings has reduced the building's shadow on the ground. Consequently, the south facade of the buildings had seen an increase in surface temperature of approximately 3 °C. However, in the BHCP scenario, in grid 2, despite the decrease in height diversity, the surface temperature on the south facade of the buildings has declined by approximately 3°C due to using cool materials on the street pavement. Therefore, the surface temperature distribution map also shows that the concurrent effect of building height diversity and using cool materials in reducing the surface temperature of the pavement near a building facade is better in the BHCP scenario. Grids 2 and 3 are presented as examples in Figure 7. Results similar to grids 2 and 3 have been observed in other grids. These results were analyzed at 14:00 at a height of 1.5 m.

Figure 7

Comparison of the Surface Temperature Distribution Maps at 14:00 Pm in Three Scenarios (Grid 2, Grid 3) (a), Comparison of the Tmrt in Grid3 at 14.00 (b)

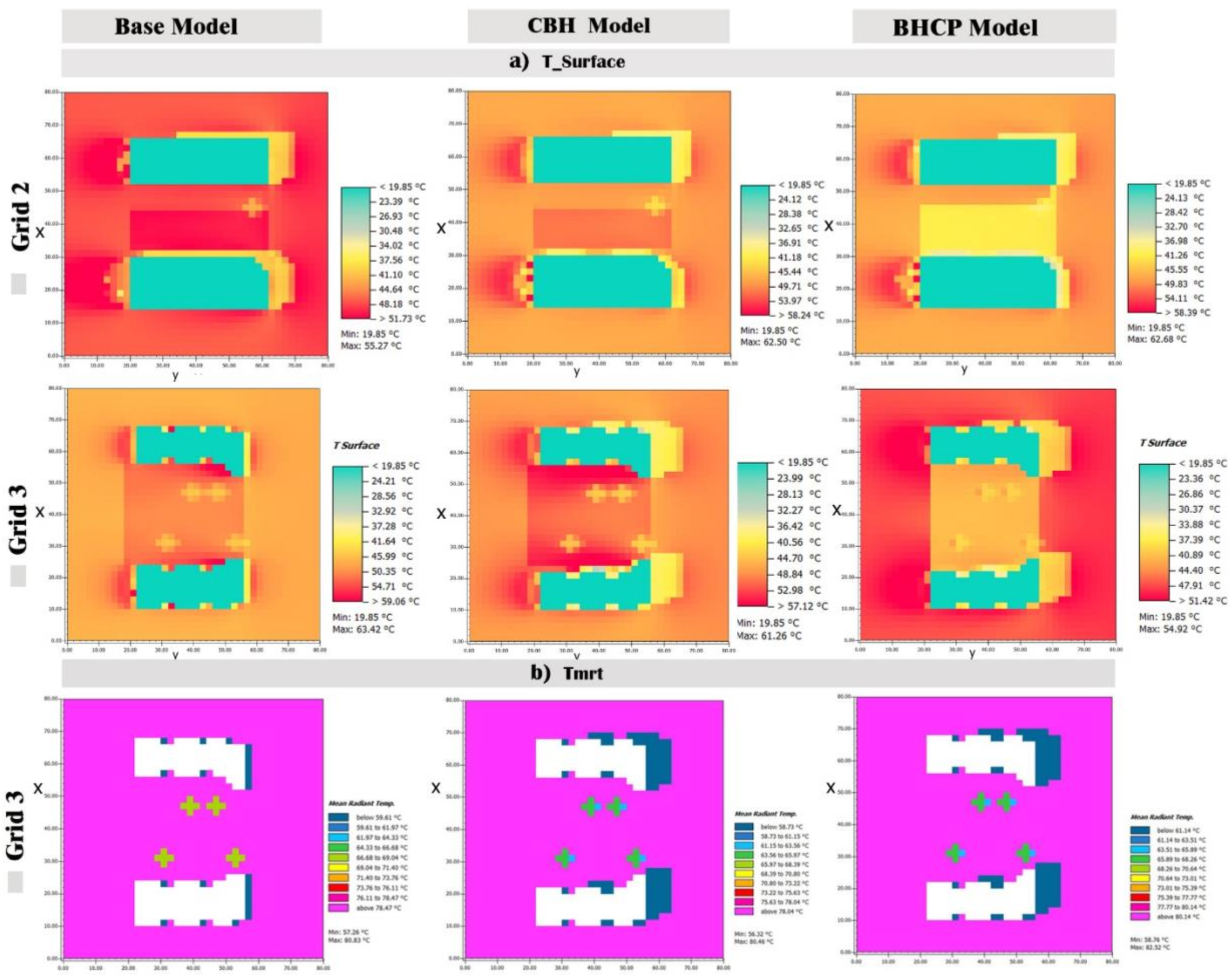


Figure 8 compares the results of two scenarios (CBH and BHCP) with model B. Moreover, the results show that in both proposed scenarios, the decrease in average potential air temperature is highest in grids 3 and 4. Increased building height diversity has increased wind speed in these two grids. The lowest wind speed is in grid 1, where the height of the buildings is low and uniform, and the increase in temperature is also higher in this grid. Also, with the decrease in building height diversity, the average air temperature has not changed significantly. The buildings height diversity and aspect ratio(H/W) are the same in both of the suggested scenarios (CBH and BHCP). In the BHCP scenario, cool materials are added to the street pavement. The results in Figure 8 show that the average air temperature decreases more with the increase in building height diversity and by using cool materials on the street pavement. The average air temperature reduction in the CBH scenario is approximately 0.6 °C, but the average air temperature reduction in the BHCP scenario is approximately 0.8 °C Table 4. These results show that the concurrent change of a morphological index (increasing SDBH) and cool materials (cool paving) is more effective in reducing the air temperature of the urban space. Global studies show that the standard deviation of a building's height, which shows the height diversity of buildings, directly correlates with wind speed. In this article, the wind speed has increased with the increase in height changes in the buildings. Wind speed is an important factor for changes in air temperature in urban areas. Wind speed assessment is only based on simulation results.

Analyzes of Receptors Near the Building’s Facade Surfaces

Receptors in ENVI-mat software collect the results at different heights. Moreover, since the research aim is to investigate the concurrent effect of building height diversity and by using cool pavement materials to reduce the air temperature near the facade of the buildings (in order to reduce the air temperature inside the building), so the receptors were located near the building's facades Figure 9. According to the proposed scenarios, the height diversity on grids 3, 5, and 1 has increased, decreased, and remained the same, respectively. The impact of these three buildings' height diversity is discussed in this section. Both of the proposed models' receptor data were compared with model B.

In grid 3 in the BHCP model, with the increase in building height diversity and by using cool materials in the street pavement, the amount of air temperature reduction at different heights is higher than in the CBH model. In the BHCP scenario and grid 3, the temperature near the building's facade on the first and second floors has decreased by 1°C; on the upper floors, it has decreased by about 0.5°C. Grid 3 building's height diversity has increased, and the retreat of buildings on both sides of the street has created an open space in grid 3. Cool materials have a high albedo, and absorption of solar radiation in materials with a high albedo is low, leading to surface cooling. Cool materials on the street pavement reflect the sun's radiation towards the sky. It leads to the cooling of the air temperature in the urban space and the space near the building's facade, and because there is much open space in grid 3, the reflection of the sun's radiation returns to the sky.

Neither of the two proposed scenarios (CBH and BHCP) significantly change the air temperature near the building facades in grid 5. In fact, in the BHCP scenario, the air temperature reduction near the facade of buildings is less than 0.5 °C. In Grid 5, building height diversity and shadow have decreased. Due to the increased in pavement albedo, there was an increase in the Tmrt index in grid 5 in the BHCP scenario, which was completely expected. Indeed, the increase in Tmrt has prevented the decrease in air temperature near the facade of buildings because multiple reflections have created more solar radiation. In grid 1, the building height diversity has not changed in the proposed scenarios. Therefore, the results of CBH scenario receptors are similar to scenario B. Yet, as shown in the BHCP scenario, in receptor 1 of grid 1, despite the height diversity remaining constant, the effect of cool materials alone can lead to a decrease in the air temperature near the facade of the buildings up to a maximum of 1 °C in the entire height of the building, as shown in Figure 9. The location and number of receptors in each grid are shown in Figure 3.

Figure 8

Air Temperature Changes in CBH and BHCP Models Compared to the Base Model B (a), SDBH Changes (SDBH of Both Models CBH and BHCP is the Same) Compared to the Base Model B (b)

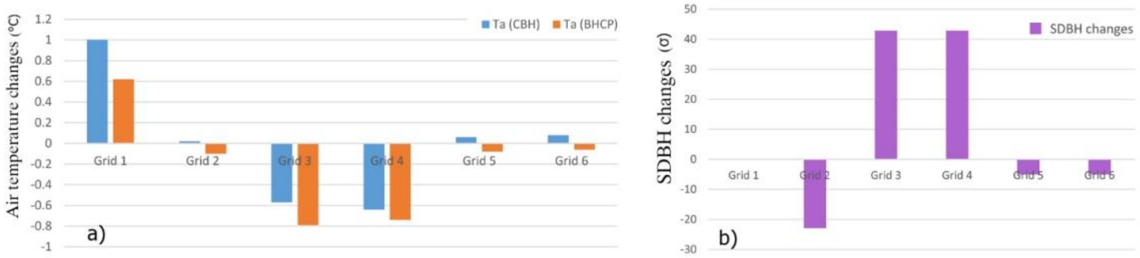


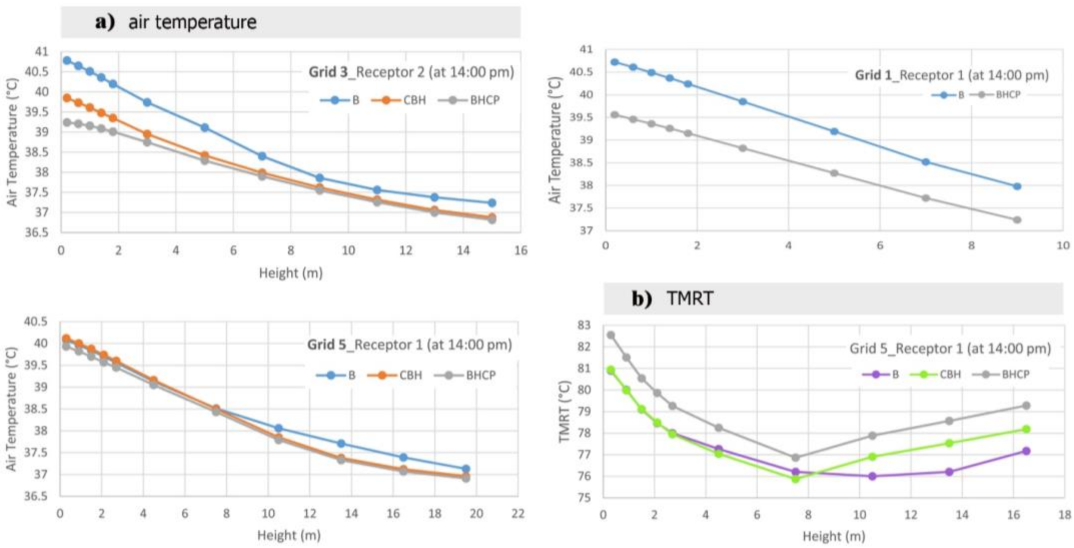
Table 4

Comparison of SDBH, MWS, Ta and H/W in All Grids

		Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
B	**SDBH**	42.85	42.85	0	0	25	55
	MWS	1.56	1.95	1.5	1.57	1.81	1.84
	Ta	38.83	39.4	39.93	40.02	39.38	39.38
	H/W	0.58	0.58	0.12	0.12	0.66	0.9
CBH	**SDBH**	42.8	20	42.85	42.85	20	20
	MWS	1.56	1.78	1.98	1.9	1.68	1.7
	Ta	39.83	39.42	39.36	39.38	39.44	39.46
	H/W	0.35	0.41	0.34	0.34	0.41	0.41
BHCP	**SDBH**	42.8	20	42.85	42.85	20	20
	MWS	1.56	1.78	1.98	1.98	1.68	1.7
	Ta	39.45	39.3	39.14	39.28	39.3	39.32
	H/W	0.58	0.41	0.34	0.34	0.41	0.41

Figure 9

Comparison of air Temperature Near the Building's Facade at Different Heights at 14:00 (Grid 2, 3, 5) (a), Comparison of Tmrt Near the Building's Facade inDdifferent Heights at 14:00 (Grid 5) (b)



The main reason that the increase of albedo on the ground of the urban space behaves more strongly is that the reflection of sun's radiation returns to the sky and the ground of the urban space is cooled. This research has proven that with the concurrent change of height diversity and using cool materials, the air temperature of the urban microclimate has decreased near the urban facade. This is a more optimal combination to reduce the air temperature of the urban microclimate. Therefore, with the air temperature reduction in the urban microclimate, there is an expectation of improving the air temperature inside the buildings.

This study has examined the concurrent effect of these two parameters in a newly built urban street of 500 meters on a micro-scale. In previous studies, these two parameters, i.e. height variation of buildings and increase of pavement albedo, have not been investigated together. This study can show the effect and importance of changing the color of the pavement (white color with high albedo) in reducing the air temperature of urban space. Due to its large width and use of white pavement, streets like Shahriar Street are, more effective.

CONCLUSION

Global warming has dramatically affected the increase in energy demand in buildings. This increase in demand is directly influenced by the microclimate of the urban space that surrounds buildings and plus, as compared to the past, this increase has created more concerns about the supply of fossil fuels and renewable energy sources. In the meantime, several studies have found that the change of urban morphology such as increasing building height variation and, material albedo, has significantly decreased the need for energy in buildings. So far, various approaches, such as "changes in city morphology parameters" or "using cool materials in paving urban surfaces", have been studied to improve the urban microclimate.

This research investigates the concurrent effect of "changes in city morphology factors" and "using cool materials in paving urban surfaces" in an urban street in Isfahan, which has not been examined in previous studies. Moreover, the results of this research showed that the change in these two parameters in urban space is an optimal combination. As the average air temperature distribution maps show, in the first scenario (CBH), where only the height diversity has changed, in some street grids where there is, an increase in height diversity, the average air temperature has decreased by approximately 0.6 °C. While in the second scenario (BHCP), increasing height diversity and cool materials in the street pavement has reduced the average air temperature by approximately 0.8 °C.

Also, the surface temperature (Ts) near the south facade of the buildings in the BHCP scenario has decreased by 14 °C in some grids. All receptors have collected the air temperature near the facade of the buildings at different heights. Their results show that in some grids in the BHCP scenario, the air temperature near the facade of the buildings on the first and second floors has decreased by 1 °C; on the upper floors, it has decreased by about 0.5 °C. As the receptors results show, the air temperature in the parts of the street where height diversity is reduced, the air temperature reduction near the facades of buildings is minor. Generally, the effectiveness of the BHCP scenario was better in reducing the air temperature near the facade of the buildings. Previous studies have proven that reducing the air temperature of the urban environment has an influential role in reducing the energy demand inside buildings.

Shahriar Street is in one of the new districts of Isfahan, where the buildings share a similar appearance. Since urban development is the leading cause of the major problem of increasing urban temperatures, several approaches have been offered in prior research for reducing urban air temperatures in which most focus on the transformation of the urban configuration. Yet these changes in urban spaces are very expensive and practically impossible in big cities. This research tries to state that existing urban surfaces, such as the ground of urban spaces, have a great potential to reduce the air temperature of urban space. In the first proposed scenario, the changes in urban air temperature were investigated by creating building height diversity, and in the second scenario, street paving with high albedo was added. By increasing pavement albedo and combining it with height variation, the results were far more effective.

REFERENCES

Acero, J. A., & Herranz-Pascual, K. (2015). A comparison of thermal comfort conditions in four urban spaces by means of measurements and modelling techniques. *Building and Environment, 93*(12), 245–257. https://doi.org/10.1016/j.buildenv.2015.06.028

Akbari, H., Cartalis, C., Santamouris, M., Synnefa, A., Kolokotsa, D., Muscio, A., Pisello, A. L., Rossi, F., Wong, N. H., & Zinzi, M. (2016). Local climate change and urban heat island mitigation techniques-The state of the art. *Journal of Civil Engineering and Management, 22*(1),1–16. https://doi.org/10.3846/13923730.2015.1111934

Akbari, H., Levinson, R., Rosenfeld, A., & Elliot, M. (September 21–23, 2007). *Global cooling: Policies to cool the world and offset global warming from CO2 using reflective roofs and pavements*. SICCUHI: 2nd International Conferrence on Countermeasures to Urban Heat Islands, Berkeley, California. https://www.osti.gov/biblio/984960/

Allegrini, J., Dorer, V., & Carmeliet, J. (2012). Influence of the urban microclimate in street canyons on the energy demand for space cooling and heating of buildings. *Energy Build, 55*(11), 823–832. https://doi.org/10.1016/j.enbuild.2012.10.013

Bardhan, R., Kurisu, K., & Hanaki, K. (2015). Does compact urban forms relate to good quality of life in high density cities of India? Case of Kolkata. *Cities, 48*(16), 55–65. https://doi.org/10.1016/j.cities.2015.06.005

Chen, H. C., Han,Q., & De Vries, B. (2020). Modeling the spatial relation between urban morphology, land surface, temperature and urban energy demand. *Sustainable Cities and Society, 60*(12), Article 102246. https://doi.org/10.1016/j.scs.2020.102246

Chen, X. L., Zhao, H. M., Li, P. X., & Yin, Z. Y. (2006). Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. *Remote Sens. Environ, 104*(16),133–146. https://doi.org/10.1016/j.rse.2005.11.016

Deng, J. Y., & Wong, N. H. (2020). Impact of urban canyon geometries on outdoor thermal comfort in central business districts. Sustain. *Cities Soc., 53*(10), Article 101966. https://doi.org/10.1016/j.scs.2019.101966

Giridharan, R., Lau, S. S. Y., Ganesan, S., & Givoni, B. (2007). Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong. *Building and Environment, 42*(19), 3669–3684. https://doi.org/10.1016/j.buildenv.2006.09.011

Habitzreuter, L., Smith, S. T., & Keeling, T. (2019). Modelling the overheating risk in a uniform high-rise building design with a consideration of urban context and heatwaves. *Indoor Built Environ, 29*(5), 133–146. https://doi.org/10.1177/1420326X19856400

Kakon, A. N., Mishima, N., & S. Kojima. (2009). Simulation of the urban thermal comfort in a high density tropical city: Analysis of the proposed urban construction rules for Dhaka, Bangladesh. *Building Simulation, 2*, 2915–305. https://doi.org/10.1007/s12273-009-9321-y

Krüger, E. L., Minella, F. O., & Rasia, F. (2011). Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. *Building and Environment, 46*(3), 621–634. https://doi.org/10.1016/j.buildenv.2010.09.006

Lee, H., Mayer, H. & Chen, L. (2016). Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany. *Landscape and Urban Planning, 148*(12), 37–50. https://doi.org/10.1016/j.landurbplan.2015.12.004

Nasrollahi, N., Hatami, Z., & Taleghani, M. (2017). Development of outdoor thermal comfort model for tourists in urban historical areas; A case study in Isfahan. *Building and Environment, 125*(11), 356–372. https://doi.org/10.1016/j.buildenv.2017.09.006

Natanian, J., Maiullari, D., Yezioro, A., & Auer, T. (2019). Synergetic urban microclimate and energy simulation parametric workflow *Journal of Physic: Conference Serires, 1343*, Article12006. https://doi.org/10.1088/1742-6596/1343/1/012006

Oliveira, V., & Silva, M. (2017). Urban form and energy demand: A review of energy-relevant urban attributes. *Journal of Planning Literature, 32*(4), 15–26. https://doi.org/10.1177/0885412217706900

Palme, M., Inostroza, L., Villacreses, G., Lobato-Cordero, A., & Carrasco, C. (2017). From urban climate to energy consumption. Enhancing building performance simulation by including the urban heat island effect. *Energy and Buildings,145*(5), 107–120. https://doi.org/10.1016/j.enbuild.2017.03.069\

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. *Sustainable cities and society, 39*(12), 16–36. https://doi.org/10.1016/j.scs.2018.02.004

Pisello, A. L. (2017). State of the art on the development of cool coatings for buildings and cities. *Solar Energy, 144*(14), 660–680. https://doi.org/10.1016/j.solener.2017.01.068

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. *Sustainable Cities and Socities, 26*(12), 318–343. https://doi.org/10.1016/j.scs.2016.07.005

Santamouris, M., Gaitani, M., Spanou, A., Saliari, M., Giannopoulou, K., Vasilakopoulou, K., & Kardomateas, T. (2012). Using cool paving materials to improve microclimate of urban areas–Design realization and results of the flisvos project. *Building and Environment, 53*(12), 128–136. https://doi.org/10.1016/j.buildenv.2012.01.022

Santamouris, M., Cartalis, C., Synnefa, A., & Kolokotsa, D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings-A review. *Energy and Buildings, 98*(8)119–124. https://doi.org/10.1016/j.enbuild.2014.09.052

Shi, Z. (2020). *Energy-driven urban design at the district scale for tropical high-density cities* [Doctoral dissertation, nETH Zurich]. https://doi.org/10.3929/ethz-b-000447096

Srivanit, M. & Jareemit, D. (2020). Modeling the influences of layouts of residential townhouses and tree- planting patterns on outdoor thermal comfort in Bangkok suburb. Journal of *Building and Engineering, 30*(25),101–262. https://doi.org/10.1016/j.jobe.2020.101262

Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities? *Environment Health Perspective, 118*(10),1425–1428. https://doi.org/10.1289/ehp.0901879

Sun, Y., Heo, Y., Tan, M., Xie, H., Wu, C. F. J., & Augenbroe, G. (2014). Uncertainty quantifcation of microclimate variables in building energy models. *Journal of Building Performance Simulation, 7*(1), 17–32. https://doi.org/10.1080/19401493.2012.757368

Taleghani, M., Kleerekoper, L., Tenpierik, M., & van den Dobbelsteen, A. (2015). Outdoor thermal comfort within five different urban forms in the Netherlands. *Building and Environment, 83,* 65–78. https://doi.org/10.1016/j.buildenv.2014.03.014

Wei, R., Song, D., Wong, N. H., & Martin, M. (2016). Impact of urban morphology parameters on microclimate. *Procedia Engineering, 169*,142–149. https://doi.org/10.1016/j.proeng.2016.10.017

Xu, X., Liu, Y., Wang, W., Xu, N., Liu, K., & Yu, G. (2020). Urban layout optimization based on genetic algorithm for microclimate performance in the cold region of China Appl. *Science, 9*(22), Article 4747. https://doi.org/10.3390/app9224747

Yahia, M. W., Johansson, E., Thorsson, S., Lindberg, F., & Rasmussen, M. I. (2018). Effect of urban design on microclimate and thermal comfort outdoors in warm-humid Dar es Salaam, Tanzania. *International Biometeorology, 62*, 373–385. https://doi.org/10.1007/s00484-017-1380-7

Yin, C., Yuan, M., Lu, Y., Huang, Y., & Liu, Y. (2018). Effects of urban form on the urban heat island effect based on spatial regression model. *Science of Total Environment, 634*, 696–704. https://doi.org/10.1016/j.scitotenv.2018.03.350