THE IMPACTS OF URBAN MORPHOLOGY ON OUTDOOR AIR TEMPERATURE CASE STUDY: THE CENTER AREA OF HOI AN CITY, VIETNAM

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Abstract - Assessing the impact of urban morphology on the outdoor air temperature in a tourism city in central Vietnam – Hoi An – is a primary objective of this study. The research process is carried out by a variety of methods including in situ surveys, measuring with temperature measuring devices, data analysis, and map analysis. Four outdoor positions, located in two areas with different urban forms, were selected for measurement within 12 hours to investigate the differences in outdoor air temperature. The impact of urban morphology on outdoor air temperature was thereafter determined. Based on these empirical measurements and data collected, the paper addresses solutions to improve urban morphology for reducing the urban air temperature.

Key words - Urban morphology; urban heat island; urban air temperature; outdoor air temperature.

Tóm tắt - Đánh giá tác động của hình thái đô thị đến nhiệt độ không khí ngoài trời tại thành phố du lịch miền Trung Việt Nam – thành phố Hội An – là mục tiêu chính của nghiên cứu này. Quá trình nghiên cứu được thực hiện bằng nhiều phương pháp bao gồm khảo sát tại chỗ, đo đạc bằng các thiết bị đo nhiệt độ, phân tích dữ liệu và phân tích bản đồ. Bốn vị trí ngoài trời, nằm ở hai khu vực có hình thái đô thị khác nhau, đã được chọn để đo đạc trong vòng 12 giờ nhằm khảo sát sự khác biệt về nhiệt độ không khí ngoài trời. Tác động của hình thái đô thị lên nhiệt độ không khí ngoài trời sau đó đã được xác định. Dựa trên các phép đo thực nghiệm và dữ liệu thu thập được, bài báo đề cập đến các giải pháp cải thiện hình thái đô thị để giảm nhiệt độ không khí đô thị.

Từ khóa - Hình thái đô thị; đảo nhiệt đô thị; nhiệt độ không khí đô thị; nhiệt độ không khí ngoài trời.

1. Problematic

According to Middel, A. et al., urban morphology is one of the main factors driving climate change on a local and microscale in the city [1]. The other studies on urban morphology also show that the spatial heterogeneity of the city influences air temperature [2], ground temperature [3], ventilation [4], etc. at the urban canopy layer. The technical parameters of the microclimate have a close connection to energy consumption [5] and the physical shape of urban morphology [6], [7].

Therefore, urban morphology is one of the key factors affecting regional climate conditions. To restrict the phenomenon of "urban heat island" in city center areas, solutions related to urban morphology are eternal of primary concern. Hoi An Ancient Town is likened to a living museum in the heart of the city. Every year, it greets plentiful visitors from all over the world. The development of tourism has promoted this unique heritage, but the city also faces potential risks due to rapid but poor-quality infrastructure development, incoherent and sporadic planning between old and new areas [8]. In addition, Hoi An also attracts residents in neighboring areas to converge on the city center for business and living. For that, the construction density is increasing quickly. The green space is shrinking to give sit to residential land, business land, and production land. This land-use conversion gains a significant contribution to the increase in urban air temperature and surface temperatures. Recognizing the aforementioned issues, this study focuses on assessing the impact of urban morphology on outdoor air temperature. In this study, two research areas in Hoi An are proposed: the old town and the new city. Morphological analysis of the two areas helps to understand the characteristics and morphology of each area, thereby help to make comments on their advantages and disadvantages. Secondly, attempts are made to conduct surveys and measurements to estimate the impact of surrounding urban morphology on the outdoor air temperature in each area. The research results provide the basis for proposing solutions on urban morphology to improve local climate conditions, bringing comfort in outdoor temperature to people.

2. Research methods

The survey and measurement period for this paper is within July 2022 - one of the hottest months of the year in Hoi An. Limiting the adverse impact of heat on buildings and urban areas is a top requirement in design and urban planning. Therefore, July was selected to carry out survey and temperature measurement. The work consists of two main phases. The first phase is a morphological survey of two urban areas in Hoi An City, including the old town area and the new city area. The methods utilized during this period include site surveys, measuring road and pavement widths, and analyzing the collected image/map data. The second phase is monitoring and measuring outdoor air temperature directly at four positions in these two survey areas. In this phase, the research methods include site survey, measure temperature, and analysis of the temperature data obtained. Two measurement positions in the old town area are right in front of the vernacular houses at 80 and 129 Tran Phu street. The two measurement positions in the new city area are in front of houses at 259 and 296 Nguyen Duy Hieu street. The survey period of the second phase lasted 12 hours from 8:00 to 20:00 on July 27, 2022. The object of monitoring is the outdoor air temperature, and the monitoring device is described in Table 1.

Table 1. *Monitoring devices and specifications*

Measurement parameters	Device name	Measuring range	Resolution	Accuracy	Made in
Outdoor air temperature	Electronic thermometer hygrometer BEURER HM16	0 - 50ºC and 20 - 95%	0.1ºC and 1%	±0.1ºC and ±2%	Germany

Monitoring equipment is placed at the contiguous position between the roadway and the pavement, and at an altitude of 1.1 meters above the road surface. It is to ensure that the recorded temperature is air temperature instead of road surface temperature. Besides, the temperature monitoring device is always placed in the shade during the measurement. This will ensure that the measured temperature is the actual air temperature, instead of the temperature of the thermometer itself under direct solar radiation. This setting is depicted in Figure 1.

Figure 1. *Illustrate the arrangement of monitoring equipment at the 4 measurement positions*

In addition, it is necessary to collect outdoor air temperature parameters in Hoi An at the meteorological station to compare this parameter with those obtained during direct measurement. However, there is no meteorological station in Hoi An. Therefore, the outdoor air temperatures from two meteorological stations belonging to Da Nang Airport and Chu Lai Airport (Quang Nam Province) are collected. Then, applying the calculation method "Inverse Distance Weight" (IDW) to be able to infer outdoor air temperature data in Hoi An. The calculation will be presented in detail in Section 3.2.

3. Main results of the study

3.1. The Urban morphology of Hoi An City

There are two areas selected for survey and measurement in this study (Figure 2). The first area is Tran Phu street in Hoi An Ancient Town. This is the oldest street in the old town. It still retains the street structure and vernacular buildings with the highest age. Therefore, Tran Phu street can be seen as a representative of the urban morphology in Hoi An Ancient Town. On this street, there are two selected positions for measurements: Position 1 (P1) is in front of Trading Ceramics Museum at 80 Tran Phu street (House A) and Position 2 (P2) is in front of Duc An House (House B) at 129 Tran Phu.

Nguyen Duy Hieu street is the second area selected for the research. This street is a continuation road of Tran Phu street and runs to the East of Hoi An. Nguyen Duy Hieu Street as well as other roads adjacent to the old town buffer area, they must comply with the construction regulations of the Cultural Heritage Law of the Hoi An People's Committee Statute. Therefore, the urban morphology of Nguyen Duy Hieu street can represent the streets in the new city area of Hoi An. Two positions for measurements are selected on this street: Position 3 (P3) is in front of the house at 259 Nguyen Duy Hieu (House C) and Position 4 (P4) is in front of the house at 296 Nguyen Duy Hieu (House D).

The characteristics of the two urban areas are reflected through the two selected streets, so the morphology of these streets is carefully investigated. In addition, the two survey and measurement areas were selected based on the following three reasons:

- *Geographical location*: the distances between these two surveyed areas to existing river surfaces are similar. Therefore, they will be able to receive similar impacts of river wind and moisture from the river. Moreover, the locations of the surveyed areas are in the center of the city and adjacent to each other, so the differences in weather are not too far apart.

- *Street direction*: the selected streets have the same direction - the East-West direction. So, the impact of the wind and solar radiation on these streets will be equivalent.

- *The contrast between ancient and modern*: the two adjacent areas are without any physical barriers but the differences in age and the planning orientation create different morphologies in the areas. Tran Phu street is the ancientest street in Hoi An Ancient Town, so it brings out most of the characteristics of the old town while Nguyen Duy Hieu street has a modern trend.

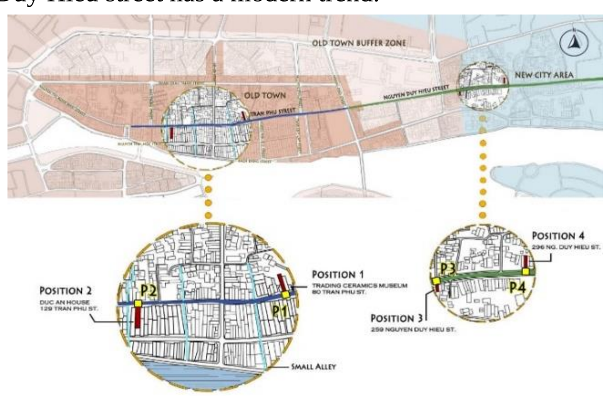

Figure 2. *Illustrate the position of four temperature monitoring devices (the yellow squares on the map)*

There are two methods of analyzing and researching urban morphology that are of most concern today: the traditional method and the Space Syntax method. The traditional methods are significantly influenced by the Conzenian and Muratorian schools [9]. Meanwhile, the Space Syntax method can efficiently quantify the spatial configuration to help categorize cities according to their street patterns [10]. Traditional methods are applied in morphological analysis in this research to analyze the general plan, street façade, and street cross-section. The urban morphology survey scope is limited to a radius of 50 meters around the four measurement positions.

With a survey radius of 50 meters at each measurement position, it is not completely express the constituent elements of urban morphology such as nature, topography, and general plan. However, the two selected areas are adjacent to each other, so the difference in these factors is not significant. In addition, the primary purpose of this study is to analyze the impact of urban morphology on air temperature, so urban morphological factors that significantly affect temperature are all mentioned as follows: construction density, trees in general plan, roof material, street façade materials and street width.

3.1.1. Analysis of the general plan

- *Construction density*: Figure 3 shows the construction area, streets, yards, natural ground, etc. In the surveyed area around P2, most of this area is only for construction. In the area around P1, construction density there is still dense, although there are a few empty lands. The areas around P3 and P4 have sparser construction density, wider streets, more yards and vacant land. Based on the pixel calculation method by computer software, the construction area of each study area around houses A, B, C and D were determined as shown in Table 2.

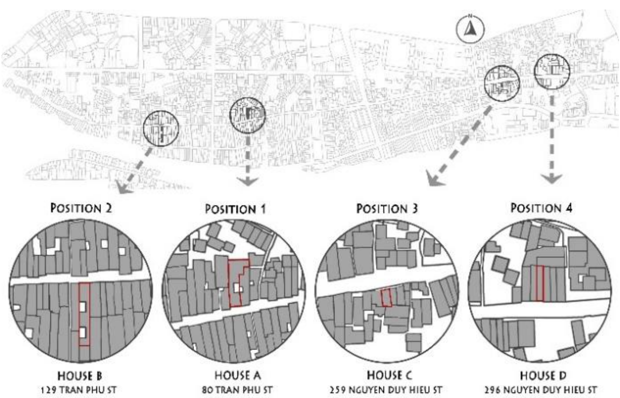

Figure 3. *Diagram of land use within a radius of 50 meters around the measuring positions*

Table 2. *Construction density within a radius of 50 meters around the measuring positions*

	Total area (m2)	Constructio n area (m2)	Construction density (%)	Number of buildings
Area around P1	7,853	6,041	76.9%	51
Area around P2	7,853	6,908	88%	45
Area around P3	7,853	4,874	62.1%	49
Area around P4	7,853	4,320	55%	28

A denser building density reduces the sky's openness and adversely affects the urban thermal environment [11]. Buildings are obstacles that reduce wind speed and alter heat convection [12]. As the building density increases, the area available for natural surfaces such as vegetation, water surfaces, etc. decreases. Solar radiation is absorbed by artificial surfaces on earth (roofs, walls, glass doors, pavements, etc.). These artificial surfaces store and reflect into the surrounding atmosphere, increasing urban temperatures [13]. Thus, surveyed areas with different building densities will form different local microclimates. If one considers only the aspect of temperature under the influence of construction density, the local urban temperature at P1 and P2 (old town area) will be higher than at P3 and P4 (new city area).

- *Map of tree positions in general plan*: Vegetation on the ground (like grass, shrubs, trees) or roof vegetation is seen as a solution to decrease the indoor cooling load demand, improve outdoor comfort and reduce urban heat island phenomenal [14]. In urban areas, the effects of evapotranspiration and shading of plants can significantly reduce the amount of heat generated by the re-radiation between building facades and other hard surfaces (road surfaces, gates, billboards, etc.) [15]. According to results from an experimental study, tree shading can reduce global temperatures by 5-7 °C and air temperatures by 1-2°C [16]. It suggests that trees play a great and possibly increasing role in keeping people comfortable in cities.

Figure 4. *Map of tree position within a radius of 50 meters around the measuring positions*

Figure 4 shows the distribution of canopy trees and climbing plants in the areas 50 meters around four measuring positions. Data of the tree were collected by us based on in situ surveys. Dark green represents canopy trees, light green represents climbing plants. The size of dots indicates the relative size of the canopies in the general map. Based on the map, it was realized that the old town area has fewer trees than the new city area. There are extremely few trees on both sides of Tran Phu street, mainly climbing plants. The shortage of vegetation and natural covering on this area's surface can lead to the urban heat island phenomenon. On Nguyen Duy Hieu street, there are many trees along both sides of the road, the trees there obtain broader coverage than the trees on Tran Phu street. Thus, the tree shading density in the new city area is higher than in the old town. This is also a factor that contributes to cooler air temperatures in the new city area than in the old town. If one considers only the aspect of temperature under the influence of greenery, the urban air temperature at P1 and P2 will be higher than at P3 and P4.

- *Roof materials*: Two types of roofs used in the surveyed areas: sloped roofs and flat roofs. The sloped roof is made from three kinds of materials as corrugated iron, fibre cement, and clay tile. The flat roof is poured with concrete (Figure 5). In 2010, Urban, B. & Roth, K. performed a comparative experiment on the surface temperatures of traditional dark roofs and cool white roofs on a sunny afternoon [17]. The obtained temperatures show that traditional dark roofs are much hotter than cool white roofs at 66.2°C and 32.2°C respectively. For roof materials that absorb most of the solar radiation, then, they release heat into the atmosphere and make the air warmer. At this time, these roofs act as a motivating agent for the urban heat island phenomenon [18]. Therefore, using the roof material with higher solar reflectivity (higher albedo) is considered a solution to restrict urban heat islands [19].

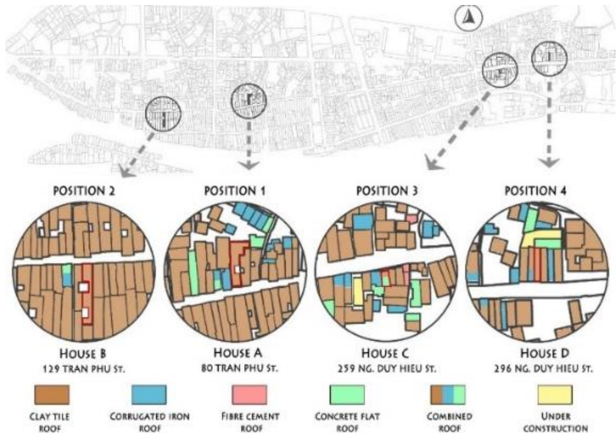

Figure 5. *Roof materials of buildings within a radius of 50 meters around the measuring positions*

Table 3 shows the quantity and percentage of kinds of roof materials used within a radius of 50 meters around four measuring positions. In which, buildings roofed with clay tiles account for the highest proportion compared to the remaining materials. The next most popular materials in these areas are corrugated iron and concrete. These three materials have a low albedo index including 0.10–0.13 for clay tiles (red or brown), 0.1–0.35 for concrete, and 0.1–0.16 for corrugated iron [20]. Therefore, these roof materials will contribute to the increase in urban air temperature.

Table 3. *Roof materials of buildings around four measuring positions*

Materials	Area P1		Area P2		Area P3		Area P4	
Clay tile	38	74.5%	44	97.8%	33	65.3%	16	57.2%
Corrugated iron	9	17.6%	0	0%	6	12.2%	6	21.4%
Fibre cement	0	0%	0	0%	3	6.1%	0	0%
Concrete	3	5.9%	0	0%	4	8.2%	2	7.1%
Combined	1	2%	1	2.2%	3	6.1%	3	10.7%
Under construction	0	0%	0	0%	1	2.1%	1	3.6%

However, according to research by Nguyen A. T. et al., the clay tiles roof is suitable for hot and humid local climates [21]. It can absorb moisture at night and release it during the daytime, especially the time with the firm activity of solar radiation, to cool roofs. Another study also proved that the thermal performance of the clay tile in its natural albedo acts as cool as its counterpart coated cool tile [22]. Thus, although the clay tile roofs in the survey areas are dark color roofs (under the impact of time and climate), they are still considered to be a cool material. These clay tile roofs are unresponsible for indoor and urban air temperature rise.

Therefore, if only considering the effect of roof material on air temperature, the measuring positions P3 and P4 in the new city area will have higher air temperature than the two positions P1 and P2 in the old town.

3.1.2. Analysis of the street façade materials

Figure 6 shows the main kinds of materials used on the façade of buildings within 100 meters at four measuring positions. The front façades of vernacular houses on Tran Phu street are built of bricks or wood. Several glass windows with metal/wooden frames appear scattered in area P1. Besides, most of the façades of modern terraced buildings on Nguyen Duy Hieu street are built of modern materials, such as brick, concrete, glass window (doors) with wooden or metal frames, and steel folding doors.

Figure 6. *Statistics of materials used in the 100 meters street façade around four measuring positions*

Currently, much research is done on the impact of building materials on indoor temperature. However, studies on the impact of building facade materials on urban air temperature have not appeared much. According to Wonorahardjo et al., to determine the cooling load and temperature of an area, these factors should be considered: the surface covering material of that area (road surface, roof, building facade, etc.), building height and distance between buildings [23]. Another research states that the vertical faces of a building's envelope have an impact on limiting heat gain, and this will affect both the building's indoor and outdoor temperature of the area where the building is located [24].

As in Figure 6, it is noticed that the buildings around P1 and P2 have one to two floors. Most of the buildings around P3 and P4 also have one to two floors, a few 3-story buildings, and only one 4-story building. Therefore, most of the buildings in the two survey areas are low-rise buildings (Following the limitation of construction height regulations of the People's Committee of Hoi An City). In his study, Abrahem et al. affirmed that the façade material of high-rise buildings had a significant impact on thermal comfort, whilst in the case of low-rise buildings, the impact was minor [25]. Indeed, Madina et al. also stated that, for low-rise buildings, the roof surface captures more heat from direct solar radiation than the wall surface [26]. Therefore, according to the above studies, façade materials of low-rise buildings in the survey areas do not affect the urban air temperature too much.

3.1.3. Analysis of the street cross-section

Figure 7 shows the street cross-sections at the four measuring positions. It is recognized that the width (including sidewalks) of Nguyen Duy Hieu street (about 11.7 meters) is larger than Tran Phu street (from 6.1 – 7.0 meters). According to Boukhabla, et al., open streets promote air movement and enhance street cooling better than narrow streets [27]. Besides, thanks to the large road width, it is easy to dissipate heat radiation, enhance ventilation, and drop air temperature faster at night, etc. In the old town, the movement of people on Tran Phu street is basically by walking. The number of tourists visiting Hoi An Ancient Town is increasingly crowded, so the amount of heat generated in the old town area is quite large. Conversely, sightseeing activities do not take place strongly on Nguyen Duy Hieu street. In addition, people use vehicles to travel, and the traffic is not crowded, so heat accumulation in this area is minimized.

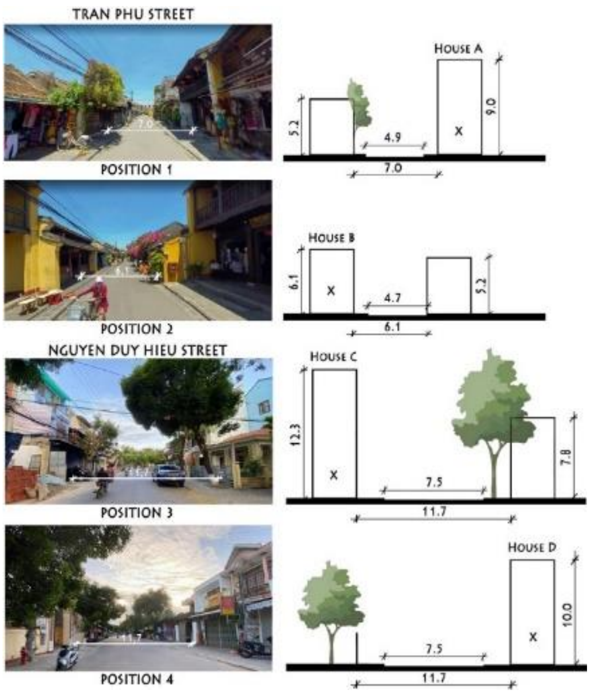

Figure 7. *Cross-section of streets at the four measuring positions*

3.2. Calculating climate in Hoi An by Interpolation method - Inverse Distance Weight (IDW)

Spatial interpolation is the process of calculating the value of unknown points from known points by a mathematical function or a mathematical method. Currently, there are many different interpolation algorithms, and they have their own strengths. It can be classified in the following ways: point interpolation/ surface interpolation, comprehensive interpolation/ local interpolation, and exact interpolation/approximate interpolation. However, this research only mentions the popular interpolation method in Arc GIS which is Inverse Distance Weight (IDW). The IDW method determines the value of unknown points by calculating the average distance weight of the known values points in the vicinity. The further from the calculating point, the less effective on the result the point is. Figure 8 illustrates the distances from Hoi An City to Da Nang International Airport and Chu Lai Airport as 23.65 km (d1) and 64.86 km (d2), respectively.

Figure 8. *Diagram of the distance between Da Nang, Hoi An, and Chu Lai*

This linear formula is applied to calculate the climate parameters of Hoi An. The below formula calculates the temperature at any point in Hoi An. Other climatic parameters are calculated similarly.

If $t^{o}_{DaNang} < t^{o}_{ChuLai}$ then $t^{o}_{HoiAn} = t^{o}_{DaNang} + (|t^{o}_{DaNang} - t^{o}_{ChuLai}| \times Frac_1)$

Else : $t^{o}_{HoiAn} = t^{o}_{ChuLai} + (|t^{o}_{DaNang} - t^{o}_{ChuLai}| \times Frac_2)$

In which: $Frac_1 = d_1/(d_1+d_2)$; $Frac_2 = d_2/(d_1+d_2)$

Based on the data obtained from two meteorological stations at Da Nang International Airport and Chu Lai Airport, and applying the above calculation formula, the results obtained are temperature data in Hoi An (Table 4).

Table 4. *Hoi An temperature data by calculation of IDW (°C)*

Time	Da Nang	Chu Lai	Hoi An
8:00	30.6	28.8	30.12
10:00	33.6	32.4	33.28
12:00	34.7	31.9	33.95
14:00	34.6	32.0	33.91
16:00	33.6	32.7	33.36
18:00	30.0	31.2	30.32
20:00	29.5	29.0	29.37

3.3. Field measurement work

Table 5 and Figure 9 present the results of live measurements at four measurement locations, and Hoi An's meteorological temperature through the IDW calculation method. It is easy to see that the air temperature at most of the measuring positions is higher than Hoi An's meteorological temperature, about 7-8°C during the peak of the heat from 10:00 to 14:00. This temperature difference decreases gradually at night. Besides, the graph shows that the temperature at P2 is the highest of all measuring positions. Followed by P1 with the number of hours with a higher temperature than P3 and P4 is 10 hours out of a total of 12 survey hours. From 8:00 to after 13:00, the temperature at P3 is lower than at P4. However, from 13:00 to 20:00, P3 has a higher temperature.

***Table 5.** Temperature by direct measurement at P1, P2, P3, P4 and Hoi An temperature by calculation of IDW (°C)*

Time	**8:00**	**10:00**	**12:00**	**14:00**	**16:00**	**18:00**	**20:00**
Pos. 1	35.03	40.73	41.03	38.60	33.50	33.07	30.97
Pos. 2	34.57	41.33	41.50	40.83	35.40	33.13	30.77
Pos. 3	34.42	36.67	38.97	40.20	34.37	31.80	30.40
Pos. 4	34.10	39.57	40.63	39.67	33.10	31.43	30.23
Temp IDW	30.12	33.28	33.95	33.91	33.36	30.32	29.37

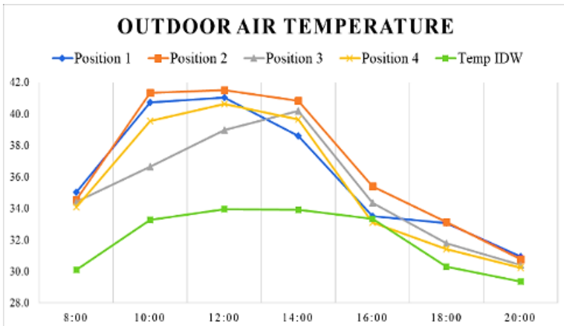

***Figure 9.** Temperature at 4 measuring positions and Hoi An's meteorological temperature*

Measuring positions P1, P2 and P4 have similar temperature fluctuations. From 8:00 to 10:00, the temperatures at these three positions increase rapidly. From 10:00 to 14:00, the temperature does not fluctuate much, with an amplitude ranging from 0.5°C to 2.13°C depending on the measurement location. The maximum temperature time at P1, P2, and P4 is at 12:00 with 41.03°C, 41.50°C, and 40.63°C, respectively. Meanwhile, the temperature at P3 increased steadily from 8:00 to 14:00 and peaked at 40.20°C at 14:00. After 14:00, the outdoor air temperature starts decreasing rapidly.

From 14:00 to 16:00, the temperature recorded at two measuring positions P1 and P4 were lower than that at P2 and P3. In which, the temperature at P2 is the highest, followed by the temperature at P3. Although the urban morphology around the measuring position P3 and P4 has a temperature advantage over that around P1 and P2, the recorded temperature gives the opposite result. The temperature at P3 is higher than at P1 during this period. The reason for this contradiction is because of the location of the instrumentation. Measuring position P1 is located right in front of house A - with the main facade facing South East. Meanwhile, P3 is located in front of house C – with the main facade facing North West (Figure 10). From 14:00 to 16:00, the sun gradually moves to the northwest. The area around P1 is shielded by buildings, so it is less affected by solar radiation than the area around P3.

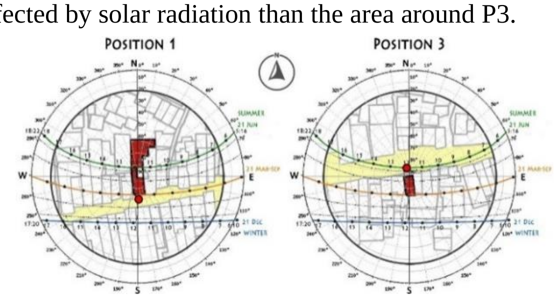

***Figure 10.** Location of P1, P3 and the sun chart*

By 16:00, most of the measurement locations reached the same or lower temperature than at 8:00 at the same position (except P2). Besides, at this time, the temperature at P1 and P4 are approximately the same as Hoi An's meteorological temperature. However, the temperature at P1 decreased slowly and reached the same temperature as P2 at 18:00 and 20:00. At 20:00, when there is no longer much influence from solar radiation, the temperature difference between measurement locations is narrowed. Thus, during most of the survey period, the outdoor air temperature background at P1 and P2 in the old town area is higher than the outdoor air temperature at P3 and P4 in the new city area. Besides, the heat dissipation rate at night at P1 and P2 is also slower than at P3 and P4.

3.4. The impacts of urban morphology on outdoor air temperature

In recent years, urban microclimate and outdoor thermal comfort have received significant attention in the urban planning and design process. To assess outdoor thermal comfort, researchers often use indicators such as Physiologically Equivalent Temperature (PET) [28], Universal Thermal Climate Index (UTCI) [29], Predicted Mean Vote (PMV) [30], etc. Some studies use urban microclimate simulation method [31-32], while other studies provide information on the influence of urban design on microclimate variables such as air temperature [33], surface temperature [34]. This research was limited to examining the impact of urban morphology on outdoor air temperature.

This paper simultaneously researches parameters of urban morphology on a three-dimensions approach including general plan, street façade and street cross-section. These parameters of urban morphology in the surveyed areas are synthesized and compared with each other. From these analyses, we can assess the beneficial or adverse effects on the outdoor air temperature. The urban morphology parameters in the two surveyed areas are summarized in Table 6. This table provides a broader view of the difference in the urban morphology between the ancient town and modern urban areas. The contents of the table are extracted from the analysis in section 3.1.

***Table 6.** Statistics of urban morphology parameters in the surveyed areas*

	Urban morphology parameters	**The ancient town**		**The modern area**	
		Around P1	**Around P2**	**Around P3**	**Around P4**
General plan	Construction density	76.9%	88%	62.1%	55%
	Map of trees	- Sparse density - Climbing plants & potted plants	- Sparse density - Climbing plants & potted plants	- Denser density - Canopy trees	- Denser density - Canopy trees
	Roof material	74.5% Clay tile roof	97.8% Clay tile roof	65.3% Clay tile roof	57.2% Clay tile roof
Street façade	Façade material	wooden, brick	wooden, brick	brick, glass	brick, glass
Street cross-section	Street width	7.0 m	6.1 m	11.7 m	11.7 m

The positive and negative impacts of urban morphology parameters on the surveyed areas have been compiled. In order to facilitate for the assessment and comparison of urban morphology in these surveyed areas, we propose the following hypotheses and regulations:

- It is hypothesized that the levels of impact of the 5 urban morphology parameters on urban air temperature are similar.

- The method of calculating the rating scale for the parameters will arrange from low to high positive impact, corresponding to points from 1 to 4.

- In case there is no difference or insignificant difference in the impact level of any parameter in the survey areas, the rating scale is 0 for all areas.

The minimum and maximum scores that an area can receive through the assessment of positive impacts from the 5 urban morphology parameters of that area are 4 and 14, respectively. Based on the difference between these two scores, we classify the quality of urban morphology into 4 levels, as shown in Table 7.

Table 7. *Quality classification of urban morphology*

Quality classification of urban morphology	Positive impact scores
Very good	13 - 14
Good	10 - 12
Normal	7 - 9
Poor	4 - 6

Table 8 presents the results of assessing the quality of urban morphology in four areas around P1, P2, P3 and P4. The "total" value is the score summarizing the positive impact level of 5 urban morphology parameters on each surveyed area. This value is only intended to observe disparities between the urban areas. When this "total" value is high, it means that the area receives a lot of positive effects from urban morphology, and the urban temperature in that area is more comfortable than in the other areas with the low "total" value.

Table 8. *Assessment and comparison of the urban morphology parameters in the surveyed areas*

<table>
<tr><th rowspan="2"></th><th rowspan="2">Urban morphology parameters</th><th colspan="2">The ancient town</th><th colspan="2">The modern area</th></tr>
<tr><th>Around P1</th><th>Around P2</th><th>Around P3</th><th>Around P4</th></tr>
<tr><td rowspan="3">General plan</td><td>Construction density</td><td>2</td><td>1</td><td>3</td><td>4</td></tr>
<tr><td>Map of trees</td><td>1</td><td>1</td><td>2</td><td>2</td></tr>
<tr><td>Roof material</td><td>3</td><td>4</td><td>2</td><td>1</td></tr>
<tr><td>Street façade</td><td>Façade material</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Street cross-section</td><td>Street width</td><td>2</td><td>1</td><td>3</td><td>3</td></tr>
<tr><td>Total</td><td></td><td>8</td><td>7</td><td>10</td><td>10</td></tr>
</table>

Through these scores, we comment that the urban area around P2 and P1 has the lowest score of 7 and 8, respectively. According to table VII, the quality of urban morphology around P2 and P1 is in normal level. The area around P3 and P4 have the same score of 10, so the urban morphological quality around P3 and P4 is rated as good level. Therefore, the area around P1 and P2 will have the higher urban temperature. The area around P3 and P4 will have the most comfort temperature condition.

4. Conclusions and recommendations

4.1. Conclusions

The focus of this study is the analysis of urban morphology in the measurement areas (around P1, P2, P3, and P4) to assess the influence of urban morphology on urban air temperature. The urban morphology of these areas is analyzed under the perspective of three-dimensional space, including the general plan, street façade, and street cross-section of urban streets. There are five parameters of urban morphology used as criteria to evaluate and compare the survey areas: building density, map of trees, roof material, street façade materials, and street cross-section. Through these criteria, this study indicates the advantages and disadvantages of each area.

There are some disadvantages in the old urban area, the areas around P1 and P2, such as a narrow street that restricts air circulation; lack of greenery that increases the air temperature and ground temperature; and receiving many tourists - an objective factor contributing to the increase in urban heat. On the contrary, areas around P3 and P4 have a wide street, lower construction density, and denser density of trees that reduce the impact of sunlight on the urban surface and limit the accumulation of urban heat. Besides, these modern areas are not tourist attractions places. So, these are advantages that contribute to the urban cooling of areas around P3 and P4.

However, the urban form around P1 and P2 also has its advantages. The roof materials around these two positions are mostly clay tiles, which are considered to be a cool material and suitable for hot and humid local climates. Meanwhile, in the modern area around P3 and P4, the roof materials used are more diverse, including clay tiles (mostly), concrete, and corrugated iron. Concrete roofs and corrugated iron roofs with low albedo are responsible for the increase in urban air temperature in this area.

4.2. Recommendations

Some recommendations that are suitable to apply to these study areas to improve urban morphology:

- Encouraging residents to build and renovate houses in the direction of reducing net construction density, such as increasing the area of the front yard, courtyard, and backyard. If each house in urban areas equips itself with one or more ecological cores, the whole street block will form a green belt. At these ecological cores, homeowners are encouraged to plant trees, grass, or natural ground to reduce the heat absorption capacity of urban surfaces. Thus, each house will contribute to lowering the building density, the surface temperature, the urban air temperature, and increasing the density of green space for the area.

- Using of materials with high albedo for external walls, roofs, sidewalks, etc. This is a solution commonly used to reduce urban surface temperatures, the cooling load of the building, and reduce the air temperature at 1.75 meters above the ground [35].

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