

Original scientific paper

The Impacts of Urban Morphology on Housing Indoor Thermal Condition in Hoi An City, Vietnam

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ARTICLE INFO:

Article History:

Received 20 July 2020

Accepted 25 August 2020

Available online 14 September 2020

Keywords:

Urban Morphology;
Indoor Thermal Condition;
Ancient Town;
Vernacular House;
Modern Terraced House.

ABSTRACT



Assessing the impact of urban morphology on the indoor thermal condition of housing in a tourism city in central Vietnam — Hoi An City is the main objective of this study. The research process is carried out by a variety of methods including in situ surveys, measuring with temperature sensors, data analysis and map analysis. Four houses, located in two areas with different urban forms, were selected for measurement within one month to investigate the differences in housing indoor temperature. The impact of urban morphology on housing was thereafter determined. Temperature sensors were permanently installed in 4 houses; based on these empirical measurements and data collected, the paper addresses solutions to improve urban morphology and indoor thermal condition.

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JOURNAL OF CONTEMPORARY URBAN AFFAIRS (2021), 5(2), 183-196.

<https://doi.org/10.25034/ijcua.2021.v5n2-4>

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1. Introduction

Hoi An City is located in central Vietnam, with severe weather amidst diverse natural disasters. Therefore, the life of the people there is very difficult. The city has an ancient town and in 1999, it was recognized as a world cultural heritage by UNESCO. Since then, Hoi An tourism has grown rapidly and it became an international tourism destination. 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

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How to cite this article:

Luu, T. H., Rojas-Arias, J., & Laffly, D. (2021). The Impacts of Urban Morphology on Housing Indoor Thermal Condition in Hoi An City, Vietnam. *Journal of Contemporary Urban Affairs*, 5(2), 183-196. <https://doi.org/10.25034/ijcua.2021.v5n2-4>



(Do & Phan, 2018; Jones, 2002; Hong Nguyen, 2016). The Inconsistencies in the planning orientation entailed many consequences which include amongst others an uneven population distribution, increased construction density in the central areas and increased urban pressure on the historical relic.

Boukhabla, et al. (2013), the open streets promote air movement and enhance street cooling better than the narrow streets. It was reported that the technical parameters of the micro-climate have a close connection to energy consumption (Vallati et al., 2015) and the physical shape of urban morphology (Wei et al., 2016; Racine, 2019). Indeed, the leading concern with housing projects in central of Vietnam is to provide a comfortable temperature environment for residents since, it has a hot humid climate and high temperature year-round (Privitera et al., 2018; Humphreys et al., 2007). Therefore, research on urban morphology in Hoi An and assessing its effects on indoor thermal conditions is the subject of this paper.

In this study, two (2) research areas in Hoi An City have proposed: the old town area and the old town buffer zone. Morphological analysis of the 2 areas helps to understand the characteristics and morphology of each area, thereby also helping in making 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 housing indoor thermal condition in each area. Two houses in each area have temperature sensors installed to monitor the indoor temperature. After a month survey, the results show that indoor temperature in the vernacular houses is higher than in modern terraced houses. This is quite surprising because vernacular houses have been proven to adapt well to local climatic conditions through solutions in materials, orientation, structure and housing form. Therefore, in addition to architectural elements, urban morphology also plays an important role in affecting the housing indoor temperatures. Based on the analysis of the results obtained, the paper addresses solutions to improve urban morphology to lower housing indoor temperature.

2 . Materials and methods

The survey and measurement period for this paper is within June 2019 (one month). The

work consists of two main phases. The first phase is a survey of two (2) urban areas in Hoi An City. The methods used during this period include site surveys; measurements of road widths, pavements, house height; and analyses of the collected image data. The second phase is the installation of indoor temperature measuring devices and data collection on the two houses selected in each of the urban areas. In this phase, the research methods include site survey, installation of measuring equipment, making housing drawings with AutoCAD and analysis of the temperature data obtained.

2.1 The Urban morphology of Hoi An City

2.1.1 Positions of research areas and criteria of their selection

Hoi An Ancient Town is located in Quang Nam Province, Vietnam, a city that has developed over time, captured opportunities and adapted to new changes. Hoi An developed significantly during the period of international commerce in Southeast Asia from the 16th to the 17th centuries with different names such as Fayfo, Faifoo, Faifo, Hoai Pho, etc. Hoi An survived after devastating wars in the late 18th century and it is one of the few places in Vietnam that retained most of the main urban structure (National Committee for the International Symposium on the Ancient Town of Hoi An, 2006).

Hoi An is located on the geology of the accretion area of the Thu Bon River, due to the accretion of the river, which has shaped the appearance of the ancient Town till now. Before the 19th century, Hoi An was a city running along Tran Phu Street. By 1841, the accretion of the river was allowed to open another road, paralleling Tran Phu street to the south (Nguyen Thai Hoc Street today). By 1886, the accretion of the river allowed to open a new road, Bach Dang Street as it is called today, parallel to the two roads. Thus, the old Japanese street corresponds to Tran Phu street now, while the west of the Japanese bridge stretches to the end of Nguyen Thi Minh Khai, which is the Guest Town (Chinese Town) (Showa Women's University Institute of International Culture, 1996).

In fact, in the late 1980s, most of the relics in Hoi An Ancient Town were seriously degraded and in danger of collapsing at any time. Therefore, the conservation project of the Ancient Town of Hoi An was approved by the government in

1997. As a result of establishing the boundary of Hoi An, the city can be divided into two areas:

the old urban area (Hoi An Ancient Town) and the new urban area. (Figure 1)

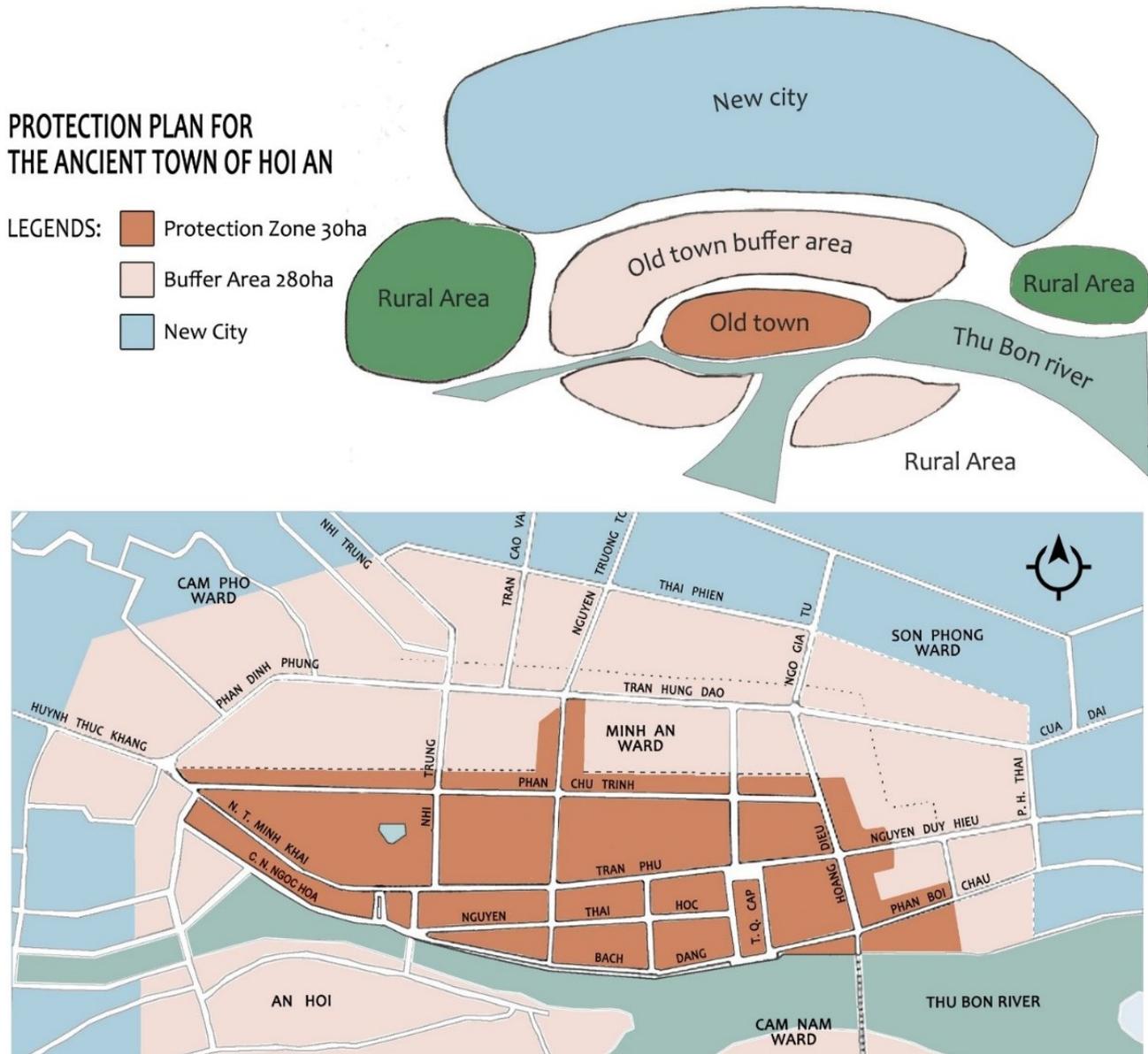


Figure 1. City map of preserving the Ancient Town of Hoi An.

Hoi An Ancient Town belongs to three wards: Minh An, Son Phong and Cam Pho with its length and width being 1000 meters and 300 meters respectively. The town is small but dense with historical buildings, antiquities and a traditional pattern of the street networks of commercial port towns (Hong Nguyen, 2016). Until now, many building types in Hoi An Ancient Town are still used and conserved. The buildings are located on main streets running along with the old town in an East-West direction and on cross streets in a North-South direction. The limits are: East by Hoang Dieu street, West by the intersection between Phan

Chu Trinh street and Nguyen Thi Minh Khai street, South by Bach Dang street and Cong Nu Ngoc Hoa street, and North by Phan Chu Trinh street. New urban areas are also formed by urban expansion due to urban pressures and they are divided into two parts. Part 1, called an old town buffer area, is an urban area with direct access to the old town. This buffer zone has the function of preserving and connecting the old town area with the remaining urban areas. Part 2 is the whole new city on the outside. In addition, there are areas of agriculture (rural area) located nearby but in

the control and joint activities of the whole (Figure 1).

There are two areas selected for surveying: the old town area (Hoi An Ancient Town) and the old town buffer area. In every two areas, a typical road is selected to survey. The first area is the old town area, the road chosen is Tran Phu — the oldest street in Hoi An. On this street, there are two selected vernacular houses for measurements: 80 Tran Phu (House A) and 129 Tran Phu (House B). The second area is the buffer zone of the old town and Nguyen Duy Hieu street is selected. Nguyen Duy Hieu street is a continuation road of Tran Phu street and runs to the East of Hoi An. Two modern terraced houses located at 259 Nguyen Duy Hieu (House C) and 296 Nguyen Duy Hieu (House D) have also been selected. The characteristics of the two urban areas are reflected through the two selected streets, so the morphology of the street is carefully investigated. The measurement of housing indoor thermal conditions of the four selected houses was also conducted with the detailed measurements in section 2.2. The location of the survey and measuring was based on the following three parameters (Figure 2):

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

- **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 oldest 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.

- **The characteristic of building:** the selected streets are in the East-West direction, so the selected houses will have the same directions. House A and House B are the typical vernacular houses in Hoi An Ancient Town in layout, facade form and roof material while, House C, and House D, are modern houses with the common layout and form.

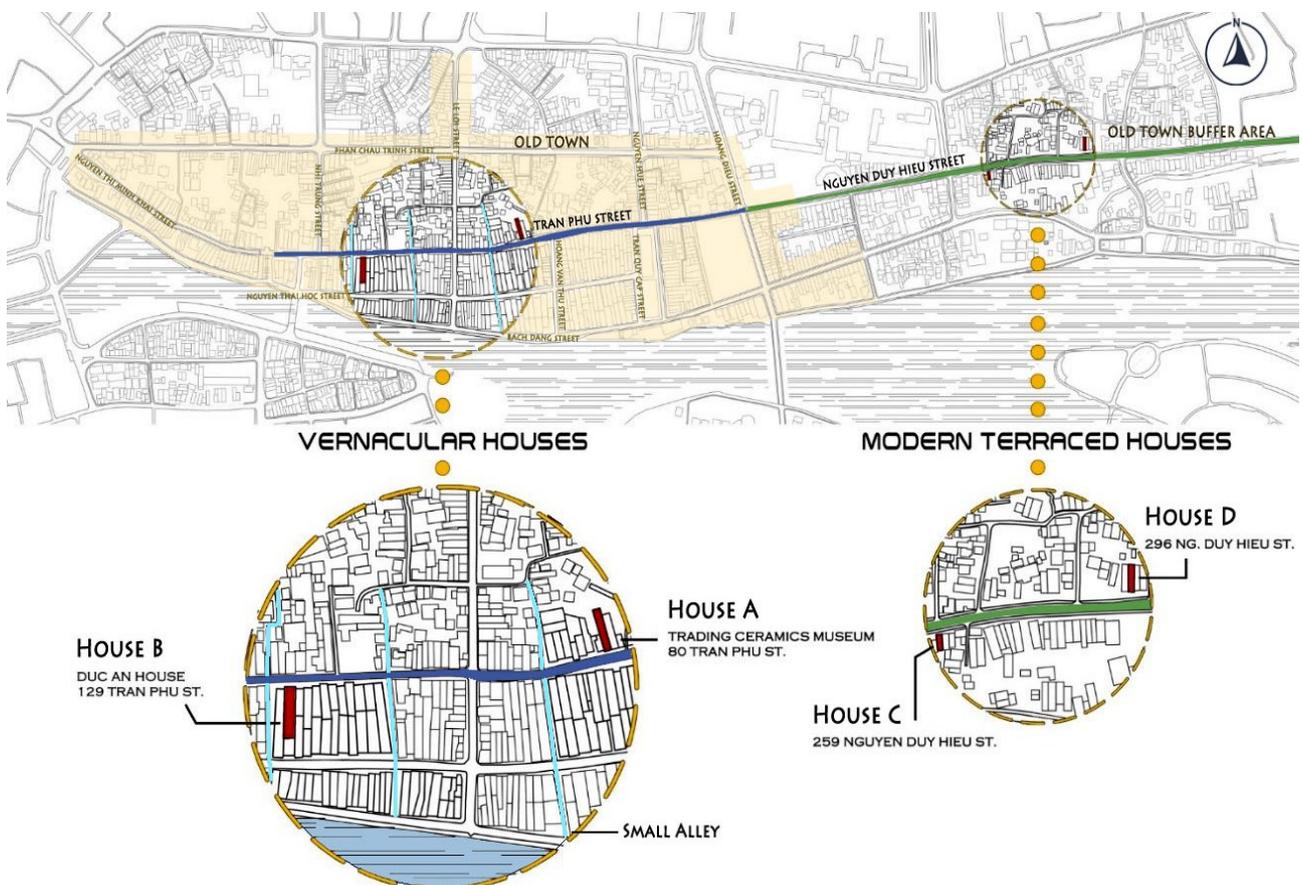


Figure 2. Diagram of research areas.

2.1.2 Hoi An Urban Morphology

The study of urban morphology focuses on the analysis of the panoramic map and analysis of building shapes in the process of urban formation and development (Doan, 2017). In this research, both study areas (old town and the old town buffer zone) are in a relatively flat area with their topography generally lowered from the North West to the South East and having an average slope of 0.015° . Therefore, analysing urban morphology is based on the analysis of the general plan, front facades and cross-sections of two selected streets in this study (Tran Phu St. and Nguyen Duy Hieu St).

Analysis of the general plan

Hoi An Ancient Town is located in the three wards Son Phong, Minh An and Cam Pho. They are also the three wards identified as having the highest population density in Hoi An City. Besides, Do and Phan (2018) showed that the

construction density of Hoi An gradually decreased from the historical nuclear zone to its buffer zone. Therefore, the construction density and population density in the old town area are higher than the old town buffer zone. In the old town, there are small alleys whose width is only one meter to nearly two meters. They start from Bach Dang street (waterfront road) crossing the old town and into the residential areas behind Tran Phu street. These alleys are not only for moving purposes, they also provide the cool breeze from the river to the buildings deep inside the old town (Figure 2).

The map below shows the distribution of canopy trees and climbing plants in the two surveyed areas (Figure 3). Data of the tree was collected by the author based on in situ surveys. The size of dots represents the relative size of trees in the general map.

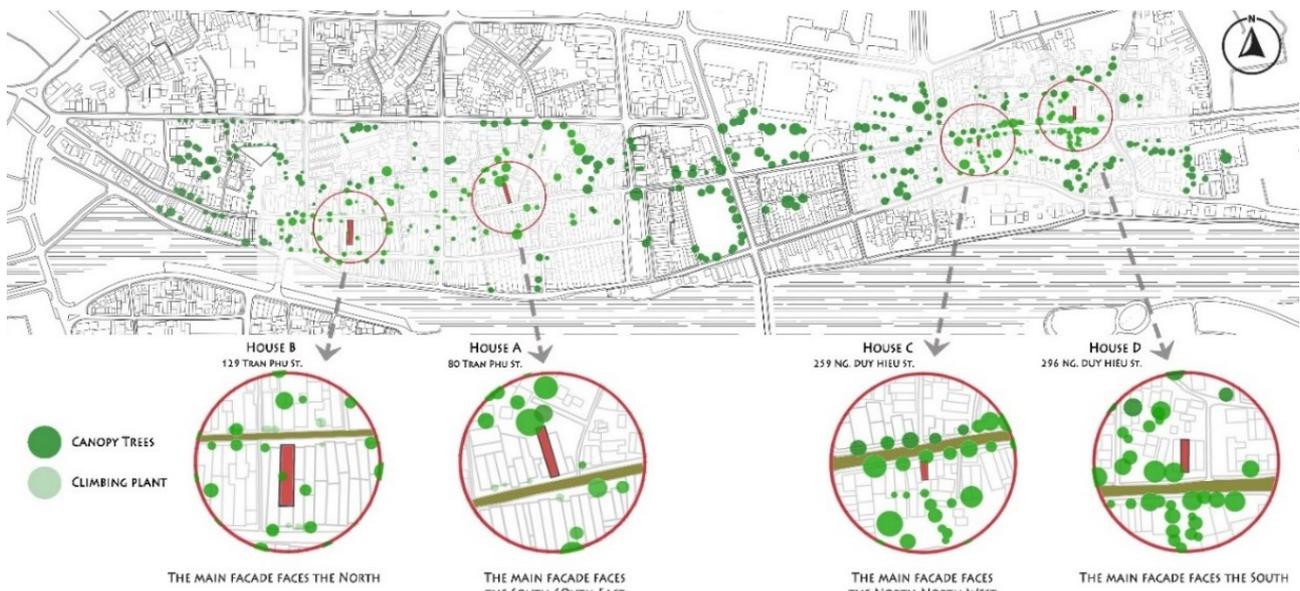


Figure 3. Map of tree position within a radius of 50 meters around the survey houses.

Based on the map, it was realized that the old town area has fewer canopy trees than the buffer area. There are very few canopy trees on both sides of Tran Phu street, mainly climbing plants. The tree density of the old town increases when going to the edge of the old town (some locations have many trees as Hoi An market, Phan Chau Trinh street, Nguyen Thi Minh Khai street). On Nguyen Duy Hieu Street, there are many canopy trees along both sides of the road, the trees here have wider coverage than the trees on Tran Phu Street. In Figure 3, the radius of 50 meters

around the four surveyed houses was enlarged to show the amount and location of trees around them. The direction of the main facade of the housing is also stated (Figure 3).

Analysis of the street facade

The images of the street facades around surveyed houses were taken separately and put together to visualize the street where the surveyed house was located. Figure 4 shows that in all cases, the vernacular houses have front porches and that there are not too many canopy trees around the surveyed houses. At

the same time, there are only some few climbing and ornamental plants. However, the large front porches reduce the direct sunlight into the houses. The common form of roof in the old town is the sloping roof, which is covered with yin-yang tile. Facades of vernacular houses are usually built of bricks or wood, and the walls on both sides of these houses are bricks. The wooden houses are usually older than the brick houses. Houses A and B dated from about 1858 and 1837 respectively. Most of

the vernacular houses in this old town are trading local goods for visitors or making restaurants, coffee shops. Nonetheless, the activities of trading and displaying products inadvertently shield all spaces in front of the house, restricting access and circulation of air. Some houses are famous because of their histories, age, and architectural form. To visit, they are organized into historical sites (House A and B are included).



Figure 4. Street facade around House A (80 Tran Phu St.) and House B (129 Tran Phu St.)

Figure 5 indicates that most of the houses shown for the modern areas do not have front porches. Awnings are added after construction; the main material of the awnings is the canvas and corrugated iron. Particularly, for House D, there is no porch and awning, the front part of this house is used as a shop. There are many canopy trees around House C and House D; these trees create shade for the main

façade of the building, replacing the porch. The roof form of two-story houses or more around houses C and D is the slopping tile type. However, for the one-story houses in these pictures, they mainly use the corrugated iron roof. This can cause an increase in heat in the area because of the heat reflection characteristics of the corrugated iron roof.



Figure 5. Street facade around House C (259 Ng. Duy Hieu St.) and House D (296 Ng. Duy Hieu St.)

Analysis of the street cross-section

Figure 6 shows the street cross-section at the houses where the temperature measuring sensors were installed (vernacular houses A, B and modern terraced houses C, D). It is recognized that the width of Nguyen Duy Hieu street is larger than Tran Phu street. As mentioned in the introduction, the open streets will promote the movement of the air which enhances streets cooling better than narrow streets. In the old town, the movement of people on Tran Phu Street is basically by

walking. With the number of tourists visiting Hoi An Ancient Town, it has become very crowded, so much so that the release of heat in the old town area is quite enormous. Conversely, the width of Nguyen Duy Hieu street is large, the sightseeing activities are not strong on this street and people use vehicles to travel, so that congestion is minimized and vehicles are rare on street. The Figure also provides information on the dimensions and relative proportions between the height of surveyed houses and the width of the road.

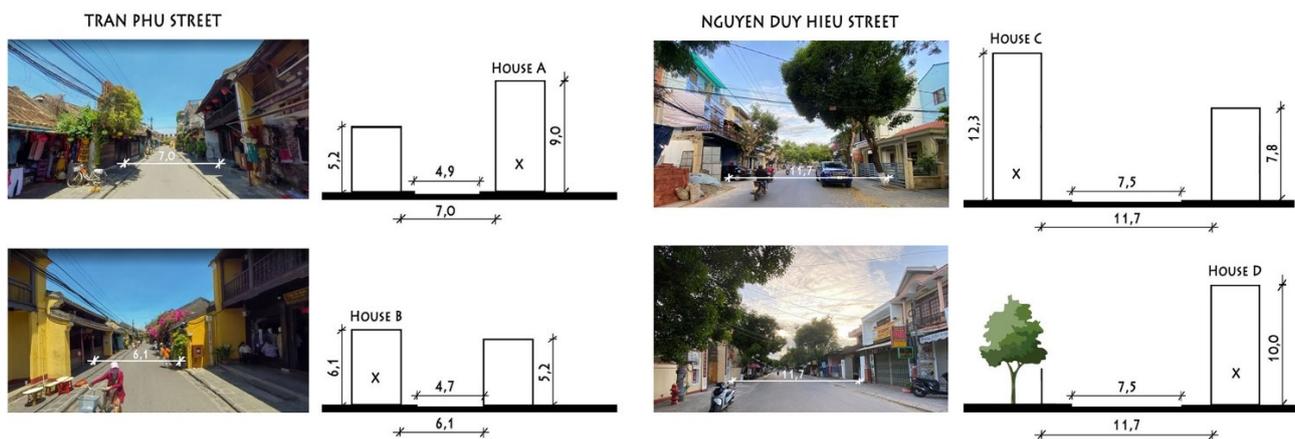


Figure 6. Cross-section of Tran Phu Street and Nguyen Duy Hieu Street

2.2 Field measurement work

The assessment of the impacts of urban morphology on indoor thermal conditions in this study is mainly based on indoor air temperature. Measurements were made by installing temperature sensors at similar locations in the four surveyed houses. These sensors are connected and transmitting data

to an Arduino circuit. This Arduino is connected to Wi-Fi and continuously records the measurement parameters every two hours. The measurements were performed for one month. The temperature data obtained were compared with each other and with meteorological weather data, obtained from the Da Nang weather station (the nearest

meteorological station to Hoi An city, about 30 km away), in the same period. Da Nang meteorological station is located in Hoa Thuan

Ward (near Da Nang International Airport). The location map of the measurement points is shown in Figure 2.

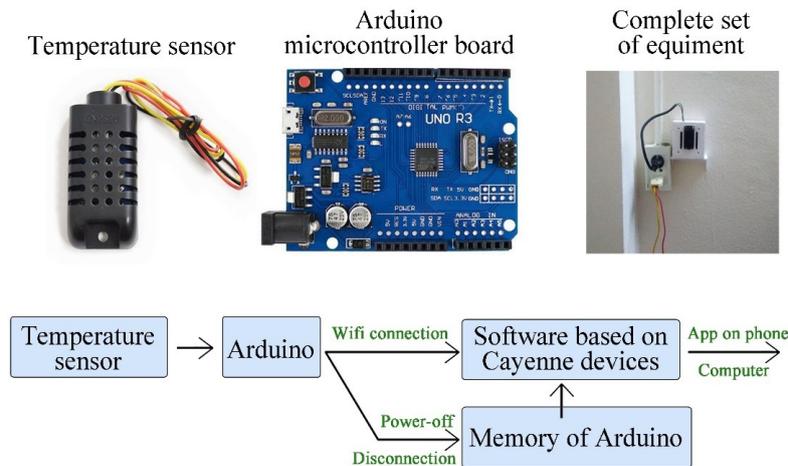


Figure 7. Instrumentation and their principle of operation.

The temperature sensor used is the AOSONG AM2301 sensor. The temperature range of the device is from -40°C to 80°C with a precision of $\pm 0.5^{\circ}\text{C}$. The Arduino microcontroller board used is Arduino Uno R3. The principle of operation of the temperature measurement works is described in Figure 7. In case of a power outage or loss of Wi-Fi connection, the data will be stored in Arduino's memory and updated later.

2.2.1 Positions of measurement stations

As mentioned earlier in section 2.1.1, there are four houses selected for installation and instrumentation. The first house is House A, located at 80 Tran Phu street in the old town area. This house was built in 1858 with a two-story. The house is 7.7 meters wide and 32.8 meters long. The main material of House A is wood including the main facade, pillars and frames. Particularly, the walls on both sides of House A are made of bricks. The roof is covered with yin-yang tile, a popular roof in Hoi An Ancient Town. House A is now the Museum of Trading Ceramics in Hoi An. The second house in the old town is House B at 129 Tran Phu street. House B dates over 180 years. The front part of House B (main building) is one-story with the wooden facade, while the rear part is two-storey building. The house is 7.2 meters wide and 44.2 meters long. Materials of pillars, frames, roofs, sidewalls are similar to those of House A. Due to the cultural influence of Chinese merchants migrating to live in commercial ports, these shophouses have a

spatial organization similar to the traditional Chinese courtyard buildings (Han & Beisi, 2016). Vernacular houses A and B in Hoi An commercial port are examples of such shophouse cases.

House C is located at 259 Nguyen Duy Hieu street in the buffer zone old town. This is a three-story house built-in 2003. The size of the house is small with 5.6 meters wide and 11.6 meters long. The house was built entirely of bricks. The roof form is sloping and tiled according to the regulations of the Hoi An government for buildings located in the buffer zone. House D at 296 Nguyen Duy Hieu was built in 2014. This is a two-story house with dimensions of 4.3 meters in width and 24 meters in length. This house is built with bricks, sloping roof with tiles.

The temperature measuring device is located 3 to 7 meters away from the main door and at a 1.2-meter height above the ground. The main reasons for choosing this position are the following:

- The structure of a vernacular house in Hoi An is different from that of a modern terraced house. Vernacular houses, which have a long length, are divided into 3 building blocks along the length of houses. Conversely, the length of modern terraced houses is shorter. It is, therefore, necessary to find the device's locations so that they are equivalent between the two kinds of houses. In the vernacular house, measuring devices are put within the main building and in the modern house, they are put in the living room. The distance of 3 to 7 meters for the main door to avoid direct

sunlight on the device causes deviations when measuring the temperature. Another important reason is that the device needs to be mounted near the power supply.

- Temperature measuring device is located about 1.2 to 1.5 meters from the ground

because if placed too close, the instrument will report the ground temperature. If placed too high, the temperature recorded will be skewed by height.

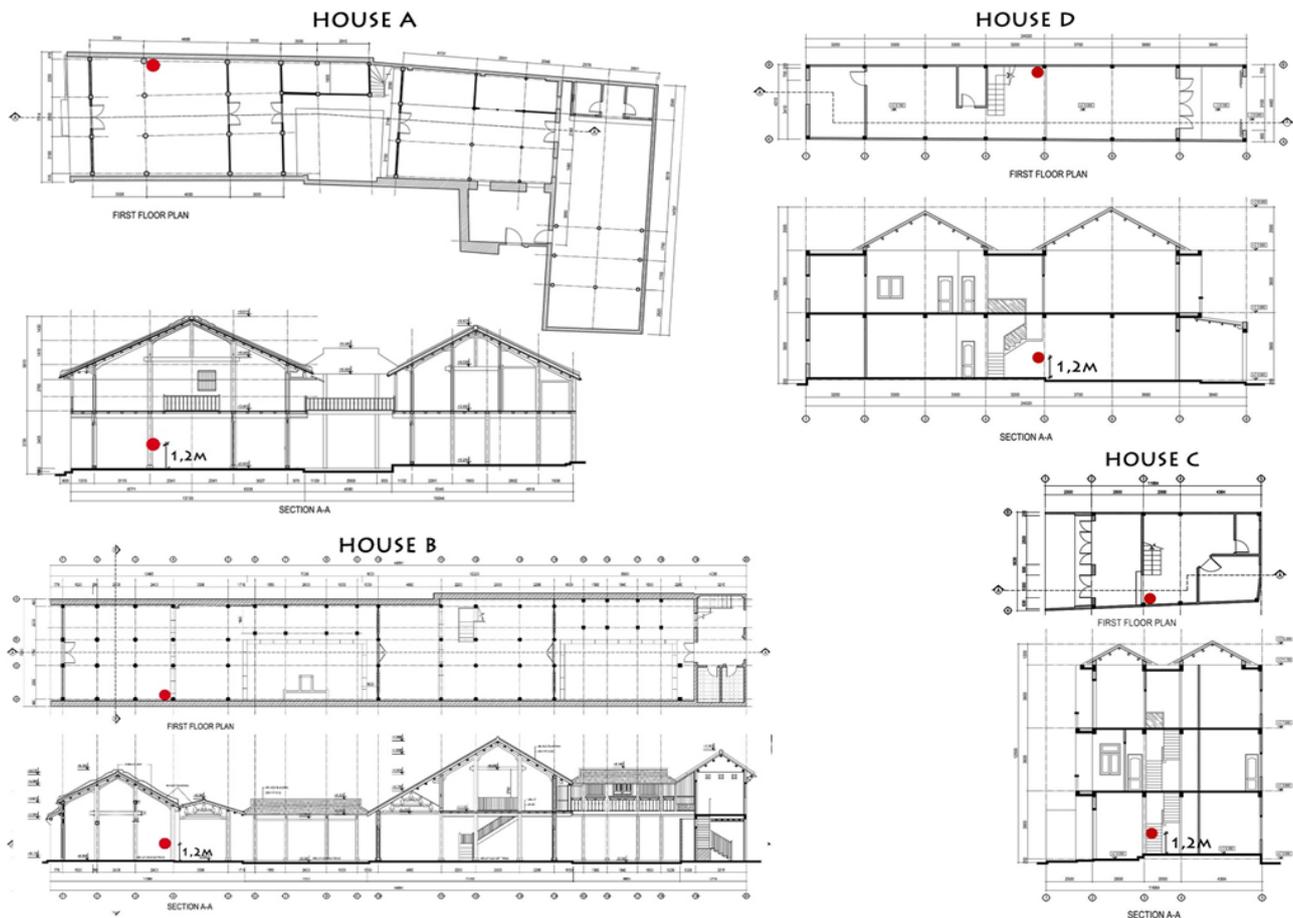


Figure 8. Location of temperature measuring devices in four surveyed houses

2.2.2 Measurement period

The measurement operation took place in June 2019 as earlier pointed out. June is recorded as one of the months with the highest average temperature in Vietnam. Therefore, the month of June is appropriate for monitoring indoor air temperature conditions as the outside air temperature rises significantly. Besides, 27th June has the highest average temperature in June (according to data from the Da Nang Meteorological Department). Hence, it is selected to investigate temperature variation every two hours at the surveyed houses.

3. Result and discussion

3.1 Variability of indoor air temperature at four measurement stations for one month

According to the measured data, this study introduces the average air temperatures at the four stations within one month. Figure 9 and Table 1 illustrate this measurement. Accordingly, numerical values in Table 1 include the measured average air temperatures at four stations, average air temperatures at Da Nang meteorological station, and their mean values (T_m). Observing Figure 9 shows that of the four temperature measurement stations, the average air temperature data at House A is the highest compared to the remaining houses and it is higher than the data obtained from the meteorological station from 1.5 °C to 3 °C. Following House, A is House C with

approximately the same temperature as House A. House B is the third-highest average house temperature and most of the days, it is lower than Houses A and C by about 1.5 °C. In particular, it can be seen that the air temperature variation for houses A and B are the same as those in the meteorological station. House D is the house with the lowest average temperature background and the lowest temperature fluctuation range amongst the four houses.

Nguyen, et al. (2011), pointed out that vernacular houses have adjusted quite well to the local climate conditions where they are located. Utilizing natural ventilation, shading solutions, construction orientations and building shapes are important criteria to decrease indoor temperatures. Vernacular houses A and B with a courtyard in the center of the house contribute to the horizontal natural ventilation. Besides, using traditional materials such as wood and yin-yang roof tiles

will limit the absorption of heat for the building envelope more than other materials such as concrete, bricks, and glass used for modern houses. In terms of architectural form, vernacular houses have an advantage over modern houses in creating a comfortable indoor temperature environment. However, this temperature survey showed the opposite result. It can be explained that, in addition to the impact of architectural form, indoor temperature conditions are also affected by urban morphology. According to the analysis in section 2.1.2, there are some disadvantages in the old urban area such as narrow streets that restrict air circulation, lack of greenery that increase the ground temperature and display goods that take up horizontal ventilation space for housing. On the contrary, modern houses C and D are located on an open road with many trees, reducing the impact of sunlight on the roof and road surface showing that limiting heat build-up increases the air temperature.

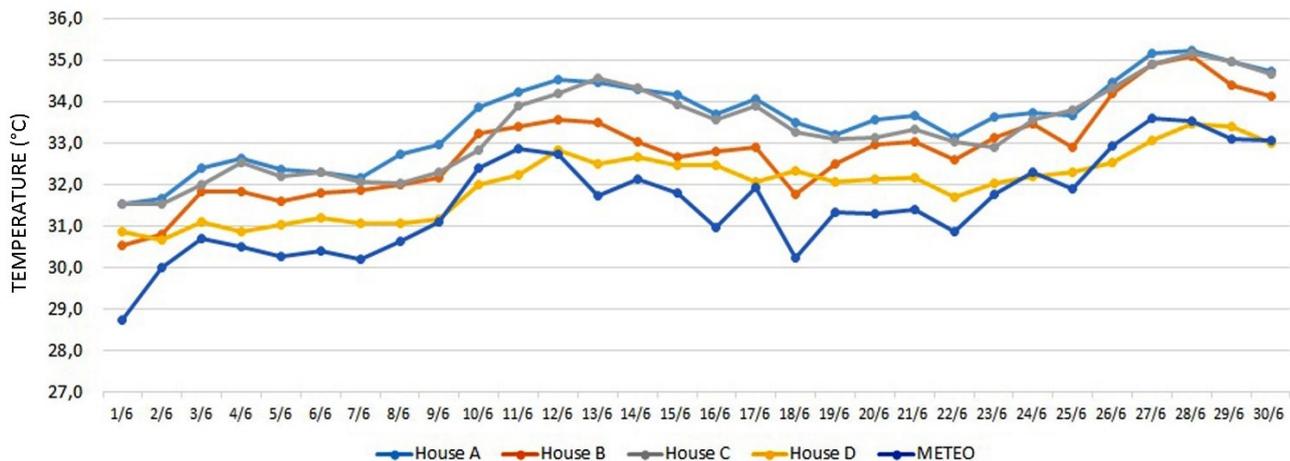


Figure 9. Graph of measuring the average air temperature at four stations compared to the temperature recorded by the Da Nang Meteorological Station in one month.

3.2 Variability of indoor air temperature at four measurement stations for one day

It is easy to see that the air temperatures obtained at the four survey stations is higher than the temperatures recorded at the meteorological station from after the 18h to 07h next day (Figure 10). For station at House A, the measured air temperatures are higher than those recorded by the Da Nang Meteorology Station from 17h to 07h30 the next day. For station at House B, the increase in temperatures appears from 15h to 08h. For Station at House C, the observed increase in temperature is from 17h to nearly 09h the next day. For station at House D, the increase in

temperature is from 18h to 07h. Looking at Table 2, we see that the 24 hours mean values of temperature (T_m) of the meteorological station is lower than the mean values of temperature of houses A, B and C from 1.2 °C to 1.4 °C, and higher than the mean values of temperature of House D is about 0.5 °C. Discrepancies in temperature after 17h to 07h the next day at four houses and the meteorological station fluctuated between 1.3 °C and 5.1 °C (as shown in Table 3). This can be explained by the increase in traffic activity (working time off in the afternoon is from 16h30 to 18h) and the temperature absorption characteristics of surfaces such as roads,



pavements, walls, and roofs. The amount of heat absorbed by the building materials during the day dissipates heat to the surrounding air at night, resulting in the increase in indoor temperature.

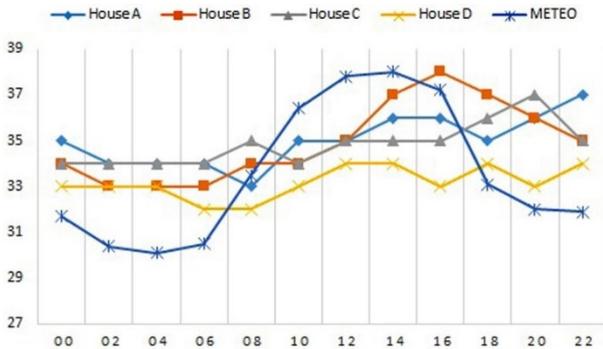


Figure 10. Comparison of temperature variation in 27th June 2019 between four temperature station and the meteorological station

According to Table 2, the maximum temperature obtained by a meteorological station is 38 °C at 12h to 14h. Meanwhile, the temperature at House A also increases sharply from 14h to 16h and reaches its maximum at 22h. The maximum temperature at House B is 38 °C at 16h (both Houses A and B have a time lag of two hours compared to the meteorological station). When air temperatures rise, the housing indoor temperature also increased rapidly thereafter. This can be explained by the fact that the

narrow road in front of houses A and B has limited the movement of air and enhanced the accumulation of long wave radiation that increase the temperature of this area and buildings. Meanwhile, with the open street, air movement is enhanced but long wave radiation is minimized; hence the indoor temperature of House C reaches a maximum of 37 °C at 20h, with a time lag of six hours compared to the time of maximum temperature at the meteorological station. After reaching the maximum temperature of the meteorological station (14h), the indoor temperature in House D changes according to the Sine graph and the difference between T max and T min is only one degree Celsius. At 22h, when the meteorological station temperature has dropped significantly and the indoor temperature of surveyed houses still high at the same time. House A has a temperature of 37 °C, which is higher than House D (4 °C). House B and House D have the same temperature of 35 °C. This is due to the impact of heat radiation which has been absorbed in the daytime from buildings and roads. From 0h to 6h the temperature at the meteorological station decreases by about two degrees Celsius. However, at the four surveyed houses, the indoor temperature is stable or reduced by one degree Celsius from 00h to 02h and continues to maintain this temperature thereafter.

Table 1. Measured air temperatures for Figure 9 and their mean value Tm.

DAY	House A	House B	House C	House D	METEO
1/6	31,5	30,5	31,5	30,9	28,7
2/6	31,7	30,8	31,5	30,7	30,0
3/6	32,4	31,8	32,0	31,1	30,7
4/6	32,6	31,8	32,5	30,9	30,5
5/6	32,4	31,6	32,2	31,0	30,3
6/6	32,3	31,8	32,3	31,2	30,4
7/6	32,2	31,9	32,1	31,1	30,2
8/6	32,8	32,0	32,0	31,1	30,7
9/6	33,0	32,2	32,3	31,2	31,1
10/6	33,9	33,3	32,8	32,0	32,4
11/6	34,3	33,4	33,9	32,3	32,9
12/6	34,5	33,6	34,2	32,8	32,7
13/6	34,5	33,5	34,6	32,5	31,7
14/6	34,3	33,0	34,3	32,7	32,1
15/6	34,2	32,7	34,0	32,5	31,8
16/6	33,7	32,8	33,6	32,5	31,0
17/6	34,1	32,9	33,9	32,1	32,0
18/6	33,5	31,8	33,3	32,3	30,2
19/6	33,2	32,5	33,1	32,1	31,3
20/6	33,6	33,0	33,1	32,1	31,3
21/6	33,7	33,0	33,3	32,2	31,4
22/6	33,1	32,6	33,0	31,7	30,9
23/6	33,6	33,1	32,9	32,0	31,8
24/6	33,8	33,5	33,6	32,2	32,3
25/6	33,7	32,9	33,8	32,3	31,9

26/6	34,5	34,2	34,3	32,5	32,9
27/6	35,0	34,9	34,8	33,2	33,6
28/6	35,3	35,1	35,2	33,5	33,6
29/6	35,0	34,4	35,0	33,4	33,1
30/6	34,8	34,1	34,7	33,0	33,1
Tm	33,6	32,8	33,3	32,0	31,6

Table 2. Measured air temperatures for Figure 10

Hour (h)	House A	House B	House C	House D	METEO
00	35	34	34	33	31,7
02	34	33	34	33	30,4
04	34	33	34	33	30,1
06	34	33	34	32	30,5
08	33	34	35	32	33,5
10	35	34	34	33	36,4
12	35	35	35	34	37,8
14	36	37	35	34	38,0
16	36	38	35	33	37,2
18	35	37	36	34	33,1
20	36	36	37	33	32,0
22	37	35	35	34	31,9
Tm	35,0	34,9	34,8	33,2	33,6



Table 3. Temperature discrepancies between the air in four surveyed houses (TsA, TsB, TsC and TsD) and meteorological temperatures (Tmt)

Hour (h)	TsA - Tmt	TsB - Tmt	TsC - Tmt	TsD - Tmt
00	3,3	2,3	2,3	1,3
02	3,6	2,6	3,6	2,6
04	3,9	2,9	3,9	2,9
06	3,5	2,5	3,5	1,5
08	-0,5	0,5	1,5	-1,5
10	-1,4	-2,4	-2,4	-3,4
12	-2,8	-2,8	-2,8	-3,8
14	-2,0	-1,0	-3,0	-4,0
16	-1,2	0,8	-2,2	-4,2
18	1,9	3,9	2,9	0,9
20	4,0	4,0	5,0	1,0
22	5,1	3,1	3,1	2,1

4. Conclusions

Through field surveys, it can be seen that the urban morphology in the old town and the old town buffer zone has its advantages and disadvantages. Experimental work was conducted to evaluate the impact of different urban morphologies on indoor temperature conditions. Vernacular houses A and B are rated as environmentally adaptable, providing comfortable indoor temperature conditions. Modern terraced houses, especially House C is small, not well-ventilated, and the temperature measuring device is located near the kitchen area. However, the temperatures inside vernacular houses A and B are approximately the same as those in modern terraced Houses C and significantly higher than House D in a monthly survey. For a day temperature survey, at the time the temperature of the meteorological station reaches the highest value (from 10h to 16h), the indoor temperature of House C and House D will only increase slightly then stabilize or decrease. In contrast, the temperature at houses A and B is increasing sharply, at this time, the temperature discrepancies between the two old houses and the two modern terraced houses are from 1 to 5 degrees Celsius. From these shreds of evidence, it can be stated that urban morphology forms the street pattern that influences the variation of indoor temperature. Open streets will promote air movement that lowers the temperature of horizontal surfaces such as roofs and road surfaces. Road covering material in the old town area and the old town buffer zone are both asphalts. Therefore, the shading should be enhanced such as with canopy trees, vegetation to limit the absorption of heat and radiation back to the surrounding. Limiting construction density is also a factor contributing to better regional temperature control. Likewise, increasing the

use of traditional local materials with good thermal performance instead of modern materials such as corrugated iron, concrete and glass improves indoor temperature. The drawback to this study is reflected in the fact that there is no specific statistic of cooling devices (fans) used at measurement locations in the 4 surveyed houses. Also, the measurement of outdoor air temperature at the surveyed housing locations would have enhanced the credibility of this paper. Future studies can improve on this.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interests

The authors declare no conflict of interest.

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**How to cite this article:**

Luu, T. H., Rojas-Arias, J., & Laffly, D. (2021). The Impacts of Urban Morphology on Housing Indoor Thermal Condition in Hoi An City, Vietnam. *Journal of Contemporary Urban Affairs*, 5(2), 183-196. <https://doi.org/10.25034/ijcua.2021.v5n2-4>

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