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Residents' Satisfaction Assessment of Outdoor Residential Spaces; A Local Study in an Urban Compact Form in Sana'a, Yemen—Winter Period

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Abstract

This paper studies the thermal performance of outdoor residential spaces in the old part—historical part—of Sana'a city in the winter period and its impact on the residents' satisfaction who occupied the buildings which overlook these spaces and use them on a pedestrian comfort basis. The analysis was carried out through the results of field measurements which study the temperature, relative humidity, and the air movement inside the selected outdoor spaces in the period of winter (2 months) data recorded through the devices used and compared with those obtained from the General Authority of Meteorology and Aviation—Meteorology Sector. Despite the passage of years, the author remained occupied with the opinion of the people whose homes overlook those outdoors spaces and what is their opinion of their performance. Therefore, an assessment was conducted in November 2020 to know the opinion of the people about the performance of these outdoor spaces and to compare the results of the field measurements with the results of the assessment. The measurements were conducted by using data-loggers that spread in some outdoor spaces in 7 spaces in old city of Sana'a and in its modern extension during the winter period which is the time of concern of this work. The measurements showed that the outdoor residential spaces in the old city of Sana'a are represented an advantage for winter climate over that of the modern city, so the focus in this paper was on that outdoors with the question of the users of the outdoor spaces in the old city only to clarify their satisfaction with it and whether it has succeeded as well from their point of view. Results presented in this paper are important to consider the relationship between the climatical performance of outdoor spaces and the comfort of the

residents in the urban environment and give implications for urban planners and architects to improve the climate-based design methodology towards sustainable developments.

Keywords

Thermal Performance, Outdoor Residential Spaces, Sana'a Old City, Modern City, Winter Period, Field Measurements, Assessment, Residents' Satisfaction

1. Introduction

The outdoor environment is one of the most critical issues which lead to several problems related to the thermal comfort of humans. Unsuitable outdoor climate will negatively affect the indoor climate and more consumed energy, so trying to enhance the built environment and study its effect on residents should take a very momentous concern. There are many field measurements in different climates that were done (AlShawesh, 2011; Ali Toudert, 2005; Johansson, 2006) clarified that urban design has an impact on the urban microclimate also the relationship between urban geometry and the urban heat island. Thus, study that and their effects on thermal comfort most take the priority.

Due to rapid urbanization in Sana'a city which is the capital of the Republic of Yemen, with large construction activity, notice the disappearance of the outdoor residential spaces from its new urban fabric, anti-reverse of the old city (Sana'a Alkadima).

Field measurement in both of old and new extension of the city (AlShawesh et al., 2010) indicate that urban design has a significant impact on the urban microclimate in winter period, although the relationship between urban geometry and nocturnal air temperatures is well known with proving that urban heat island is created in the mid of the day. It is not common to carry out assessments in how people are satisfied with the residential outdoor spaces to know their viewpoints that explain the relevance importance of suiting these spaces to their thermal comfort and social needs.

This paper is evaluating the effect of the climatic performance of outdoor spaces in the old part—historical part—of Sana'a, Yemen by field measurements and by knowing the opinion of people who are the beneficiaries of their presence with those outdoor spaces that have proven their performance and distinction in Old Sana'a in four—narrow and wide—outdoor spaces that residents were asked about their satisfaction via a questionnaire.

2. Field Measurements

The city of Sana'a is characterized by a unique climate from the rest of the other Yemeni cities which characterized by moderation throughout the year, except for the drop in temperatures in the winter season, which may reach below zero on some nights, noting that the temperatures rise in the afternoon and afternoon

in the summer, where they exceed 30˚C. The relative humidity is generally low in the city, except for the periods when rain falls on the city, in the spring (March and April) and in the summer (June, July and August). The prevailing wind direction in the city is the northeastern and northern direction, with the possibility of winds blowing throughout the year in other directions, but in small proportions. Static winds represent 55% of the total annual winds, while moving winds represent 45%. The annual solar brightness hours in the city of Sana'a range between 8 - 10 hours approximately during the months of the year, and the highest rate of solar brightness hours is in January, February, May, June, and December (Alshawesh, 2007), and since it is the capital of the Republic of Yemen, it is witnessing a rapid urban expansion in the areas of growth available in the northern and southern direction of the city in the form of new residential urban projects in which it was noted that the existence of residential urban spaces in its modern urban fabric has disappeared. Instead, it is sufficient to make asphalt streets separating the residential buildings, despite the clear presence of those voids in the fabric of the old city. The city of Sana'a—**Figure 1**—was chosen for the study because it contains two completely different parts in terms of texture and urban formation, namely: the old city, and its extensions after the revolution of September 26, 1962, which is known as the modern city (AlShawesh, 2007).

2.1. Descripting Areas of Field Measurements

Locations of field measurements in the city of Sana'a were selected in both the old and the modern part, as follows:

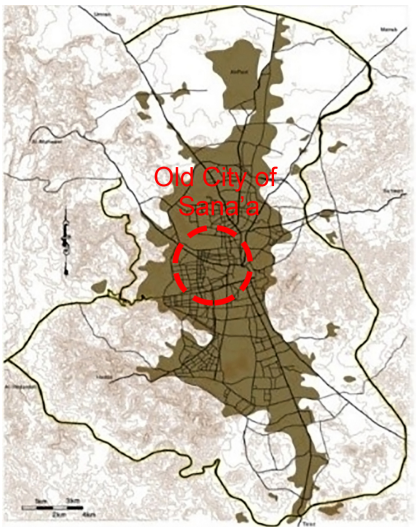
2.1.1. Old Sana'a—Al-Jala'a Neighborhood

Al-Jala'a neighborhood is located on the western side of the Sana'a old city, and the measurement spaces were chosen due to the regularity of the shapes of its spaces (corridor, square and rectangular), and because it is considered an example of most residential urban spaces in the old city with its compact urban fabric. All the studied spaces are located in one residential sector, due to the ease of inspecting the devices and moving between them and because they contain nearly regular spaces and vary between wide and narrow. The heights of the buildings overlooking these spaces are similar and the same building materials, as the building material used on the ground floor and first floor is made of stone, while the rest of the floors are made of burnt bricks (Yagour), the floors of the city spaces are all covered with stone. Four locations were selected to make the measurements in Al-Jala'a neighborhood have been detailed in both **Table 1** and **Figure 2**.

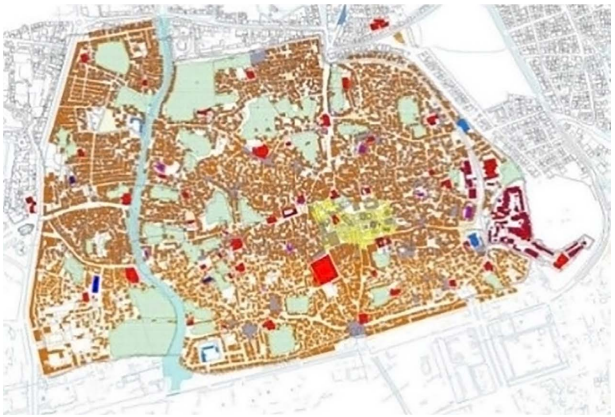
2.1.2. Modern City of Sana'a—Tourist City—Sheraton

The tourist city is located in the northern part of Sana'a city. It is a residential complex surrounded by a wall, designed by engineers from the (former) Soviet Union in the seventies (Administration, 2009). The tourist city was chosen as a

Location of Sana'a City in Republic of Yemen (Anon, 2022)



General Site Plan of the Sana'a City (AlShawesh, 2007)



Site plan of the old city of Sana'a—Yemen (CATS, 2008)

Figure 1. Sana'a city—old and modern city.

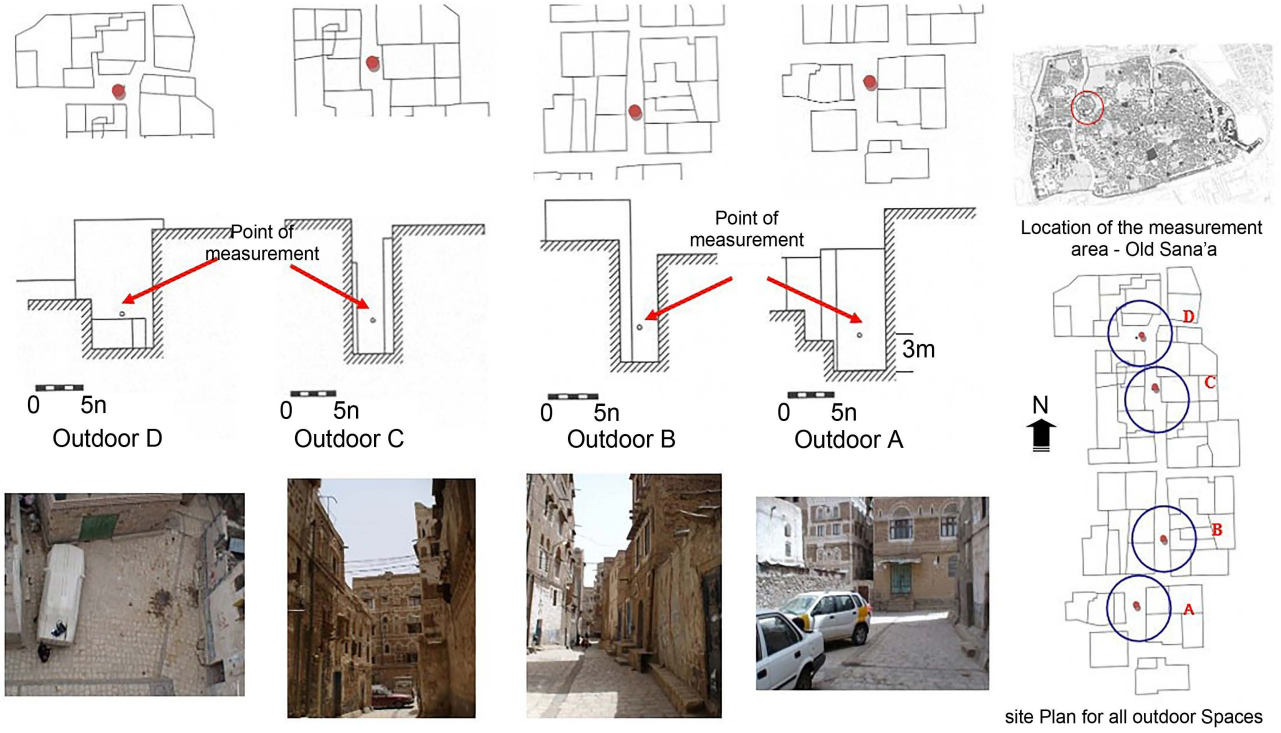


Figure 2. Residential outdoors in Al-Jala'a neighborhood—old Sana'a.

Table 1. Details of the measurement sites in Al-Jala'a neighborhood in the old city*.

Location	Direction	Ratio of Height/Width	Average of the height of buildings m	Ratio of Landscape Elements %		
				Buildings	Floors	Green Area
1	N/S	1:1.35	10	75	25	0
2	N/S	1:6.3	11	82	18	0
3	N/S	1:3.5	11	83	17	0
4	E/W	1:1.6	8	67	33	0

[*] The percentages of the elements of the measurement sites were determined with an area of a circle of diameter 100 m, around each space.

study area because it is an example of unconventional construction and because it still maintains its urban unity in terms of shape and building materials (all units are built of concrete bricks and covered with a cement layer coated with light colored paint) and with same height. The city is a residential building consisting of two floors, each floor contains two apartments, numbering 50 housing units. The city follows the open urban fabric, and overlooks two paths, one of which is an asphalt street that vehicles pass through, and the other is unpaved street for pedestrian walking only. Three measurement sites were selected with spaces of different dimensions between the housing units overlooking those spaces, and this is illustrated in Table 2 and Figure 3.

Table 2. Details of the measurement sites in tourist city—Sheraton.

Location	Direction	Ratio of Height/Width	Average of the height of buildings m	Ratio of Landscape Elements		
				Buildings	Floors	Green Area
5	N/S	1:2.5	8	23	64	13
6	E/W	1:1.1	8	25	54	21
7	N/S	1:1.2	8	23	51	26

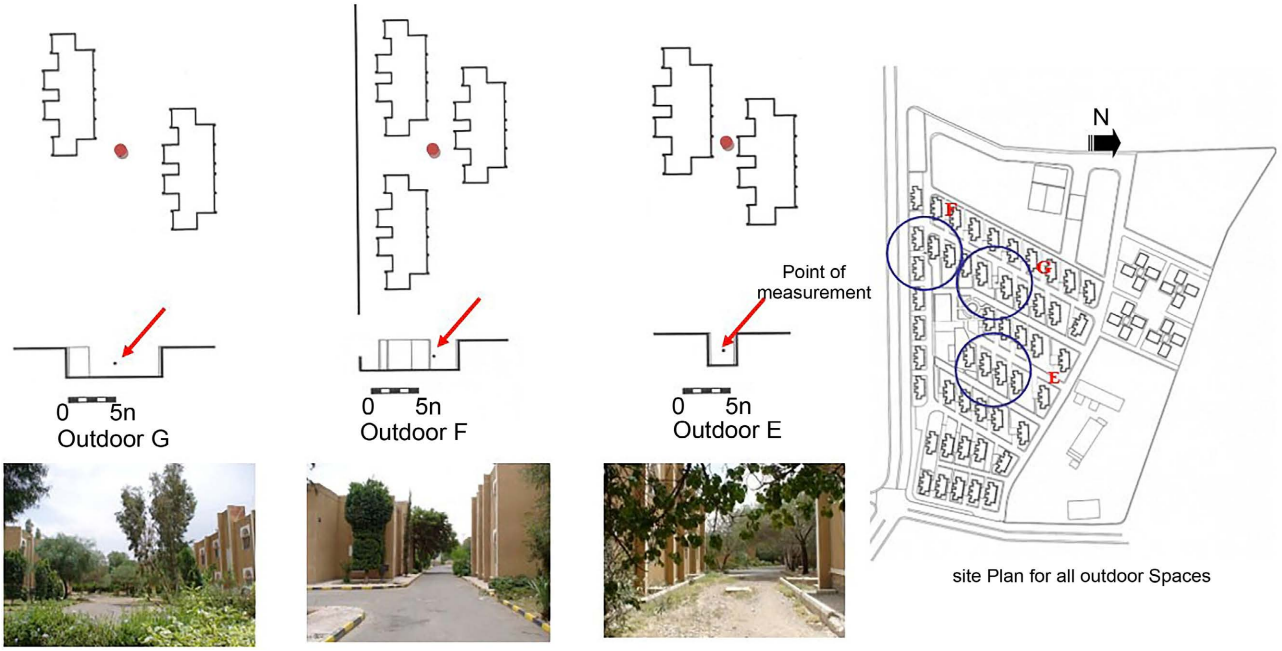


Figure 3. Residential outdoors in tourist city—Sheraton, modern city of Sana'a.

2.2. Devices Used for Measuring

Field measurements were carried out using two monitoring devices (Table 3): Automatic—Tinytag logger to measure temperature and relative humidity, which is a small device that is suspended in the middle of the outdoor spaces to take measurements continuously at a height of 3 m so as not to be tampered with and not to obstruct the passage of vehicles. The other is a manual device—45160—to measure air velocity instantaneously at certain hours only because there are no continuous measuring devices to measure air velocity permanently inside the spaces, and its readings are taken from the middle of the space and at a height of 1.2 m in two periods: six in the morning and six in the evening during 26 days, 13 days for each location, and their specifications and intervals as shown in Table 4.

3. Measurements Analysis

3.1. Temperature Measurements Analysis

Temperature measurements were carried out in the spaces selected for measurement in Al-Jala'a neighborhood in the Sana'a old city, and the tourist city in

Table 3. Devices used for measurements.

Range and accuracy	Type & Source	Device Quality	
Air Temperature/Relative Humidity −25 to +85˚C/ 0 to 100% RH	Tinytag UK	Automatic TGP-4500 *Tinytag Plus* 2 *Dual Channel Logger*	
Air velocity 0 to 30 m/s ±4%	Extech UK	Manual 45160	

Table 4. Measurement intervals in residential outdoors during 2009-2010.

Old Sana'a + No. of Outdoors	Modern City + No. of Outdoors	Period	Time period for continues measurements Air Temperature Relative Humidity	Time period for instantaneous measurements Air Velocity
Al-Jala'a 4 Outdoors	Tourism City Sheraton 3 Outdoors	Winter	2009/12/07 - 2010/02/07	2009/12/20 - 2010/01/17

order to identify their role in the thermal performance of those spaces during the winter period.

Although, temperature measurements were carried out in the spaces selected for measurement in both Al-Jala'a neighborhood and the Tourist City for a period of sixty days, with a total of 5760 readings inside each space during the winter period (at the rate of one reading per quarter of an hour), the hourly readings were taken to be compared with the hourly readings of the meteorological station. The total measurement period in all spaces was divided into averages for every five days divided into Four periods (first, second, third and fourth) throughout the day at a rate of 6 hours/period, as shown in **Figure 4**, thus their thermal performance pattern is recognized in general.

The figure shows that the curves representing temperatures in the spaces all follow the same pattern in terms of highest and lowest temperatures, with some differences between them. It was found that the highest temperatures were in the spaces of the Al-Jala'a at noon hours compared to the spaces in the tourist city, while the spaces in the tourist city recorded the lowest temperature drop compared to those in the Al-Jala'a in the early morning hours, which are the critical hours throughout the day in terms of lower temperatures.

Therefore, only the performance of the Al-Jala'a spaces will be discussed in detail, in which the questionnaire was made, in order to clarify the temperature differences between all the spaces and how they work thermally throughout the

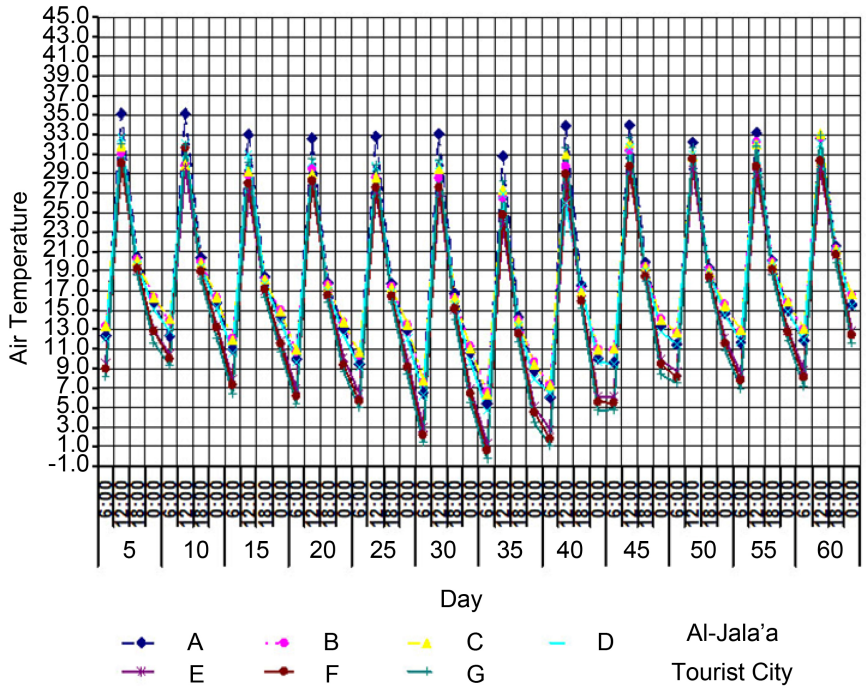


Figure 4. Air temperature in all residential outdoors—winter.

day in a more detailed manner, and the following is an analysis of the observed average temperatures in all the spaces of Al-Jala'a neighborhood as an hourly average for one day, compared to the temperatures recorded by the meteorological station[1].

Al-Jala'a Neighborhood—Sana'a Old City

Figure 5 shows that the temperature curves for the spaces of All-Jala'a neighborhood follow the same pattern and are almost identical from five in the evening until ten in the morning (18 hours) with values lower than the noon hours and beyond, after which the temperatures begin to vary among themselves.

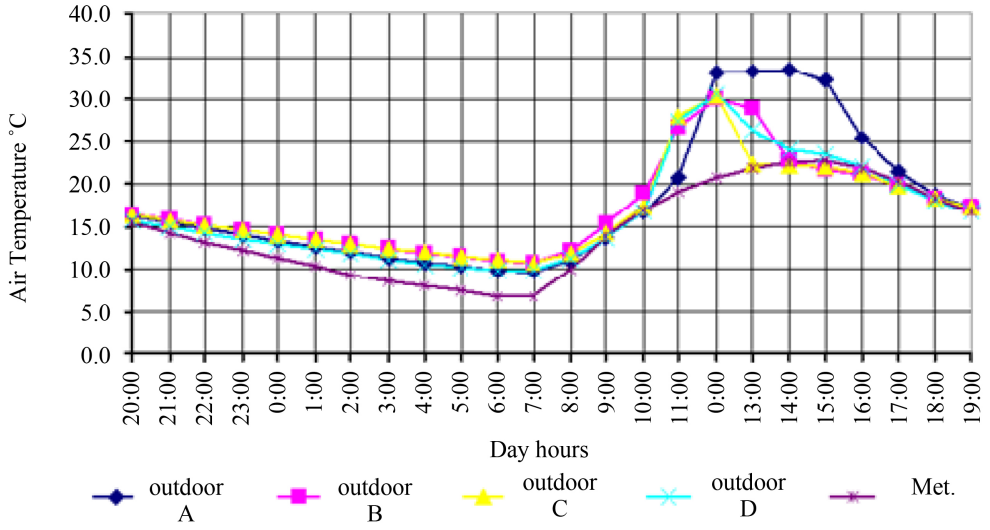
When comparing the highest and lowest temperatures in all the spaces with those recorded by the meteorological station.

3.2. Analysis of Relative Humidity Measurements

Measurements were made of relative humidity rates in the spaces chosen for measurement in Al-Jala'a neighborhood in the old city of Sana'a, and the modern city in the modern city of Sana'a, in order to identify the humidity levels in those spaces and during the winter period.

In this part of the study, the results of field measurements of relative humidity rates during sixty days are analyzed with a total of 5760 readings inside each space (at the rate of reading per quarter of an hour), divided into averages for every 5 days divided into four periods throughout the day and each period of six hours, as shown from **Figure 6**. The averages of relative humidity recorded in all

[1]The Sana'a city meteorological station is located near Sana'a airport, at an altitude of 2190 m above sea level, and about 15 km from the city center.



Outdoor	Highest temperature of the day	
	Air Temp.	Time
A	33.5˚C	12:00-2:00 pm
B	29.9˚C	12:00 pm
C	30.4˚C	12:00 pm
D	30.6˚C	12:00 pm
meteorological measurements	22.7˚C	03:00 pm

Outdoor	Lowest temperature of the day	
	Air Temp.	Time
A	9.9˚C	06:00am
B	11.0˚C	06:00am
C	11.1˚C	06:00am
D	9.8˚C	06:00am
meteorological measurements	6.7˚C	06:00am

Figure 5. Temperature in residential urban spaces in Al-Jala'a—old Sana'a.

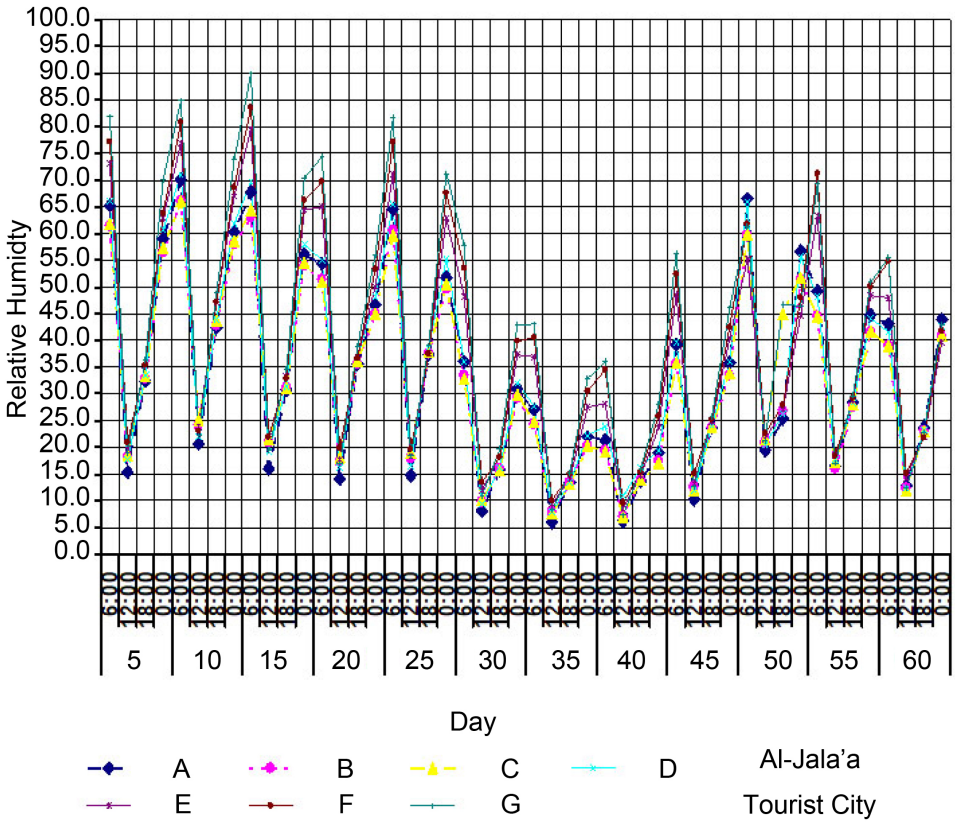


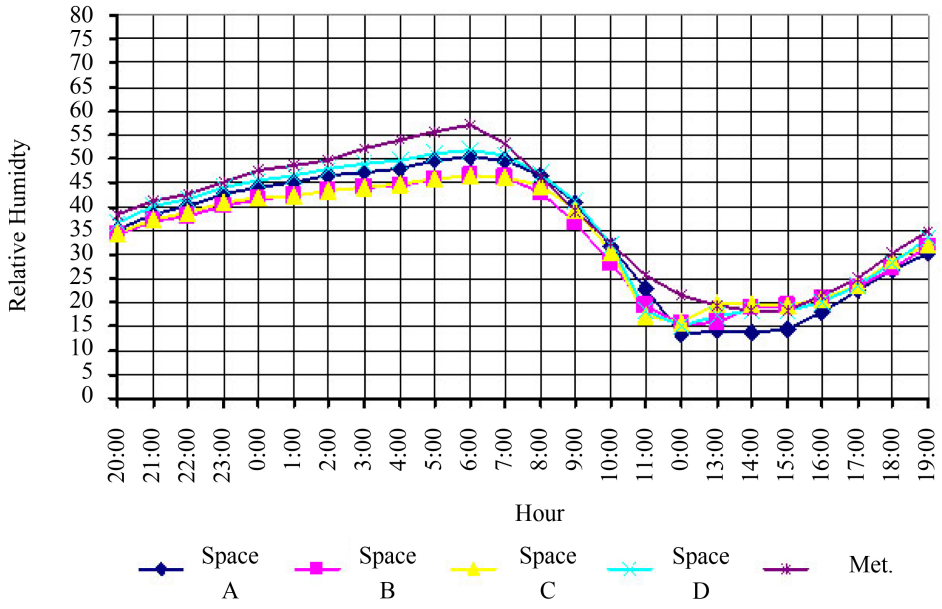
Figure 6. Relative humidity in all residential outdoors—winter.

spaces are analyzed as an hourly average for one day and compared to the relative humidity rates measured at the meteorological station.

Al-Jala'a Neighborhood—Old City

From the rates of relative humidity recorded in the spaces of Al-Jala'a neighborhood, as shown in Figure 7, it is clear that the highest rate of relative humidity was observed at six in the morning and closely between spaces (A) and (D), while the observed rates were equal in the spaces (B) and (C) But at a lower rate than the other two spaces, and it is noted that the relative humidity in general in all the spaces of Al-Jala'a lane is less than what was observed by the meteorological station and throughout the day from the rates of relative humidity recorded in the spaces of Al-Jala'a neighborhood, as shown in Figure 6, it was found that the highest rate of relative humidity was detected at six o'clock in the morning and closely between spaces (A) and (D), while the rates were equal in spaces (B) and (C).) but at a lower rate than the other two spaces, and we find that the relative humidity rates in all the spaces are less than the rates required to be achieved to reach thermal comfort from eleven in the morning until five in the evening (7 hours).

Relative humidity rates decrease in all spaces, reaching its highest value in outdoor (C) and equal in (B) and (D) and reaching its lowest value in outdoor



Outdoor	Highest R.H of the day	
	R.H	Time
A	50%	06:00 am
B	47%	06:00 am
C	47%	06:00 am
D	52%	06:00 am
meteorological measurements	57%	06:00 am

Outdoor	Highest R.H of the day	
	R.H	Time
A	13%	12:00 pm
B	15%	12:00 pm
C	16%	12:00 pm
D	15%	12:00 pm
meteorological measurements	18%	02:00 & 03:00 pm

Figure 7. Relative humidity in residential urban spaces in Al-Jala'a—old city of Sana'a—winter.

(A). It is noted that the relative humidity in general in all the spaces of the evacuation lane is less than what was observed by the meteorological station and throughout the hours of the day 4.

3.3. Analysis of Air Velocity Measurements

It is known that the speed of the air increases with the increase in the height above the surface of the earth, and its speed is rarely constant during any perceptible period of time, as it usually changes rapidly and continuously, and the air undergoes irregular changes in terms of its duration of stay and its amount (Retallic, n.d.; Retallack, 1970).

Air plays a distinctive role in the feeling of thermal comfort, as it increases the feeling of high or low air temperature, and affects the sense of relative humidity rates, and for this reason, instantaneous measurements were made within the spaces selected for the study, one at six in the morning (as a representative of the period of low temperatures) and the other at one in the afternoon (representative of the highest temperatures during the day), in order to know the rates of air velocity within those spaces at these times, in the winter period, Figure 8.

The results of the hourly measurements of wind direction and speed taken from the meteorological station in Sana'a for the winter period (December/2009 and January/2010), which included the period of field measurements to identify the speed and direction of the wind coming to the city, were also analyzed in Figure 9 and Figure 10.

4. Assessment

After the urban spaces in the old part of the city of Sana'a proved the effectiveness of their climatic performance in the winter period, it was necessary to identify the opinions of the people living around these spaces—Table 5—and their

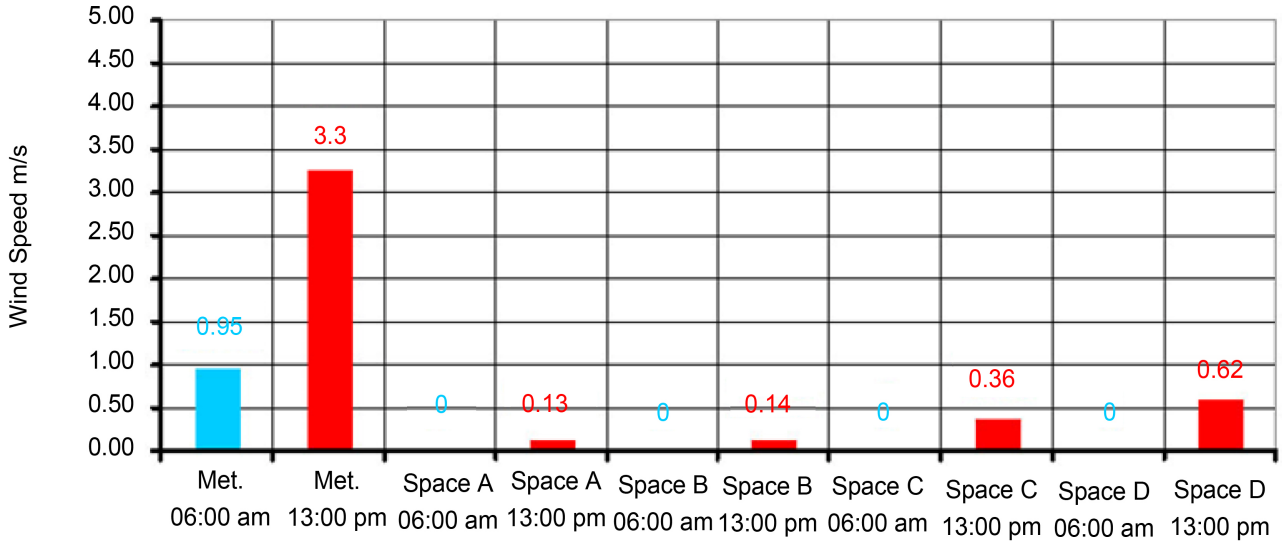


Figure 8. Average wind speed measured in Al-Jala'a neighborhood spaces—the old city, for the days 20-22-24-26-28-30/12/2009 and 2-4-6-9-11-13-16/01/2010.

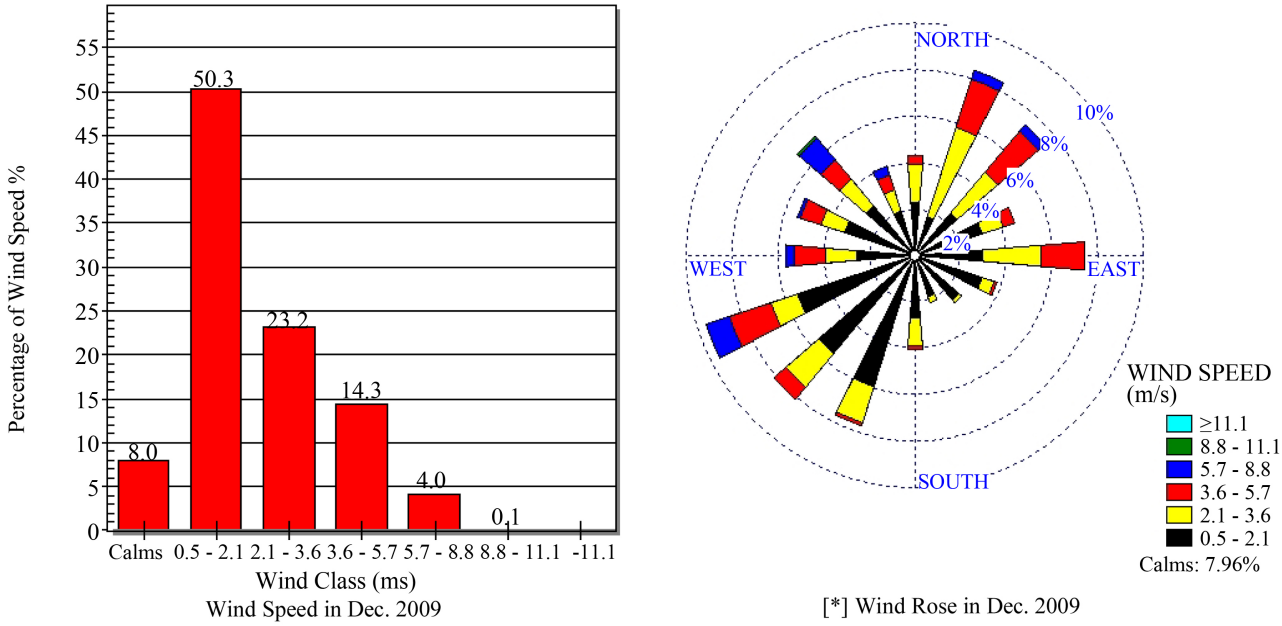


Figure 9. Wind speed and direction in Sana'a December 2009.

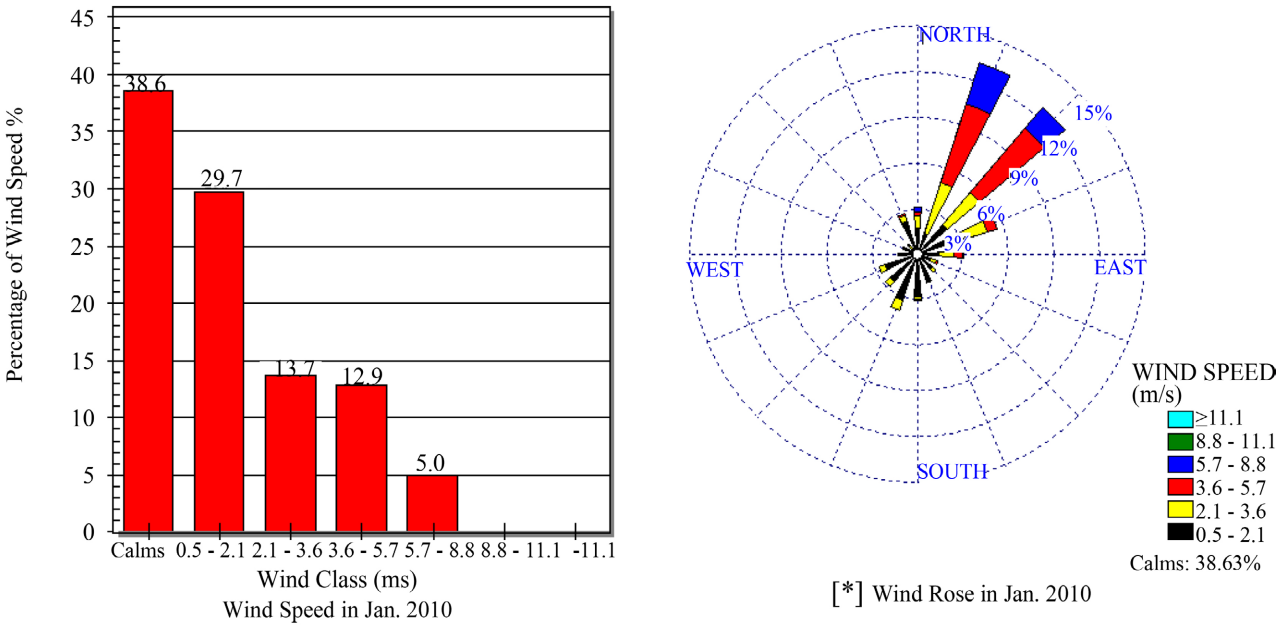
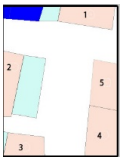
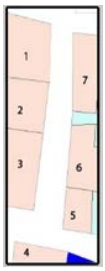
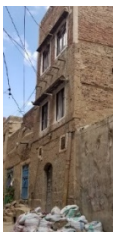
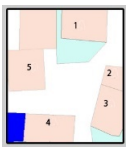


Figure 10. Wind speed and direction in Sana'a January 2010. [*] Lakes environment software 1999-2008 version 5.9.

satisfaction with their performance, by making an assessment that seeks to achieve this goal, and the questionnaire included Several axes, including:

- The relationship of the outer void to the entry of sunlight into the inner spaces
- Natural lighting
- Thermal performance of the interior spaces in the winter period
- Ventilation
- Relative humidity

Table 5. Details of the residential outdoors in Al-Jala'a neighborhood A, B, C, D.

Outdoor Space	Direction	No. of buildings	Materials	Some pictures of the surrounding buildings who agreed to take photos				
 A	North – South Wide	5	A mixture of stone and burnt bricks					Disagree to take photo
 B	North – South Narrow	7	A mixture of stone and burnt bricks					
 C	North – South Narrow	8	A mixture of stone and burnt bricks					
 D	East – West Wide	5	A mixture of stone and burnt bricks					Disagree to take photo

- Pollution: air, sound and visual
- Use of urban space
- Residents' observations about the urban space

Despite the war and the current crisis in Yemen, which imposed many challenges and obstacles, the most important of which was the difficulty of moving within cities, making questionnaires, asking people and taking pictures, a permit was taken from the General Authority for the Preservation of Historic Cities in Sana'a and the various competent security authorities to agree to conduct the questionnaire in the Old City of Sana'a and in the part in which there are outdoor spaces that were studied, in the winter and for a week, between November 30, 2020 to December 6, 2020, with the help of a team of 4 Architects, to target

all the houses overlooking the study spaces, with a total of 25 houses.

It appears from the analysis of the residents' opinions about the outdoor spaces—**Appendix I**—in general that space A and D are the best performing residential spaces, and their opinions are similar in spaces B and C as being the least performing.

5. Results

5.1. Air Temperature

It was noted that the difference in temperature between all the spaces throughout the hours of the day is the highest possible between six in the morning and twelve in the afternoon (the first period) and this difference reaches 21 Kelvin, while it is between twelve in the afternoon and six in the evening 13 Kelvin (the period the second). As for from six in the evening until twelve midnight (the third period) 6 Kelvin, that is approximately the same or less between midnight and six in the morning (the fourth period). It was found that the low-temperature curves in the tourist city are lower than those in Al-Jala'a neighborhood by approximately 2 to 4 K, noting that this value increases on the coldest days during the measurement period. Thus, the performance of Al-Jala'a spaces was better than the spaces of the tourist city.

It was found that the highest temperatures recorded in outdoor space (A), and the period of rising temperatures in it extends to four hours from twelve noon until three in the afternoon, where the highest temperature was recorded at two noon and a difference of 3 Kelvin from the rest of the other spaces, and it is noted that the temperature in this Space value jumps from 20˚C to 33˚C within one hour, between the eleventh and twelfth hours in the afternoon, and such a sudden change is not observed in other spaces in this way. The temperature in the space (B) increased from twelve noon—which is the highest—until one in the afternoon, and the high temperatures were almost identical in the spaces (C) and (D) at twelve noon. It was found that the lowest temperatures during the day's hours were detected at six o'clock in the morning, and they were close in spaces (B) and (C), with a higher value than those recorded in spaces (A) and (D), and by a difference of approximately one Kelvin.

The high temperatures at noon are more than those recorded by the meteorological station by about 8 K to 11 K—this increase varies from one space to another—and that the lowest temperatures in the spaces increase approximately from 3 Kelvin to 5 Kelvin than what was observed at the meteorological station at six in the morning.

5.2. Relative Humidity

Relative humidity rates in general in the spaces of the tourist city are higher than those recorded in the spaces of Al-Jala'a neighborhood in the early morning hours, while the relative humidity rates decrease in the noon hours to reach its lowest rate throughout the hours of the day, and it is noted that the values of

Low humidity levels in all study spaces at noon and after six in the evening.

In general, in all the spaces of Al-Jalaa lane is less than what was observed by the meteorological station the highest rate of relative humidity was observed at six in the morning and closely between spaces (A) and (D), while the observed rates were equal in the spaces (B) and (C) But at a lower rate than the other two spaces, and it is noted that the relative humidity.

The highest rate of relative humidity was detected at six o'clock in the morning and closely between spaces (A) and (D), while the rates were equal in spaces (B) and (C) but at a lower rate than the other two spaces, and we find that the relative humidity rates in all the spaces are less than the rates required to be achieved to reach thermal comfort from eleven in the morning until five in the evening (7 hours).

5.3. Air Velocity

The wind rose and its speeds for the month of December and its speeds in the month of January. It shows that static winds take up 8% and 38.6% of the total winds during December and January, respectively.

The prevailing wind direction in the city of Sana'a is the northeastern and eastern direction, with a large presence of southwestern winds in December. In January, the prevailing wind direction is the northeastern direction. As for the wind speed coming to the city where the velocity that is repeated more often than others is between 0.5 - 2.4 m/s.

The average air velocity measured in the study spaces in the old city, where it appears the readings of air in all the spaces of Al-Jala'a neighborhood at six in the morning are zero, meaning that there is no air movement at this time, and its recorded speed at the same time is slow outside the city, as shown by the air velocity readings obtained from the meteorological station, where its speed does not exceed 1 m/s. While monitoring the movement of air inside the spaces at one o'clock, but it is not large. We find that the space (D) records the highest air velocity among all the spaces of the evacuation lane, followed by the space (C), while the air velocity converges in the two spaces (A) and (B). It should be noted here that all speed rates measured at this time of noon are not big speed rates.

5.4. Assessment

It appears from the analysis of the residents' opinions about the outdoor spaces—**Appendix I**—in general that space A and D are the best performing residential spaces, and their opinions are similar in spaces B and C as being the least performing.

6. Conclusion

6.1. Measurements

The thermal performance of the residential urban spaces selected for climatic study in Sana'a City in its old and modern parts was identified through a de-

tailed and analytical study of field measurements of temperature, relative humidity and air velocities for the winter period, and the following was concluded:

6.1.1. Temperatures

- In general, the temperatures rise in all the outdoor residential spaces that were studied in the noon hours during the measurement period, and their thermal behavior is similar in the old and modern spaces, separately, during the night.
- Due to the distinguished performance of the outdoor residential spaces in Al-Jala'a neighborhood in Sana'a old city in terms of temperatures compared to the tourist city—Sheraton, the questionnaire was conducted only for the residents in Al-Jala'a neighborhood in the old city to determine the extent of their satisfaction with it.
- The highest temperatures are recorded in space (A) in the afternoon, and the period of rising temperatures extends to four hours from twelve noon until three in the afternoon, where the highest temperature was recorded at two o'clock in the afternoon and a difference of 3 Kelvin from the rest of the other spaces and this may be due to the direction of the axis of the north-south space and the width of the void where it is exposed to great solar radiation during the mentioned period and since the morning hours. It is noted that the temperature in this space jumps from approximately 21˚C to about 33˚C in one hour, between eleven and twelve o'clock in the afternoon. This sudden change in the other spaces in this large form, while the temperatures in the space (B) increased from twelve noon—which is the highest—until one in the afternoon, and the high temperatures were almost identical in the two spaces (C) and (D) at twelve noon and the performance of the space was similar (D) almost with the two spaces (B) and (C) although it is not a corridor but a wide space and this may be due to its east-west direction, which led to it not being exposed to direct radiation in the winter period, as happened with the space (A) which has a north-south direction. It has been found that fewer temperatures during the day's hours were monitored at six o'clock in the morning, and they were close in spaces (B) and (C), and a value higher than those recorded in spaces (A) and (D), and by approximately one Kelvin.
- When comparing the highest and lowest temperatures in all the spaces with those recorded by the meteorological station, we find that the high temperatures at noon are more than those recorded by the meteorological station by about 8 K to 11 K—this increase varies from one space to another—and the lowest temperatures in the spaces increase approximately from 3 Kelvin to 5 Kelvin than those observed by the meteorological station at six in the morning.
- We find that the two spaces (A) and (D) Al-Jala'a neighborhood—the old city have almost the same temperatures, but the space (A) has slightly higher temperatures than the space (D) due to the direction of the two spaces and their breadth and the nature of the building blocks surrounding them. High values

of temperatures in the afternoon hours (the highest values of temperatures throughout the day) than other spaces in the same lane (B) and (C).

- Spaces (B) and (C) in which the temperature values almost converged, and the lowest temperatures among all the spaces were observed, especially space (B) in the noon hours, and they also recorded the highest temperatures in the early morning hours (the lowest temperatures during the day) but with a difference of one Kelvin from the two wide spaces, and this may not make a big difference, and it was noted that space A is slightly higher than space D.
- The continuous exposure of the wide outer spaces A and D to solar radiation for a long time during the daylight hours, especially in space A, as well as the high temperatures inside the two spaces contributed to the storage of heat inside the building materials of the facades and its time delay, and the heating of the interior spaces and the feeling of people's warmth during the winter period, and this is what was concluded by asking the residents in all study spaces.
- The thermal range between the highest and lowest temperatures throughout the day is large and during a few hours in the afternoon, and this affects the comfort of the users of outdoor spaces and exposes them to heat stress in the winter period in the afternoon, as if the climate is summer, and also leads to the exposure of building materials on the facades of residential buildings overlooking the outer spaces of a large and sudden convection, the temperature range appears throughout the day between 19 - 24 Kelvin, while the temperature range in the weather is 16 Kelvin.
- Temperatures are generally higher in the spaces of the old city than in the spaces of the modern city throughout the hours of the day, and this is due to the effect of the city's compact fabric. Also, the differences are clear between the temperatures recorded in the measurement spaces (inside the city) and those observed at the weather station (outside the city).
- The big difference appears at noon, and this is an indication that the heat island phenomenon occurs in the city of Sana'a during the day.

6.1.2. Relative Humidity

- The highest rates of relative humidity were monitored in all the studied spaces in the early morning hours. It is noted that the relative humidity in general in all the spaces of Al-Jalaa neighborhood is less than what was observed by the meteorological station and throughout the day and that was recorded in the tourist city because of the vegetation cover.
- We find that the relative humidity rates in all spaces are less than the rates required to achieve thermal comfort from eleven in the morning until five in the evening (7 hours). Relative humidity levels decrease in all spaces, but it reaches its highest value in space (C) and is equal in spaces (B) and (D) and reaches its lowest value in space (A) in the noon hours, and this has contributed to the rise in temperatures, but the differences between all spaces are not important, and it can be said that the humidity levels in them are all low

and do not meet the requirements of thermal comfort, and that the air velocity does not have an appreciable effect due to the non-large air velocities, noting that even with the presence of plants in the spaces of the modern city, it did not contribute to an increase in humidity rates during this period. This is because plants, by their nature, work to close their gaps on the surfaces of their leaves in order to avoid solar radiation that they are exposed to in order to preserve water, and thus the transpiration process stops, and this means that the relative humidity does not increase in those spaces, so it is preferable to spray the space s and plants during this period of the day to contribute to increasing humidity rates Relativity. Here we note that the increase in relative humidity ranges from its lowest rate to the highest rate of 35% - 45%.

- The differences between the relative humidity rates observed in all the spaces and taken from the meteorological station are not large, but are almost close, as they do not in any way exceed 8%, whether high or low, because the city of Sana'a suffers from low relative humidity rates during the winter period.

6.1.3. Air Movement

- The prevailing wind direction in the city of Sana'a during the winter period takes the eastern and northeastern direction and shows the effect of the southwestern winds in the month of December, and the prevailing wind speed outside the city ranges between 0.5 - 2.4 m/s and this can be described as calm to a calm breeze according to the classification of Beaufort.
- It is noted that the movement of air in all spaces is not considered to have an effective effect due to the low rates of its speed, as the speed of the air arriving to it decreases as a result of the roughness coefficient due to the presence of buildings on the outskirts of the city, which act as air buffers that limit its speed and also change its direction.
- The wind movement is faster in the outskirts of the city and slow or static inside the city. It is noted that the air is still in all the study spaces in the two cities at the time of instantaneous measurement during the morning hours and calm to a calm breeze in the afternoon hours, which is faster in the spaces of the modern city (the fabric is open) than the spaces of the old city (compact fabric) in the winter period.
- The air velocity arriving at the city during the winter period is at not great speeds, as is evident from the results taken from the meteorology, which is the highest possible in the afternoon, and most likely that the air that appears in the spaces during the winter period, especially the open ones, may be due to the difference in pressure resulting from different degrees high and low temperatures throughout the day.

6.2. The Assessment

The following is the conclusion of the residents' opinion on all the studied spaces:

- The outdoors spaces A and D have access to the sun throughout the day, ex-

cept for houses with an eastern direction in space D, which was only one floor, and a house with a northern direction in spaces A and D, because the sun does not visit this direction.

- The houses painted on the outer spaces B and C do not enter the sun except from noon to the afternoon, from 3 - 5 hours depending on the height of the buildings. As for the north in space B, the sun does not visit it.
- Residents indicated that the width and breadth of spaces A and D allowed sunlight to enter their interior spaces, in contrast to the narrow spaces B and C, the direction of their buildings played a major role in that in addition to the heights of the opposite buildings.
- All residents indicated that natural lighting is appropriate in all spaces except for those on the ground floor, either due to the lack of windows on the ground floor and their small size, or the narrowness of the outdoor space. The use of artificial lighting has been used in the indoor spaces of the buildings overlooking the outdoor spaces B and C since afternoon period.
- Space D in which the house with the southern direction is warm to moderate in the winter period, while the houses with the eastern and western direction reported that its residents are from mild to cold, while the house with the northern direction is very cold. Space B and C, the residents indicated that their inner spaces in the winter period range from mild in the western direction to cold in the eastern direction, but the house with a northern direction in the space C is very cold. Space A, all residents reported that their internal spaces have moderate to warm thermal performance, except for the house with a northern direction, its facade has been closed due to the prior knowledge of the residents that it will be cold, and the windows are opened on the eastern and western directions.
- The small upper windows 10 × 20 cm (Shawaqees) in the houses are opened for ventilation throughout the day in all the spaces. As for the houses with a northern and eastern direction, they do not open except in the morning only because of the cold wind.
- With regard to relative humidity, all residents indicated that they suffer from severe dry skin due to the climate.
- Residents in Space D suffer from the presence of a peanut roasting plant within the residential group, and they are bothered by the odors emitted from it, and the residents confirm that they are not disturbed by the voices of the users of the space because they are their neighbors, and what bothers them is the movement of vehicles and motorcycles and the use of the space as a parking lot with no plants or any green spaces in addition to leaving garbage and construction waste and maintenance work, and the same observations made by the residents in space A, noting that they are bothered by the presence of the steam bath near them and the resulting smells and fumes for the purpose of heating the bathroom. As for the residents in spaces B and C, they added that garbage collection and burning bother them, in addition to the movement of

motorcycles.

- All the residents and in all the spaces notice the presence of dust in their interior spaces, as the surfaces of windows, tables and other furniture are cleaned either daily or at least 2 - 3 times a week.
- These spaces are used on a daily basis by all family members, while wearing normal clothes that are not heavy during the day in winter and heavy at night.
- Residents use the outdoor spaces to enjoy, walk and play for children, as it is safe and provides protection for them, and they can be monitored from the windows while they play.
- The elderly also uses it for exposure to the sun in the morning.
- These spaces are used for camping and holding various social events such as weddings, for example, and others social activities.
- These wide spaces serve as an outlet for neighbors to meet and talk with them, and it is also used by neighbors in narrow spaces.
- Regarding the general observations on the outdoor spaces, the residents indicated about the spaces A and D as follows:

- Pay attention to hygiene and litter.
- Eliminate the inconvenience of vehicles and motorcycles and the pollution.
- Resulting from them.
- They wish there were plants or green spaces.
- Eliminate the smells of the peanut shop, as well as the smells from the steam bath.

- People in spaces B and C had their opinion of their outer spaces B and C as follows:

- The spaces are narrow, and they wish they were wider.
- Studying the heights of buildings so that one building does not affect the right of another building to insolation.
- What they prefer in these spaces is that they do not encourage the passage of strangers.
- Residents feel comfortable in the outdoor spaces because of the fresh air in them and the warmth they feel inside.
- Family and children use it to enjoy time with neighbors and watch the kids.

7. Recommendations

According to the opinions of the residents whose homes overlook the study spaces: that the wide spaces D and A had preference for them, while the opinion of the residents in the narrow spaces B and C was that it deprived their facades of obtaining the required solar radiation for their internal spaces, and their social requirements and comfort were not met, as did the wide spaces.

This study concluded with the following recommendations:

7.1. Outdoor Spaces

- All residents in the studied spaces prefer wide outdoor spaces over narrow

spaces.

- It is preferable that the axis of the large residential outdoor spaces be in the east and west direction, such as space D, to ensure the entry of solar radiation for a longer period during daylight hours and to avoid the sharp and sudden rise in temperatures in the afternoon that appeared in the outer residential spaces that were toward the north and south and could be due to Increasing the period during which the vacuum is exposed to direct solar radiation and the length of its axis in the north-south direction, which allows the temperature to rise more.
- It is recommended to increase the number of houses facing the south direction, then the western direction, and reduce their number in the eastern and northern direction, considering the appearance of streets or corridors leading to the residential spaces on the eastern and northern sides. The directions, which in turn will contribute to increasing the air movement in the spaces that calm down inside the outer spaces of the city, as this is the prevailing wind direction in the city of Sana'a, which may reduce the temperature rise inside the external spaces and reduce and mitigate the exposure of building materials for facades to great heat stress during daylight hours.
- Encouraging the movement of air within the external residential spaces will mitigate the effect of the heat island phenomenon, which appeared in the city of Sana'a in the afternoon, with the noticeable rise in temperatures from ten in the morning until two in the afternoon, which makes the thermal range large in a few hours.
- The air movement will also allow the ventilation of the interior spaces during the day, coinciding with the air movement, which appeared to increase in the afternoon in the city of Sana'a, according to meteorological data, but it decreases movement and speed inside the city due to the narrowness of the corridors, the organic fabric and the way buildings are stacked.
- Separating the residential buildings completely from the service functions and taking into account the uses of the land so as not to allow the polluting commercial and industrial activities or disturbing sound, visual and movement to harass the residents and infringe their social, security and health comfort.
- Considering that each residential group has its own wide urban space that fulfills the needs of the houses overlooking it of privacy, sun, view, thermal and social comfort for users.
- Considering the proportions of the external residential spaces in length, width and height, and this needs a thorough research study to reach and adopt these proportions to achieve thermal and social comfort for the population in the new residential communities in the city of Sana'a, and the dimensions of the spaces studied in this research paper can be taken advantage of.
- Emphasis on the separation of all types of automated traffic from the resi-

dential complex and its external spaces, and vehicles and motorcycles are not allowed to enter it, with the allocation of remote parking spaces for them, but within the human scale for walking.

- Paying attention to the coordination of the outdoor spaces, the allocation of places for children to sit and play, and the cultivation of appropriate plants. It is recommended for plants that are not evergreen throughout the year, whose leaves fall during the winter period to allow the penetration of solar rays into the external spaces, and the addition of some plants suitable for the facades of residential buildings on the walls and elements of the facades and inside the internal spaces to increase rates of relative humidity in the external and internal spaces, taking into account that irrigation is carried out in the morning and noon period to contribute to raising the relative humidity rates.
- Adding water elements within the coordination of the external spaces to work on increasing the relative humidity rates in them, such as fountains, public fountains, and even water fountains, which are Islamic elements that appeared significantly in the scheme of Islamic cities, and it is necessary to study and consider their design and try to add them within the external residential spaces.
- The wide outdoor space is preferred by the residents over the narrow ones. Therefore, it must be taken into account that its design achieves flexibility and sustainability in order to meet the needs and requirements of the population in terms of social activities such as places to sit, play children, talk to neighbors, enjoy the sun, and sunbathe for the elderly who prefer to sit in front of their homes.
- Benefiting from the rich environmental thought in its planning and design details in the old Yemeni cities and analyzing it in detail to reach sustainable environmental principles that contribute to the planning and design of modern residential groups.
- Putting humanitarian considerations at the center of attention and consulting residents in the various residential communities and making the necessary questionnaires to ensure community participation and considering the human, social and cultural requirements of the population with regard to planning and designing the residential communities and their external housing spaces.

7.2. Indoor Spaces

The heights of the buildings overlooking the outdoor residential space and the importance of ensuring the rights of all residents whose homes overlook it must be studied to take into account the fulfillment of everyone's needs as much as possible from insolation and views, and through the distribution of windows in the facades, and studying their dimensions and number. I committed to increasing the number of windows with the height in addition to the widening of the dimensions of those openings as we rose to the top so that the sun was caught

and entered into the interior spaces.

- Not to use the ground floor spaces as living spaces for the residents, and they can be replaced as warehouses or entrance and reception halls, or they are raised on columns and used as a shaded garden, seating areas, and entrance to the residential building and other spaces and uses that do not directly affect the residents' thermal requirements and their need for sun entry and heating in the cold winter in the city of Sana'a in particular, in the sleeping and living spaces, it also affects the privacy requirements of the population according to the culture of Yemeni society, and therefore the requirement not to use the ground floor for sleeping and living spaces will be appropriate in all respects.
- Emphasis on not directing important spaces for the population on the northern side, and that it overlooks the southern, then western and finally eastern directions, and that building laws and regulations are strict in this regard. A building permit should not be given to any residential facility except after observing this condition, as people in the city of Sana'a know well the importance of direction when building their homes, and they have an inherited building culture for hundreds of years regarding this matter. Therefore, the view of important internal spaces such as sleeping and living should be avoided in this direction, provided that other service spaces such as stairs, stores, bathrooms and entrance halls are directed in this direction. If they have another available direction, they close the walls overlooking this direction if the internal spaces are important such as sleeping, living and guests, and opening windows on other directions to avoid the effect of the northern direction, which is not reached by the sun and is exposed to cold winds during the critical winter period in Sana'a's climate throughout the year.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix I: A Brief Description of the Opinion of the Residents in the Targeted Outdoor Spaces in This Study—Al-Jala'a Neighborhood A, B, C, D—Old Part of Sana'a City.

Spaces	The sun's rays enter the outdoor space and facades	The presence of urban space allows more sunlight to enter	Natural lighting in the overlooking spaces is appropriate	Is artificial lighting used during the day?	Thermal performance of interior spaces in the winter period	Ventilation	Relative humidity	Pollution			Satisfaction with the existence of urban space	General notes about the urban space
								Optical	acoustic	antenna		
Space A	It enters all day period and to the facades by its directions except for the house in the north D3	Yes, because of the urban space view	very suitable	No	A house with a south direction is warm to moderate. A house with an eastern and western direction is moderate to cold. A house with a north direction is very cold	The windows are opened during the day, and the small windows (Shawaqis-Upper openings of sizes 10 × 20 cm are located at the top of the wall and between the windows of the room) are opened for ventilation at night when needed, but the northern and eastern houses do not open except in the morning because of the cold wind	All residents indicated that they suffer from severe dry skin due to the climate	Unpleasant odors from the steam bath, which burning woods and other stuff to heat it, smoke from vehicles, motorcycles, and dust, as the surfaces of windows and furniture are cleaned daily or at least 2 - 3 times a week	Residents were not disturbed by the sounds of space users, but rather by the noise of vehicles and motorbikes and the movement of the users the close steam bath	The space is used as a car park	We feel comfortable with its presence because of its direction and its spaciousness. It is used daily by all family members. We wear normal clothes that are not heavy during the winter day and heavy at night. - to have fun - Walking - Monitoring children, safety, and protection for them For camping and social events such as marriage, etc. We find an outlet in it and meet the neighbors and talk to them	Take care of its cleanliness Eliminate odors from the adjacent bathroom Lots of strangers because of the bathroom next door Getting rid of the hassle of vehicles and bikes Taking care of plants and green space
Space B	It enters from noon to the afternoon, about 3 - 5 hours for the upper floors only, as for the lower floors and the first floors, the sun does not visit them due to the narrowness of the space As for the house C4, do not enter it at all because it is north	Yes, but due to the narrow urban space, it intervened for a short period	Yes, except on the ground floor	in the afternoon	cold	The small windows (Shawaqis) are opened for ventilation during the day, but at night they are not opened	All residents indicated that they suffer from severe dry skin due to the climate	Unpleasant odors from sewage, garbage, garbage fire, motorcycle smoke, and the presence of dust, as the surfaces of windows and furniture are cleaned daily or at least 2-3 times a week	Annoying from the noise of motorbikes.	Leaving garbage, construction waste and maintenance work	Residents feel comfortable from the space because of the fresh air that enters because of its presence. The family and children use it daily to enjoy with talking to the neighbors and watch the children	If it was bigger to provide a space for sitting and more space for children to play, and to get more sun, take care of its cleanliness, cover the sewer holes, and get rid of the hassle of motorbikes Not putting garbage and construction waste in the space
Space C	The sun enters from noon to the afternoon, about 3 - 5 hours for the upper floors only, as for the lower floors and the first floors, the sun does not visit them due to the narrowness of the space	Yes, for a short period of some hours because it is tight	Yes, except on the lower floors	Yes, in the afternoon	cold	The small windows (Shawaqis) are opened for ventilation during the day, but at night they are not opened	All resi-dents indicated that they suffer from severe dry skin due to the climate	Unpleasant odors from garbage, garbage fire, motorcycle smoke, and the presence of dust, as the surfaces of windows and furniture are cleaned daily or at least 2 - 3 times a week	Annoying from the noise of motorbikes	Leaving rubbish and construction waste for maintenance	Strangers do not pass through it, and it is the narrowness of the opposite buildings of height that contribute to its narrowness and deprivation of the sun	Paying attention to hygiene, getting rid of the inconvenience of motorbikes, and the presence of plants or green spaces Not putting garbage and construction waste in the space

Continued

Space D	The houses in the southern D1 and western directions D4, D5 are exposed to the sun, except in the eastern direction, because it is one floor, and the sun is blocked from it because of the height of the house opposite it.	Yes, this is allowed due to its spaciousness, but the direction plays a role in addition to the heights of the corresponding buildings	Very suitable in all floors except the ground floor because its openings are	No	A house with a south direction is warm to moderate. A house with an eastern and western direction is moderate to cold. A house with a north direction is very cold	The windows are opened during the day, and the small windows (Shawaqis) are opened for ventilation at night when needed, but the northern and eastern houses do not open except in the morning because of the cold wind	All residents indicated that they suffer from severe dry skin due to the climate	Residents suffer from the presence of a peanut factory within the residential group and smoke from vehicles, motorcycles, and dust, as the surfaces of windows and furniture are cleaned daily or at least 2 - 3 times a week	Residents were not bothered by the sounds of the space users, but by the movement of vehicles and motorbikes	Use of the space as a car park, no plants, or green spaces, Leaving garbage, construction waste and maintenance work	All residents are satisfied with the presence of a wide space they use to enjoy talking with neighbors, Children play safely, Elderly sit to sunbathe and talk to passersby from the neighbors	paying Attention to cleanliness, getting rid of the inconvenience of vehicles and motorcycles, the presence of plants or green spaces