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URBAN MICRO CLIMATE PERFORMANCE IN DEFERENT URBAN FABRIC IN MOSUL, IRAQ

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ABSTRACT

City of Mosul has a traditional urban core called *old city*, side by side with a modern fabric adopted by municipal authority since the rapid urbanization which the city had witnessed in the fifties of the last century, the traditional one characterizes with a compact and organic tissue, Introverted courtyard buildings built with a heavy thick masonry structure, while the modern is open geometric one with a wide streets and extraverted buildings build with concrete. City of Mosul has a hot dry climate summers and cool rainy winter, this research aims to make a comparative study for the urban micro climate performance (air temperature and relative humidity) in the two deferent urban fabrics (traditional and modern), during both the hottest and the coldest period of the year, using the meteorological data as a reference for evaluating the performance. The way cities are planned and built is therefore important for the global energy use environmental comfort. So it's important to study the relationship between urban form and outdoor climate. The preliminary results confirm that the climatic conditions are much more stable in the traditional city than in the modern part of the city, regarding both air temperature and relative humidity.

INTRODUCTION

It is well known that the built environment Modify the climate. It has found that the geometry of buildings and properties of building materials have a strong influence on the urban climate. Parameters such as building density, height to width ratio of street canyon thermal admittance and color have a direct influence on the climate around buildings. This climate affects the comfort of humans at street level. It also influences the thermal stress on buildings and thus affects indoor comfort as well as energy use for heating and cooling [1].

It is possible to create a good urban climate through conscious urban planning and design. However, in most cases the climate is not sufficiently considered in the planning and design processes and as a consequence, many urban areas are uncomfortable. Whereas comfort and energy use on single buildings have been studied extensively, outdoor comfort and energy use in urban areas have had little attention [2]. Climatic aspects are seldom considered in urban planning codes. The problem is especially great in developing countries with rapid urbanization, where cities grow with

little control. Today's urban design and planning is often inspired by western movements and trends developed for a totally different climate.

City of Mosul has a traditional urban core called *old city*, side by side with a modern fabric adopted by municipal authority since the rapid urbanization which the city had witnessed in the fifties of the last century, the traditional one characterizes with a compact and organic tissue, Introverted courtyard buildings built with a heavy thick masonry structure, while the modern is open geometric one with a wide streets and extraverted buildings build with concrete. City of Mosul has a hot dry climate summers and cool rainy winter, this research aims to make a comparative study for the urban micro climate performance (air temperature and relative humidity) in the two deferent urban fabrics (traditional and modern), during both the hottest and the coldest period of the year, using the meteorological data as a reference for evaluating the performance. The final results confirm that the climatic conditions are much more stable and a better performance in the traditional city than those at the modern part of the city, regarding both air temperature and relative humidity.

BACKGROUND

Mosul, with almost two million inhabitants, is the third largest city in Iraq. Mosul is situated **36.19 N, 43.09 E**, at **230 m** above sea level in a hilly area between the Mountains in the North and the *Al-jazeera* plane in the South and the West, Tigress River divides the city into two parts. The climate of Mosul is characterized by hot and dry summers and cold winters with rare snow, [3]. Annual mean temperature is **19.5**◦ C and rainfall is **383** mm, [4]. Monthly climate data is shown in figures (1, 2).

Mosul consists of two contrasting parts: the traditional Arabic-Islamic, organic urban pattern, the *old city,* and the modern city with its gridiron urban pattern. One housing district in each part of the city was studied.

Almakkaoui in the *old city* is one of the most densely developed areas. Introverted courtyard buildings in two to three stories surround the narrow streets, which cut deep ravines through the city. The street network is irregular, which means that the buildings shade each other, there is a great variation of traditional building elements and a large number of building details provide shade at street level.

Almalia is a modern, two story housing area in the new part of Mosul, planned and built as a suburb with extroverted detached and semi detached houses. The area has a

regular pattern wide street planned for car ownership. This low density means both buildings and the ground are exposed to a great amount of solar radiation. Only a few trees provide shade for some facades and footways.

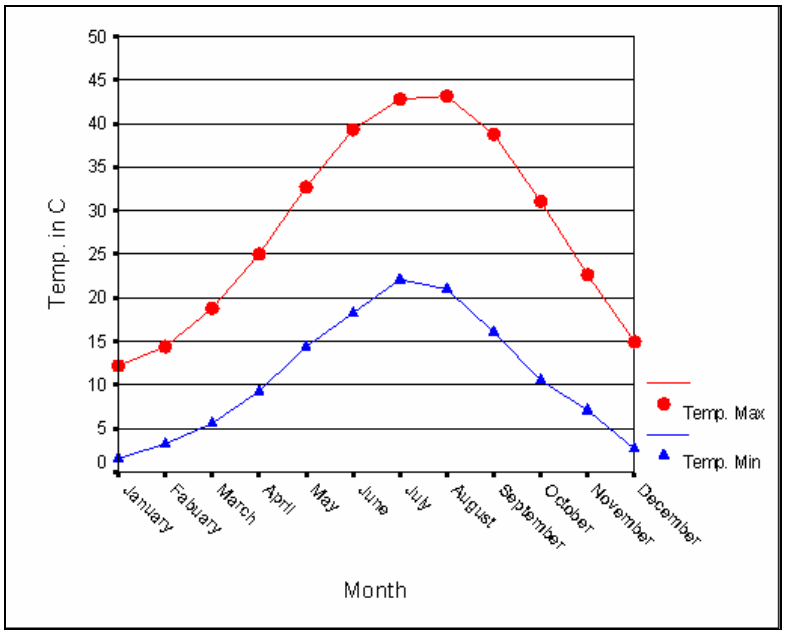

Figure 1. Max. & Min air temperature in Mosul City

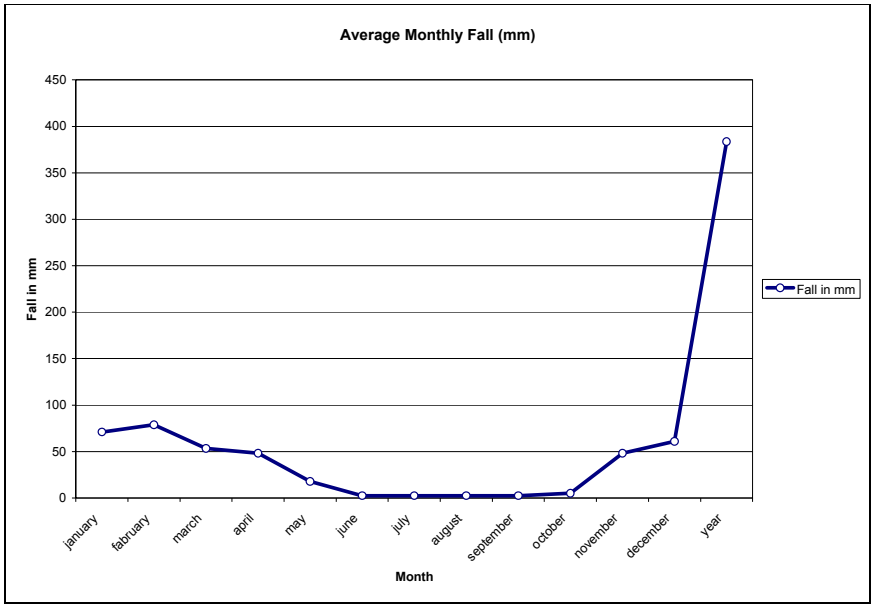

Figure 2. Monthly and Annual Rain Fall in Mosul City

PROBLEM

Different urban shapes result in different urban microclimates. This study seeks to define relevant parameters in traditional and modern living areas. The aim is to find combinations of qualities from both environments, to be used in guidelines for future housing development in Iraq.

METHODOLOGY

Measuring Points: In each neighbourhood several measuring points were studied. Measurements were made in two different street orientations, fig (3). In *Almakkaoui* the height to width (H/W) ratio of the street canyons varied between 4.25 and 3.64, whereas in *Almalia* the (H/L) ratios were 0.17-0.2. While the sky view factor (SVF) in *Almakkaoui* was between 0.056-0.061, whereas in *Almalia* the (SVF) was between 0.74-0.8.

For each measuring point, air temperature and relative humidity were measured in the middle of the street canyon, 2 m above street level. The instrument was protected from sunlight during the measurements. The measurements took place each hour per day from the sun rise to sun set, in summer (from 20th of July to 5th of August 2006) and winter (from the 20th of January to 5th of February in 2007). The measurements were made in one district at a time: seven days in one district followed by seven days in the other district.

All measurements were made with the testo-179-H2 instrument. The accuracy of the air temperature is ±0.5°C and 3% for the relative humidity

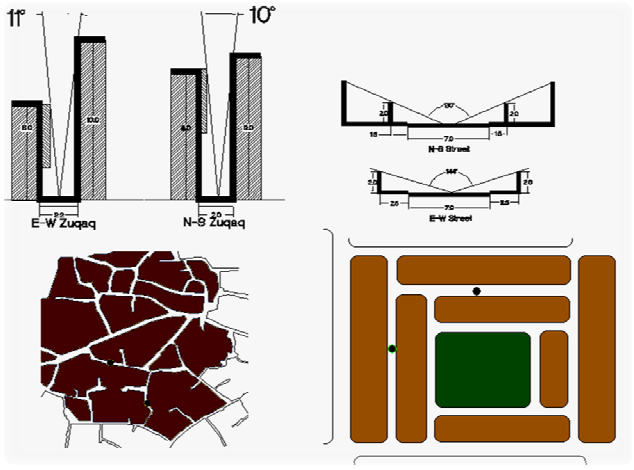

Figure 3. Plans and sections of measuring points in the traditional and modern urban fabric in Mosul city.

Climate Measurements: The measurements were made during summer, 20 July-5 august 2006, and winter 20 January-5 February in 2007. The "official" climate for Mosul (non urban climate) for the actual periods, measured at the Meteorological station situated on the outskirts of the city.

RESULTS

The measurements can be divided in two category; air temperature and relative humidity.

Air Temperatures

(1) - Summer:

The air temperatures measured in the *Almakkaoui* district (in the old city) varied very slightly and steadily in different hours of the day, with a Standard deviation 2.08-2.74 less than that one at Meteorological station 6.67. The minimum temperatures were 3.1-2.8°C higher than the "Meteorological station" for all measurement points all the days of measuring. The maximum temperatures were 8.9-8.3°C lower than the Meteorological station ones. The daily mean of air temperature was 4.9-4.5°C lower than the Meteorological station ones. Table (1, 2). No significant difference could be observed between streets of different orientation.

.The air temperatures measured in the district *Almalia* varied roughly during the hours of the day with a standard deviation 6.62 which is almost the same one at the Meteorological station 6.69-6.83. The minimum temperatures were 0.4-0.5°C higher than the ones measured at the Meteorological station. The maximum air temperatures were 2.3-2.6°C higher than the Meteorological station. The daily mean of air temperature was 1.59-1.63°C higher than the Meteorological station ones. Table (3, 4) As in Almakkaoui, no significant difference could be observed between streets of different orientation.

Table 1. Summer daily cycle of air temperatures in (N-S) Traditional street canyon compared with meteorological station records.

Time	Air temp. in the Traditional Path	Air temp. at meteo. station	Deference in air temperature
6:00 AM	31.1	28.0	3.1
7:00 AM	31.0	29.6	1.4
8:00 AM	31.5	32.9	-1.4

9:00 AM	33.3	35.6	-2.3
10:00 AM	34.3	38.7	-4.3
11:00 AM	35.6	41.5	-5.9
12:00 AM	35.9	42.3	-6.4
1:00 PM	36.2	44.0	-7.8
2:00 PM	36.3	45.2	-8.9
3:00 PM	36.9	45.4	-8.5
4:00 PM	36.9	45.1	-8.2
5:00 PM	36.3	44.6	-8.3
6:00 PM	36.0	43.1	-7.2
7:00 PM	35.3	39.5	-4.2
Mean	34.8	39.7	-4.9
Daily variance	5.6	17.4	
Standard deviation	2.08	6.67	

Table2. Summer daily cycle of air temperatures in (E-W) Traditional street canyon compared with meteorological station records.

Time	Air temp. in the Traditional Path	Air temp. at meteo. station	Deference in air temperature
6:00 AM	30.8	28.0	2.8
7:00 AM	31.0	29.6	1.4
8:00 AM	31.7	32.9	-1.2
9:00 AM	33.6	35.6	-2.0
10:00 AM	34.9	38.7	-3.7
11:00 AM	35.9	41.5	-5.5
12:00 AM	36.7	42.3	-5.6
1:00 PM	36.9	44.0	-7.2
2:00 PM	36.9	45.2	-8.3
3:00 PM	37.6	45.4	-7.8
4:00 PM	37.6	45.1	-7.5
5:00 PM	36.8	44.6	-7.8
6:00 PM	36.2	43.1	-6.9
7:00 PM	35.7	39.5	-3.8

Mean	35.2	39.7	-4.5
Daily variance	7.4	17.4	
Standard deviation	2.74	6.67	

Table 3.Summer daily cycle of air temperatures in (N-S) Modern street canyon compared with meteorological station records.

Time	Air temp. in the Modern Path	Air temp. at meteo. station	Deference in air temperature
6:00 AM	31	30.5	0.5
7:00 AM	31.5	29.9	1.6
8:00 AM	33.2	29.6	3.6
9:00 AM	34	31.8	2.2
10:00 AM	35.5	34.8	0.7
11:00 AM	38.2	37.4	0.8
12:00 AM	44.9	42	2.9
1:00 PM	45.1	43.6	1.5
2:00 PM	46.7	44.8	1.9
3:00 PM	48.3	46	2.3
4:00 PM	47.3	46.2	1.1
5:00 PM	45.7	44.8	0.9
6:00 PM	44.6	44	0.6
Mean	40.46	38.87	1.59
Daily variance	17.3	16.7	
Standard deviation	6.62	6.69	

Table 4.Summer daily cycle of air temperatures in (E-W) Modern street canyon compared with meteorological station records.

Time	Air temp. in the Modern Path	Air temp. at meteo. station	Deference in air temperature
6:00 AM	30.9	28.3	0.4
7:00 AM	31.5	28.0	1.6
8:00 AM	33.1	29.6	3.5
9:00 AM	34.3	32.9	2.5
10:00 AM	35.8	35.6	1
11:00 AM	38.3	38.7	0.9
12:00 AM	44.5	41.5	2.5
1:00 PM	45.9	42.3	2.3
2:00 PM	46.8	44.0	2
3:00 PM	48.6	45.2	2.6
4:00 PM	47.4	45.4	1.2
5:00 PM	45.3	45.1	0.5
6:00 PM	44.2	44.6	0.2
Mean	40.51	39.7	1.63
Daily variance	17.7	17.4	
Standard deviation	6.63	6.83	

(2) - winter:

The air temperatures measured in the *Almakkaoui* district (in the old city) varied slightly and steadily between different hours of the day, with a very small Standard deviation 1.74 less than that one at Meteorological station 4.18. The minimum temperatures were 4.93-4.6°C higher than that recorded at the "Meteorological station" 1.5°C. The maximum temperatures were 10.23°C slightly lower than the Meteorological station ones. But the daily mean of air temperatures were 8.68-8.83°C higher than the Meteorological station ones by 1.83-1.98°C. Table (5, 6). No significant difference could be observed between streets of different orientation.

Tables (7, 8) shows air temperatures measured in *Almalia* in winter. The air temperatures measured in this district varied slightly during the hours of the day with a standard deviation 2.17-2.57 but higher than that one at the Meteorological station 1.5. The minimum temperatures were 0.67- 1.07°C higher than the ones measured at the Meteorological station. The maximum air temperatures were 1.2-1.7°C higher than the Meteorological station. The daily mean of air temperature was 0.67-1.07°C higher than the Meteorological station ones. No significant difference could be observed between streets of different orientation for both types of districts.

Table 5. Winter daily cycle of air temperatures in (N-S) Traditional street canyon compared with meteorological station records.

Time	Air temp. in the Traditional Path	Air temp. at meteo. station	Deference in air temperature
7:00 AM	6.43	1.50	4.93
9:00 AM	7.17	3.27	3.9
12:00 AM	9.83	9.27	0.56
3:00 PM	10.23	10.97	-0.74
5:00 PM	9.73	9.23	0.5
Mean	8.68	6.85	1.83
Daily variance	3.8	9.47	
Standard deviation	1.74	4.18	

Table 6. Winter daily cycle of air temperatures in (E-W) Traditional street canyon compared with meteorological station records.

Time	Air temp. in the Traditional Path	Air temp. at meteo. station	Deference in air temperature
7:00 AM	6.10	1.50	4.6
9:00 AM	7.13	3.27	3.86

12:00 AM	9.53	9.27	0.26
3:00 PM	10.30	10.97	-0.67
5:00 PM	11.07	9.23	1.84
Mean	8.83	6.85	1.98
Daily variance	3.8	9.47	
Standard deviation	1.74	4.18	

Table 7.Winter daily cycle of air temperatures in (N-S) Modern street canyon compared with meteorological station records.

Time	Air temp. in the Modern Path	Air temp. at meteo. station	Deference in air temperature
6:00 AM	2.17	1.50	0.67
7:00 AM	3.53	2.03	1.50
8:00 AM	4.80	3.03	1.77
9:00 AM	5.67	4.00	1.67
10:00 AM	6.37	5.13	1.23
11:00 AM	7.80	6.27	1.53
12:00 AM	9.70	7.53	2.17
1:00 PM	9.53	8.40	1.13
2:00 PM	9.60	8.40	1.20
3:00 PM	8.30	7.90	0.40
4:00 PM	7.80	7.73	0.07
5:00 PM	7.53	6.57	0.97
6:00 PM	6.90	5.43	1.47
Mean	7.53	7.9	0.67
Daily variance	2.45	2.51	
Standard deviation	2.17	1.50	

Table 8.Winter daily cycle of air temperatures in (E-W) Modern street canyon compared with meteorological station records.

Time	Air temp. in the Modern Path	Air temp. at meteo. station	Deference in air temperature
6:00 AM	2.57	1.50	1.07
7:00 AM	3.70	2.03	1.67
8:00 AM	4.90	3.03	1.87
9:00 AM	6.07	4.00	2.07
10:00 AM	6.83	5.13	1.70
11:00 AM	8.23	6.27	1.97
12:00 AM	9.87	7.53	2.33
1:00 PM	9.50	8.40	1.10
2:00 PM	9.13	8.40	0.73
3:00 PM	8.43	7.90	0.53
4:00 PM	7.50	7.73	-0.23
5:00 PM	9.55	6.57	2.98
6:00 PM	6.98	5.43	1.56
Mean	7.3	6.9	1.07
Daily variance	2.43	2.51	
Standard deviation	2.57	1.50	

Relative Humidity

(1) - Summer:

Almakkaoui district has a higher and more stable relative humidity (Standard deviation 7) than *Almalia* (Standard deviation 11), the daily means of the RH at *Almakkaoui* were 35%-31% whereas at *Almalia* was 24% for both deferent orientation streets, and the traditional district had recorded a higher mean RH than the Meteorological station by 7% in contrast to the modern district which recorded lower than the Meteorological station by 2%. There was a small difference could be observed between streets of different orientation for the traditional district only. Tables (9, 10, 11, 12).

Table 9. Summer daily cycle of Relative humidity in (N-S) Traditional street canyon compared with meteorological station records.

Time	Relative humidity in the Traditional Path	Relative humidity at meteo. station	Deference in Relative humidity
6:00 AM	41.7	42.3	-0.7
7:00 AM	38.3	44.7	-6.3
8:00 AM	45.4	42.7	2.7
9:00 AM	41.0	35.0	6.0
10:00 AM	38.3	27.7	10.6
11:00 AM	31.5	22.3	9.2
12:00 AM	27.2	20.7	6.5
1:00 PM	25.8	18.7	7.1
2:00 PM	29.5	15.3	14.1
3:00 PM	31.1	15.0	16.1
4:00 PM	22.1	15.3	6.8
5:00 PM	27.2	15.0	12.2
6:00 PM	29.2	18.0	11.2
7:00 PM	32.3	26.4	6.9
Mean	35.2	39.7	7.31428571
Daily variance	53.2	129.8	
Standard deviation	7.3	11.4	

Table 10. Summer daily cycle of Relative humidity in (E-W) Traditional street canyon compared with meteorological station records.

Time	Relative humidity in the Traditional Path	Relative humidity at meteo. station	Deference in Relative humidity
6:00 AM	39.3	42.3	-3.1
7:00 AM	43.2	44.7	-1.4
8:00 AM	43.2	42.7	0.6
9:00 AM	39.2	35.0	4.2
10:00 AM	36.9	27.7	9.2
11:00 AM	33.1	22.3	10.8
12:00 AM	29.7	20.7	9.0

1:00 PM	26.8	18.7	8.1
2:00 PM	24.6	15.3	9.3
3:00 PM	20.2	15.0	5.2
4:00 PM	24.1	15.3	8.8
5:00 PM	26.6	15.0	11.6
6:00 PM	27.1	18.0	9.1
7:00 PM	25.2	23.3	1.9
Mean	31.37	25.43	5.95
Daily variance	58.75	123.92	
Standard deviation	7.66	11.13	

Table 11. Summer daily cycle of Relative humidity in (N-S) Modern street canyon compared with meteorological station records.

Time	Relative humidity in the Modern Path	Relative humidity at meteo. station	Deference in Relative humidity
6:00 AM	36.1	42	-5.9
7:00 AM	38.2	44	-5.8
8:00 AM	36.1	47	-10.9
9:00 AM	36.2	40	-3.8
10:00 AM	35.9	38	-2.1
11:00 AM	30.9	22	8.9
12:00 AM	13.3	21	-7.7
1:00 PM	14.3	19	-4.7
2:00 PM	14	16	-2
3:00 PM	14.5	13	1.5
4:00 PM	10.1	12	-1.9
5:00 PM	12.4	13	-0.6
6:00 PM	22.6	15	7.6
Mean	24.2	26.30769	-2.10769
Daily variance	130.046667	183.73	
Standard deviation	11.4038005	13.555	

Table 12. Summer daily cycle of Relative humidity in (E-W) Modern street canyon compared with meteorological station records.

Time	Relative humidity in the Modern Path	Relative humidity at meteo. station	Deference in Relative humidity
6:00 AM	36.5	42	-5.5
7:00 AM	39	44	-5
8:00 AM	36.2	47	-10.8
9:00 AM	35.7	40	-4.3
10:00 AM	34.8	38	-3.2
11:00 AM	29	22	7
12:00 AM	11.7	21	-9.3
1:00 PM	16.8	19	-2.2
2:00 PM	13.2	16	-2.8
3:00 PM	8.8	13	-4.2
4:00 PM	13.4	12	1.4
5:00 PM	16.8	13	3.8
6:00 PM	27	15	12
Mean	24.53077	26.30769	-1.77692
Daily variance	127.413974	183.73	
Standard deviation	11.2877799	13.555	

(2) - winter:

In comparison with the Meteorological station the traditional district (*Almakkaoui*) relatively has a higher and more stable RH (Standard deviation 4.4-4.9) than *Almalia* (Standard deviation 9), the daily means of the RH at *Almakkaoui* were 58%-57% lower than the Meteorological station by 7%, whereas at *Almalia* was 65% lower than the Meteorological station by 8-9%. No significant difference could be observed between streets of different orientation for both types of districts. Tables (13, 14, 15, 16).

Table 13. Winter daily cycle of Relative humidity in (N-S) Traditional street canyon compared with meteorological station records.

Time	Relative humidity in the Traditional Path	Relative humidity at meteo. station	Deference in Relative humidity
7:00 AM	62.43	83.00	-20.57
9:00 AM	62.93	78.00	-15.07
12:00 AM	54.80	57.67	-2.87
3:00 PM	53.20	46.00	7.2
5:00 PM	58.17	60.67	-2.5
Mean	58.31	65.07	-6.762
Daily variance	19.19263	231.61	
Standard deviation	4.3809394	15.219	

Table 14. Winter daily cycle of Relative humidity in (E-W) Traditional street canyon compared with meteorological station records.

Time	Relative humidity in the Traditional Path	Relative humidity at meteo. station	Deference in Relative humidity
7:00 AM	62.77	83.00	-20.23
9:00 AM	62.20	78.00	-15.8
12:00 AM	54.47	57.67	-3.2
3:00 PM	51.70	46.00	5.7
5:00 PM	56.00	60.67	-4.67
Mean	57.43	65.07	-7.64
Daily variance	23.72697	231.61	
Standard deviation	4.87103377	15.219	

Table 15. Winter daily cycle of Relative humidity in (N-S) Modern street canyon compared with meteorological station records.

Time	Relative humidity in the Modern Path	Relative humidity at meteo. station	Deference in Relative humidity
7:00 AM	81.30	92.33	-11.03
8:00 AM	77.53	85.33	-7.80
9:00 AM	71.93	79.33	-7.40
10:00 AM	70.27	76.00	-5.73
11:00 AM	65.40	74.33	-8.93
12:00 AM	60.57	69.67	-9.10
1:00 PM	56.70	63.33	-6.63
2:00 PM	52.83	58.67	-5.83
3:00 PM	53.37	60.00	-6.63
4:00 PM	59.60	66.33	-6.73
5:00 PM	63.37	66.67	-3.30
6:00 PM	72.03	73.67	-1.63
Mean	65.41	73.49	-8.08
Daily variance	86.34239697	102.8690333	
Standard deviation	9.292060965	10.14243725	

Table 16. Winter daily cycle of Relative humidity in (E-W) Modern street canyon compared with meteorological station records.

Time	Relative humidity in the Modern Path	Relative humidity at meteo. station	Deference in Relative humidity
7:00 AM	80.10	92.33	-12.23
8:00 AM	74.83	85.33	-10.50
9:00 AM	72.17	79.33	-7.17
10:00 AM	69.40	76.00	-6.60
11:00 AM	65.47	74.33	-8.87
12:00 AM	60.13	69.67	-9.53
1:00 PM	53.70	63.33	-9.63

2:00 PM	51.10	58.67	-7.57
3:00 PM	54.90	60.00	-5.10
4:00 PM	59.83	66.33	-6.50
5:00 PM	62.03	66.67	-4.63
6:00 PM	61.15	73.67	-12.52
Mean	64.40	73.49	-9.09
Daily variance	79.39999015	102.8690333	
Standard deviation	8.910667211	10.14243725	

CONCLUSIONS

- As measurements did not take place at the same time in both neighbourhoods, the results by no means give a complete picture of the climate. However, the measurements indicate great differences in climate between the extremely dense old city and the very open urban tissue of the modern one.
- In the modern district the heat island phenomenon is clear with higher temperatures than reported from the Meteorological station outside the city.
- During daytime, however, the two neighbourhoods show totally different behaviour. In the densest part, of the old city the air temperature is normally *lower* than the Meteorological station temperature whereas it is *higher* in modern district. One explanation to this is that the sun does not penetrate down into the narrow street canyons; and most of the sunshine is reflected by the light coloured roofs. Furthermore the dense and heavy structure of the Medina reacts very slowly to temperature differences.
- In general, the climatic conditions are much more stable in the old city than in modern part of the city regarding both air temperature and relative humidity, which is play an important role in the physical comfort of the pedestrians. The stable climate in the traditional canyon is partly attributed to the large mass of the traditional area. The ratio between the total surface of walls and street and the air volume in the canyon is considerably higher in the old city. Hence, a large part of the increased air temperature during daytime will be absorbed by the canyon surfaces and not released until the night, which reduces diurnal swings due to its high thermal inertia, the old city withstands sudden climatic changes better than modern area.

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