Outdoor Microclimate Observation for Thermal Comfort in Harsh Desert Condition: A Study in Kashan Iran

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Abstract Traditional architecture of the historical cities of Iran contains valuable lessons related to architecture and urban design. A group of these strategies are those used in outdoor urban spaces in desert cities providing a safe and sustainable microclimate for pedestrian. This research paper will highlight some of these strategies by doing a field study research in hot summer and cold winter in Kashan, a historical city of Esfahan Province. The weather data are collected in 11-12 July 2011 and 11-12 Jan 2012 by a mobile Kestrel Personal Weather station in the traditional part of the city. The collected data are analyzed for human thermal condition by UTCI (Universal Thermal Climate Index) on the psychrometric chart. The different thermal zones on this chart are compared with people's behaviour according to their exposure time, clothing and activity. The collected weather data of observation days are compared in four levels of long-term meso climate, short-term meso climate, local climate and microclimate. To speed up the analyzing process a new software is designed called SIKRON. The result of this research has shown the effect of architectural strategies on modifying the microclimate condition in hot summer and cold winter for outdoor living in hot-arid climate.

Keywords Microclimate, Local Climate, Meso Climate, Outdoor Thermal Condition, UTCI, Historical City

1. Introduction

Despite of harsh climatic condition of desert regions, traditional architecture of the historical cities in Iran, have some valuable lessons for climatic consideration in architecture and urban design. Kashan with approximately 6-7 thousand years of civilization and its precious architecture provides a great opportunity for us to discover part of these lessons by doing a field study research. Climatic data and architectural information are gathered in the summit of winter and summer in 2011-12 in the historical part of the city. Using outdoor thermal index of UTCI (Universal Thermal Climate Index) [1] helps to determine thermal condition of each place. Comparing different places

according to their thermal condition will show their efficiency to respond to human thermal comfort needs.

2. Research History

To help architects and designers for better decision making in design procedure, some thermal indices are provided for prediction according to climatic condition. The first groups of thermal outdoor indices are based on thermal stress model. Cold stress indices such as Wind Chill Equivalent Temperature (WCET) are prepared for cold conditions. Heat stress indices such as Wet Bulb Globe Temperature (WBGT) are prepared for hot conditions. The second group of thermal outdoor indices are prepared base on heat budget model. They are capable to evaluate both cold and hot conditions such as Perceived Temperature (PT), Temperature Humidity Index (THI), and Universal Thermal Climate Index (UTCI). The latest index (UTCI) is based on comprehensive heat budget model of human biometeorology. It is being prepared by a group of specialists [1] and is supposed to cover all shortcomings of other indices [2]. In this research, UTCI is used for data analysis on cold and hot conditions of the studied places.

2.1. Universal Thermal Climate Index (UTCI)

The Universal Thermal Climate Index (UTCI)¹ is one of the indices that provide an assessment of outdoor thermal environment in bio-meteorological applications based on the equivalence of the dynamic physiological response predicted by a model of human thermoregulation, which was coupled with a state-of-the-art clothing model [3]. The

1 - The UTCI is the completion of another index called Perceived Temperature (PT). The perceived temperature (PT) in the dimension °C is the air temperature of a reference environment in which the perception of heat and/or cold would be the same as under the actual conditions [38] [39]. In the reference environment the wind velocity is reduced to a slight draught, and the mean radiant temperature is equal to the air temperature (for example, an extensive forest). The water vapor pressure is identical with the actual environment as far as it is not reduced by condensation [49]. Perceived heat and cold is computed by means of the comfort equation by Fanger (1970) which is based on a complete heat budget model of the human body [40].

purpose of the Universal Thermal Climate Index (UTCI) is to inform the public of how the weather feels, taking into account factors such as wind, radiation and humidity. In order to help the general public to relate directly to the UTCI, it is proposed that this index should be on the temperature scale (e.g. in degrees Celsius) [4] [1]. The operational procedure, which is available as software from the UTCI website [5], showed plausible responses to the influence of humidity and radiation in the heat, as well as to wind speed in the cold and was in good agreement with the assessment of ergonomics standards concerned with the thermal environment.

Table 1. UTCI thermal categories [3]

UTCI C °	Thermal category
below - 40	Extreme cold stress
- 40 to - 27	Very strong cold stress
- 27 to -13	Strong cold stress
- 13 to 0	Moderate cold stress
0 to + 9	Slight cold stress
+ 9 to +26	No thermal stress
+ 26 to + 32	Moderate heat stress
+ 32 to + 38	Strong heat stress
+ 38 to + 46	Very strong heat stress
above + 46	Extreme heat stress

UTCI will be calculated online at <http://www.utci.org/utcienu/utcienu.php> [5]. It takes into account all climatic factors: air temperature ($-40^{\circ}\text{C} < T_a < +45^{\circ}\text{C}$), mean radiant temperature ($-10\text{K} < T_{\text{mrt}} - T_a < +40\text{K}$),

relative humidity ($5\% < rh < 95\%$), wind speed ($1.1\text{m/s} < V_r < 17.6\text{m/s}$) and human factor of cloth insulation ($0.4 < clo < 2.6$) and activity of walking 4 km/h (2.3 MET or 135 W/m^2) [6]. Table 1 shows the thermal zone categories of UTCI. Using the formula of UTCI and above categories the main thermal zones for outdoor spaces is drawn on psychrometric chart (Figure 1). [2]

2.2. Humidity, Air Movement and Sunshine Effect in Hot Conditions

Humidity of the atmosphere has little effect on thermal comfort sensation at or near comfortable temperatures, unless it is extremely low or extremely high. It does, however, play an important part in the evaporative regulation zone [7]. Low humidity can dry the skin and mucous surfaces and lead to comfort complaints about dry nose, throat, eyes, and skin, typically when the dew point is less than 0°C . In compliance with discomfort observations ASHRAE Standard 55 recommends that the dew point temperature of occupied spaces not be less than 2°C . At high humidity, too much skin moisture tends to increase discomfort, particularly skin moisture of physiological origin (water diffusion and perspiration). [8, p. 8.12]

Air movement accelerates evaporation providing a physiological cooling. In low humidity (below 30%), this effect is significant as there is an unrestricted evaporation even with still air. In high humidity (about 85%), the evaporation is restricted; thus, even the air movement cannot adequately increase cooling effect. Evaporation is most significantly accelerated in medium (40–50%) humidity. [7]

Figure 1. Thermal zones of (UTCI) on psychrometric chart [2]

Figure 2. Humidity zones on psychrometric chart in high temperatures [9]

Figure 3. Thermal zones on psychrometric chart in low temperatures [9]

Drawing important limits on psychrometric chart, upper and lower boundaries of accepted humidity shows that in hot arid conditions evaporative cooling has more important effect than wind speed. Whereas in hot humid conditions wind speed has more effect and evaporative cooling is a dependant of high air velocity [2]. Figure 2 shows the humidity zones on psychrometric chart in high temperatures. In hot conditions sunshine will cause thermal situation worse and must be prevented as much as possible.

2.3. Humidity, Air Movement and Sunshine Effect in Cold Condition

In cold conditions air movement has a great effect on thermal sensation. By increasing the air speed in temperatures less than 5°C the chill wind effect happens and lowers the effective temperature². If clothing were to get wet,

the cooling effect would be greater than that predicted by wind chill model and the chance of hypothermia would be greater. [10]

Sunshine, even in a cold winter day, can make a difference in the thermal sensation. Bright sunshine can make person feels as 6-10 °C warmer as advised in the "new" wind chill chart [11] [12]. The effect of sunshine is much more pronounced at low wind speeds and gradually diminishes as wind speed intensifies and its effects become dominant [13].

In cold temperatures, humidity levels will reach the saturation condition by low amounts of mixing ratio (g/kg). In wet, windy conditions, someone wearing inadequate clothing can become hypothermic in quite mild temperatures [14]. Activity is an important factor in such conditions. This can be very important because when there is high clothing insulation the range of metabolic rates which are within the band between sweating and shivering is

2 - Effective temperature (AT) is a comfort index or scale that takes into

account the temperature of air, its moisture content, and movement [45]

reduced so there is a danger of sweating and creating thermal bridges in the clothing. Unfortunately none of the indices related to cold conditions, did study the relation between high activity levels and clothing [2]. Figure 3 shows the cold stress zones of UTCI on psychrometric chart.

3. Research Method

In this research the data are gathered in the historical part of the city of Kashan that is located in the hot arid climate of Iran. The field data are collected by a Kestrel personal weather station that is able to collect the data of temperature, humidity and wind, the three out of four important climatic elements of thermal condition³. The data is collected each 30 second to show the microclimate changes in different outdoor spaces. Using outdoor thermal index of UTCI to interpret these data, the thermal condition of the observed places are transferred on psychrometric chart. SIKRON software [15] is used to accelerate the process of data transfer to psychrometric chart.

To control the intervening factors affecting the observation method, the collected data of the fixed and moving Kestrel weather station (as the representative of local climate and microclimate respectively) is compared with other climatic data of meteorology station [16] of Kashan in four levels: 1- long term meteorology data of the city as the representative of the typical urban climate (meso-climate), 2- short term meteorology data as the representative of the short term urban climate, 3- the collected data of the fixed Kestrel data logger on the roof of a building (the reference data logger) as the representative of the local climate. 4- The data collected by the moving Kestrel in different outdoor areas as the microclimate of the observed places. Comparing the long term meteorology data with the short term data of the observed days, will show the thermal condition of the chosen days in comparison with the typical weather of the city. Comparing the meteorology data of the observation days with the data of the reference data logger will show the changes of the local climate according to the urban construction. Comparing the data of the reference data logger with the data of the observation places (moving Kestrel data logger) will show the microclimate changes according to the architectural condition of the outdoor public spaces.

3.1. Field Data Collection in Traditional Part of the City

Kashan in the central part of Iran in 33° 59 'north latitude and 51° 27 'east longitude by 982 meters height above the sea level is located between "Zagross Mountain" in the west and "Dasht Desert" in the east. Hot summer temperature increases to 47°C and cold winter temperature decreases to -10°C. By precipitation almost 150 mm per year it is one of

the most arid cities in Iran. Hot summers by dusty hurricane and cold winters by chill winds have caused very harsh climate in this area. In spite of this, Kashan is one of the oldest cities in Iran. Archaeological discoveries in the Sialk Hillocks which lie 4 km west of Kashan reveal that this region was one of the primary centers of civilization from 7000 years ago. [17]

To show some of the climatic strategies caused the sustainability in this city, this article has studied some of the passages I the historical part of the city by the field observation in summit summer (11-12 July 2011) and summit winter (11-12 Jan 2012). The path between Bazar and Ameri historical house was chosen for observation. (Figure 4)

The chosen route is selected according to its passages' diversity such as situation, direction, proportion, head covered and elongation. These properties are called as: deep and shallow passages and squares, roofed passages (Sabat), bazaar and mosque's courtyard. As it is shown in Figure 5, refer to the sky view and sunlit condition, deep passages are those with height more than width ($H/W > 1$) and shallow passages are those with height less than width ($H/W < 1$) [19] [20]

3.2. Data Collection Instruments

Local and micro weather data are gathered by Kestrel WS-4500-KIT portable weather station data logger [21]. This data logger is capable to collect data of temperature, humidity and wind speed. As the comparison of different weather stations kits shows, it has a good overall rating and has an acceptable accuracy for outdoor weather data collecting [22]. (Figure 6)

An infrared FLIR i7 is used to get thermal images. This data logger camera is capable to get thermal images by 120×120 dpi and accuracy of 0.1°C [23]. Thermal pictures of this camera will show the surface temperature of different materials in the chosen passages. (Figure 7).

3.3. Data Analysis Method

To analyze the data that is gathered by Kestrel personal weather station, UTCI (Universal Thermal Climate Index) is used as one of the most reliable thermal outdoor indices. This index analyzes the outdoor thermal condition of the pedestrian wearing seasonable cloths. Referring to UTCI, the thermal zones are defined from cold stress⁴ to heat stress⁵ conditions [1] [3].

3 - The accuracy of each of these instrument's primary measurements was individually calibrated and tested against standards traceable to the National Institute of standards and Technology (NIST) or calibrated intermediary standards [43].

4 - Cold strain disorders include hypothermia (abnormally low body temperature) and frostbite [42].

5 - Heat stress is the physiological strain caused by an increase in core body temperature above safe levels where the individual is at risk of overheating [42].

Figure 4. Kashan’s historical part and the observation route [18]

Figure 5. Deep and Shallow passage refer to the sky view and sunlit condition [19]

Manufacturer	Model	Price'	Wind Speed (mph)	Wind Direction (°)	Outdoor Temperature (°F)	Indoor Temperature (°F)	Outdoor Humidity (%)	Indoor Humidity (%)	Barometric Pressure (inHg)	Rainfall (in)	UV
Kestrel Instruments	WS-4500-KIT 4500 Portable Weather Station Kit	\$308.90				---		---		---	---
	WS-4500NVTAN-KIT 4500NVTAN Portable Weather Station Kit	\$368.90	Range: 0-135	Resolution: 22.5°	Range: -40 - 257		Range: 0 - 100%		Range: 0.3 to 32.5		
	WS-4500NV-KIT 4500NV Portable Weather Station Kit	\$368.90	Resolution: 0.1	Accuracy: ± 5°	Resolution: 0.1		Resolution: 0.1%		Resolution: 0.02 inHg		
			Accuracy: ± 3%	Accuracy: ± 2.0 °F	Accuracy: ± 3%		Accuracy: ± 3%		Accuracy: ± 0.05 inHg		

Figure 6. Kestrel portable weather station data logger WS-4500 [22]

Figure 7. FLIR i7 thermal image and the surface temperature of the materials

Figure 8. Chart's legend to show the thermal condition refer to UTCI [15]

Figure 9. Long term meteorology data of Kashan on UTCI psychrometric chart, produced by SIKRON software

Figure 10. Sun-path chart of Kashan according to UTCI, produced by SIKRON software

To show the thermal situation of the city according to outdoor thermal indices, the psychrometric charts of outdoor indices are generated by SIKRON software [15]. SIKRON software helps to show thermal condition on each index according to main heat or cold stress zones. Rainbow colours are chosen to show different outdoor thermal conditions. Red colours refer to “extreme” and “very strong” heat stress that may cause “heat stroke”⁶. Orange and yellow colours refer to “strong” and “moderate” heat stress that may cause “heat exhaustion”⁷. Green colours refer to “no thermal stress”. It means that outdoor long term exposure⁸ is tolerable or pleasant. Light blue colors refer to “slight” cold stress that will feel cool. Dark blue, light and dark purple colors refer to “moderate cold stress”, “strong”, “very strong” and “extreme cold stress” that may cause “hypothermia”⁹ and “frostbite”¹⁰. Thermal conditions are distinguished visually and easily by using these colors. Figure 8 shows the charts’ legend and its rainbow colours.

SIKRON software is used to transfer the data from Kestrel or meteorology station to psychrometric chart with thermal zones that have been defined in UTCI index [15] [3]. It will show the thermal condition of the observed places in winter and summer, day and night. Fig 9 shows the long term meteorology data of Kashan on UTCI psychrometric chart and Fig 10 shows the results of UTCI thermal information on sun path chart of Kashan.

4. Field Study in Traditional Part of Kashan

4.1. Meso and Local Climate

To compare the short term and the long term data of Kashan city, the hourly data of the meteorology station of the observed days is compared with the average data of long term meteorology data available at Iran meteorology website [16] in Table 2. These data are transferred to psychrometric chart by SIKRON software. Figure 11 shows that in the observed days of 11-12 July 2011 at daytime the weather is warmer and dryer than ordinary summer days and at night it is a little bit dryer. In the days of 11-12 Jan 2012 at daytime the weather is dryer than the ordinary days (long term data) while at night it is the same as ordinary winter nights. In the peak hot hours of summer days the thermal condition goes to

the very strong heat stress zone (orange colour) while it is in comfortable zone (green colour) at night. In the peak cold hours of winter days the thermal condition is in the slight cold stress (light blue colour) while it may go to the moderate cold stress zone (dark blue colour) at night.

Table 2. Long term and short term meteorology data of Kashan in the observation days

Kashan		Ave. T _{min}	Ave. T _{max}	RH _{Min}	RH _{Max}
Mid summer	Observed days	°C	°C	%	%
	11 July 2010	24	40	9	20
	12 July 2010	25	41	7	26
	Average data July 1966-2005	24.8	40.8	19	35
Mid winter	11 Jan 2011	1	15	26	66
	12 Jan 2012	2	13	28	76
	Average data of Jan 1966-2005	-0.3	10.2	52	76

Comparison of the hourly data of Kashan’s Meteorology station by the fixed Kestrel data logger on the roof (reference data logger), shows the differences of the short term meso climate with the local climate. In the observed summer days the local weather has been dryer than the meso weather and temperature swing was larger (Figure 12). In winter, the local temperature is some few degrees more than the meso climate at day and night (Figure 14). According to UTCI, local weather of the traditional part of Kashan in the peak hours of summer days is in the very strong heat stress zone (orange colour) and at night it is in no thermal stress condition (green colour) (Figure 12). In winter days in the warmest hours it is in the zone of no thermal stress (light green colour) or slight cold stress zone (light blue) while at night, in the coldest hours, it may reach the moderate cold stress zone (dark blue) (Figure 14). It means that because of the high thermal mass of materials that absorb the solar energy, local climate in summer day is warmer than meso climate. In spite of this, microclimate of the courtyard with water pound and vegetation is some degrees less than local climate (Figure 13). In winter, high thermal mass materials of the built environment are beneficial for local climate. It means that in winter day and night, local climate is some degrees warmer than meso climate. Micro climate of the courtyard has even better thermal condition. Observed trench yard of Figure 15, shows this fact.

6 - Heat stroke - Defined by a body temperature of greater than 40.6 °C (105.1 °F) due to environmental heat exposure with lack of thermoregulation. Symptoms include dry skin, rapid, strong pulse and dizziness [47] [44].

7 - Heat exhaustion - Can be a precursor of heatstroke; the symptoms include heavy sweating, rapid breathing and a fast, weak pulse [47] [33].

8 - Heat exposure limits are based on some set of assumed physiological, personal, and environmental conditions [42].

9 - Hypothermia is defined as a core temperature of the body less than 35 degrees Celsius (cold stress) [34].

10 - Frostbite is the freezing of some part of the body. Fingers, toes, and even whole arms and legs can be lost as a result of frostbite [34]. At or below 0 °C (32 °F), blood vessels close to the skin start to constrict, and blood is shunted away from the extremities via the action of gloms bodies. The same response may also be a result of exposure to high winds [37].

Figure 11. Comparison of long term and short term weather data of Kashan

Figure 12. Daily local climate temperature is more than meso climate in summer

Figure 13. Comparison of Kashan climate in three climatic layers in summer

Figure 14. Daily local climate temperature is more than meso climate in winter

Figure 15. Comparison of Kashan climate in three climatic layers in winter

Figure 16. Temperature comparison of different passages in summer midday

4.2. Microclimate of the Observed Passages

Comparison of the meteorology data with the fixed Kestrel on the roof and moving Kestrel in outdoor places shows the relationship between city climate, local climate and micro climate. The data collected from different passages in the historical part of the city in 12 July 2011 is shown in Figure 16. Transferring these data on the Psychrometric chart of UTCI shows that while the hottest hours in summer are in very strong heat stress zone (orange colour), deep north/south passages and roofed passages (Sabat) have better thermal condition than deep west/east or shallow passages, with one level modification to strong heat stress (light orange zone) (Figure 17). Roofed low height passages have the best thermal condition in summer days by

moderate heat stress condition (yellow colour). These passages have the possibility to reduce the very strong heat stress to moderate heat stress condition that is two levels more tolerable (Figure 17).

Thermal condition of the passages in the observed winter days of 11-12 Jan 2012 shows that the architecture of the historical part of the city has caused an acceptable thermal condition in day and night (Figure 17). In winter midday thermal condition has improved from no thermal stress to comfort zone. In winter nights thermal condition has improved from slight cold stress (light blue) to no thermal stress zone (green). Lowering the wind speed in these passages has controlled the effect of chill winds. Figure 18 and table 3 show the effect of architecture to make different temperatures in microclimate condition in winter midday.

Figure 17. Thermal condition of different passages on UTCI psychrometric chart

Figure 18. Temperature comparison of different passages in winter midday

4.2.1. Uncovered Passages and Squares

Shallow passages and squares, because of their large sky view (Figure 19) will receive a great amount of solar energy in daytime while they emit it to the cold sky at night. This phenomenon is beneficial in winter day and summer night respectively, but is not beneficial in summer day and winter night and will cause a huge daily temperature swing (Table 4).

Using cloth shades in wide open spaces and shallow passages will reduce daily temperature swing. Fig 20 shows that in this case thermal condition has improved one level from slight cold stress (blue) in local climate to no thermal stress under cloth shade in winter day and night. It means that the cloth shade helps to modify the thermal condition in shallow passages and squares (Table 5).

Table 3. Surface temperature differences in different passages in winter midday

Low height roofed passage in winter midday, $T_{local}=9-10\text{ }^{\circ}\text{C}$, $T_{microclimate}=12-13\text{ }^{\circ}\text{C}$	Deep shaded passages in winter midday, $T_{local}=9-10\text{ }^{\circ}\text{C}$, $T_{microclimate}=9-10\text{ }^{\circ}\text{C}$	shallow sunny passage in winter midday, $T_{local}=9-10\text{ }^{\circ}\text{C}$, $T_{microclimate}=13-14\text{ }^{\circ}\text{C}$

Table 4. Surface temperature swing in shallow passages in winter

Winter noon with high solar gain, $T_{local}=9-10\text{ }^{\circ}\text{C}$, $T_{microclimate}=12-14\text{ }^{\circ}\text{C}$		Winter night with high solar loose, $T_{local}=7-8\text{ }^{\circ}\text{C}$, $T_{microclimate}=7-8\text{ }^{\circ}\text{C}$

Figure 19. Large sky view of shallow passages and squares on sun-path chart [19]

Figure 20. Shallow open and cloth shaded passages in day and night, winter and summer

Table 5. Daily thermal condition under cloth shade in winter

Table 6. Limited sky view of deep passages on sun-path chart [19]

Figure 21. Deep passages in day and night, winter and summer

Figure 22. Thermal condition of large Sabat in summer and winter

Deep passages according to their direction have different thermal condition. As it is shown in table 6 all unroofed passages are sunlit in midday. Deep north/south passages are capable to get appropriate shadow in summer morning and afternoon but they have unpleasant shadow in cold winter.

Deep west/east passages have even worse condition. They are sunlit in summer warm days while they are deprived from it in cold winter days. Thermal condition of deep passages on UTCI index shows that they are not capable to modify the thermal condition for one level (Figure 21).

4.2.2. Sabat Passages (covered passages)

Sabat that is a long covered passage has a good ability to modify the thermal condition in summer and winter. High thermal mass materials in these passages will lower daily temperature swing and provide better thermal situation for long exposure time (Figure 22). In summer midday it can reduce thermal condition from strong heat stress (light orange) to moderate heat stress (yellow). In winter midday it

can increase slight cold stress (light blue) to no cold stress condition (green). Thermal mass of these passages help to control daily temperature swing and are appropriate for outdoor long term stay. Existence of halt places such as cistern and shops in these passages shows their ability as a lively outdoor space in all thermal conditions. Table 7 shows winter daily temperature swing in Sabat passages.

Table 7. Surface temperature and ambient temperature control in Sabat passages in winter

Winter midday, $T_{local}=8-10\text{ }^{\circ}\text{C}$, $T_{Sabat}=10-12\text{ }^{\circ}\text{C}$		Winter night, $T_{local}=6-8\text{ }^{\circ}\text{C}$, $T_{Sabat}=8-10\text{ }^{\circ}\text{C}$

4.2.3. Traditional Bazar

Traditional Bazar building is a long covered passage with several shops, mall and warehouse (Figure 23). It has an extraordinary potential to modify thermal condition in summer and winter, day and night. Because of the long roofed passages with dome roofs and high thermal mass materials used in Bazaar building, high daily temperature swing is reduced appropriately. In summer with local temperature swing of 8 degrees between 36 to 44 °C, temperature swing in Bazar is only 3 degrees between 31-34 °C. In warm situations, ceiling and clerestory openings, cause natural ventilation and evacuation of the warm weather (Figures 24).

Figure 23. Kashan traditional Bazar

Figure 24. Bazaar thermal condition in summer (day & night)

In cold afternoon and night, thermal mass of Bazaar building and crowding of customers, cause the inside temperature of Bazar increase. In winter with local temperature 10-14 °C at noon and 7-9 °C in afternoon, inside Bazar's temperature is 12-14 °C at noon and 14-15 °C in afternoon (Figure 25 and Table 8).

Table 8. Bazar's internal temperature in winter in comparison with local temperature

Figure 25. Bazaar thermal condition in winter (day & night)

Figure 26 shows that in summer days by the local temperature in very strong heat stress zone (orange colour), inside Bazar with one level modification is in strong heat stress level. At this time as a tradition, shops are closed. In the afternoon when the hot local weather drops one level to strong heat stress zone, the thermal condition inside Bazar drops one level to moderate heat stress zone. At this time Bazar is reopen with people presence. It was observed that at this time although most of the ceiling fans were off, shopkeepers and costumers were actively do their business. (Table 9)

Table 9. Bazar activity in summer and winter

Summer noon $T_{local}=36-44\text{ }^{\circ}\text{C}$ $T_{Bazar}=31-34\text{ }^{\circ}\text{C}$	Summer afternoon $T_{local}=36-40\text{ }^{\circ}\text{C}$ $T_{Bazar}=31-34\text{ }^{\circ}\text{C}$	Winter noon $T_{local}=10-14\text{ }^{\circ}\text{C}$ $T_{Bazar}=10-12\text{ }^{\circ}\text{C}$	Winter afternoon $T_{local}=7-9\text{ }^{\circ}\text{C}$ $T_{Bazar}=14-15\text{ }^{\circ}\text{C}$

Figure 26. Comparison of local climate and Bazar's microclimate in summer and winter

5. Conclusions

The study of the historical part of Kashan city centre in summer hot and cold winter - as a representative of hot-arid architecture - has delighted the clever response of this architecture to human's thermal needs in different seasons. The field data showed that the local climate of the historical part of the city was warmer and dryer than the meso climate in summer and winter. In summer, local climate was in the strong heat stress zone of UTCI index. In spite of this the special architecture of roofed passages (Sabat and Bazaar), constructed with high thermal mass materials and its possibility of natural ventilation, have provided tolerable thermal condition appropriate for long term exposure time in summer and winter. Existence of shops, presence of population, play-ground for children and meeting places for adults testifies the ability of these places to modify the thermal condition in different seasons.

Shallow passages and squares with more possibility for chill wind and irradiation at winter night and more solar gain in summer day, are roofed in the historical part of the city with high ceilings. Because of this, they have become an appropriate large place for long term presence of people in the most time of the year in spite of the bad outdoor local climate.

Deep north/south passages have better thermal condition because of their shadows in the summer morning and afternoon. But they are sunlit in summer noon and have unpleasant shadows in winter. Deep east/west passages have the worst thermal condition because they have nonstop

sunshine in summer and permanent shadows in winter. Nevertheless in the historical part of the city because of diversity of the passages according to their direction, deepness, shortness and being roofed in some places especially in intersections, pedestrians will experience different thermal condition in short periods. This situation helps their thermoregulation to adapt with microclimate.

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