

## Urban Design

# Microclimate Observation by Outdoor Thermal Indices (Case Study of Five Climates)

M. Tahbaz<sup>1,\*</sup>

<sup>1</sup>Assistant Professor, School of Architecture, Shahid Beheshti University (SBU), Tehran, Iran

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### Abstract

Because of the differences between indoor and outdoor thermal condition, preparing some outdoor thermal indices is a way to understand and categorize the outdoor thermal sensation. The aim of these indices is not to provide thermal comfort - as it is the aim of indoor indices. Instead, they are provided to analyze outdoor thermal sensation to help architects, landscape architects and urban designers in design procedure to provide the most possible tolerable thermal condition in outdoor places such as urban public spaces. This article is the result of some field studies have been done in 2010 - 2012 in five different climates: hot semi humid (Ahvaz, Iran), tropical (Kuala Lumpur, Malaysia), hot-arid (Kashan, Iran), moderate-arid (Tehran, Iran) and cold (Sheffield, UK) in their worst thermal period. The main question in this research is: which outdoor thermal index is appropriate for a specific climate? And how much it is accurate to evaluate outdoor thermal sensation especially in different levels of cold stress and heat stress condition? In each field study the weather data including temperature, humidity and wind speed, are collected by two portable Kestrel weather stations to show weather condition in local and microclimate levels. People's behavior in outdoor spaces is observed to understand their reaction to the different thermal conditions. A nominal observation scale is used for people's age, health, clothes, activity and exposure time. Outdoor thermal indices that are used in this research are: Humidex, WBGT (wet bulb globe temperature), TSI (tropical summer index), Summer Outdoor Comfort Zone, WCET (wind chill equivalent temperature), THI (temperature humidity index) and UTCI (universal thermal climate index). The results show that outdoor thermal indices may have not the same explanation for the same thermal condition. Some of them are more appropriate for some specific condition while others are not. At last it would be summarized that they have acceptable sensitivity to temperature but most of them need to become more sensitive to humidity and air velocity.

**Keywords:** Outdoor thermal sensation, UTCI, WCET, WBGT, THI, TSI.

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## 1. INTRODUCTION

Regarding to importance of thermal sensation in outdoor public spaces, several indices are provided. Architects, landscape architects and urban designers - as the designer of outdoor public spaces-need to use this information to provide better microclimate in their design. This article is the result of five case study researches have been done in five different climates to find out the accuracy of the outdoor thermal indices in real case studies. Here 5 different climate types are studied by field observation. Climate data are collected by some meteorology data logger. People's behavior in different conditions is gathered by photography and description. This descriptive-explanative research will help to show the shortcuts of the outdoor indices related to people's behavior and acclimatize to adapt

with hard thermal conditions.

## 2. OUTDOOR INDICES FOR THERMAL SENSATION ANALYSIS

Outdoor spaces will have different microclimate conditions in a year. A designer needs to predict thermal sensation in each time of the year that will help him/her for better design strategies. Outdoor thermal indices are prepared by laboratory researches for outdoor thermal analysis. Some of these indices are prepared by thermal stress models and are divided in two groups of cold stress and heat stress moles. They will cover heat stress or cold stress conditions [1]. Some of them are provided according to heat budget model and are appropriate for a whole year.

In this article the outdoor thermal indices that are used to analyze the thermal sensation in observed cities are as bellow: From thermal stress models, Humidex, Tropical Summer Index (TSI), Summer Outdoor Comfort Zone

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\* Corresponding author: M-tahbaz@sbu.ac.ir  
Tell: +982122431628; Fax: +982129903210

(Tropics) and Wet Bulb Globe Temperature (WBGT) are used for hot conditions Table 1. Wind Chill Equivalent Temperature (WCET) is used for cold stress condition Table 2. From heat budget modes, Temperature Humidity Index (THI) and Universal Thermal Climate Index (UTCI) are used for both cold and hot conditions Table 3.

**Humidex:** humidex is created for very hot and humid weather to show how it will be felt by an average person and how hot it actually feels outside. The humidex combines the temperature and humidity into one number and is widely used in Canada. An online Canadian Humidex Calculator is available [2]. Humidex does not account solar radiation and wind velocity Table 1.

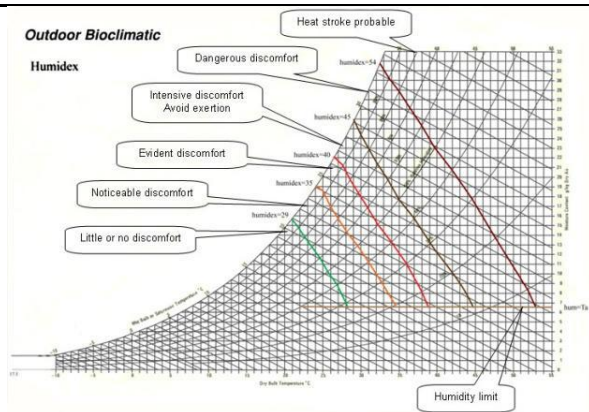
**Wet-bulb globe temperature (WBGT):** WBGT is the most widely used heat stress index throughout the world. It includes three thermometers to measure three different environmental factors as dry bulb (DB), wet bulb (WB) and black globe (BG) temperature [3]. It was developed in the US Navy as part of a study on heat related injuries during military training [4] and takes into

account temperature, humidity and radiant temperature that will be taken by black globe in the WBGT kit [5] Table 1.

**Tropical Summer Index (TSI):** TSI is prepared by Sharma & Sharafat in India (1986) and is appropriate for hot-dry and warm-humid conditions when radiant flux is not excessively high and the subjects have sufficient air motion. It takes into account all four environmental variables (air temperature, globe temperature, humidity, air velocity) in proportion to their influence on the thermal sensation [6] Table 1.

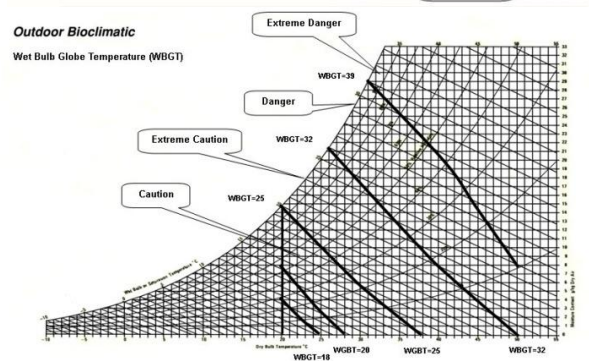
**Summer Outdoor Comfort Zone:** It is prepared for outdoor tropical locations by Ahmed (2003). The comfort zone in the shade is derived from the field study conducted in summer conditions in the city of Dhaka by wet-Tropical weather. Hence the lower threshold for comfort may vary in the winter season due to seasonal adaptation. The model includes among other conventionally accepted factors, thermodynamic effect of airflow and issues of radiation [7] Table 1.

**Table 1** Heat stress indices for thermal sensation prediction in public spaces [8]



| Humidex (°C) | Degree of comfort and discomfort   |
|--------------|------------------------------------|
| Less than 29 | Little or no discomfort            |
| 30 to 34     | Noticeable discomfort              |
| 35 to 39     | Evident discomfort                 |
| 40 to 45     | Intense discomfort; avoid exertion |
| 45 to 54     | Dangerous discomfort               |
| Above 54     | Heat stroke probable               |

**Humidex [2]**



| WBGT     | Thermal zones   |
|----------|-----------------|
| 20-25    | Caution         |
| 25-32    | Extreme caution |
| 32-39    | Danger          |
| above 40 | Extreme danger  |

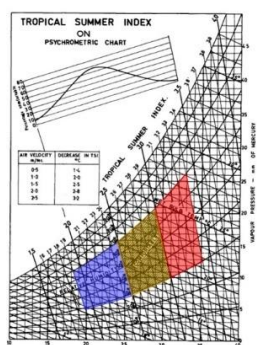
**Wet bulb globe temperature [9]**

$$WBGT \text{ Index} = 0.7 \text{ WB} + 0.2 \text{ BG} + 0.1 \text{ DB}$$

Comfort and tolerable zone for acclimatized people

- Slightly warm ■
- Comfortable ■
- Slightly cool ■

| Thermal sensation | Range (°C) | Optimum value (°C) |
|-------------------|------------|--------------------|
| 1. Slightly cool  | 19.0-25.0  | 22.0               |
| 2. Comfortable    | 25.0-30.0  | 27.5               |
| 3. Slightly warm  | 30.0-34.0  | 32.0               |

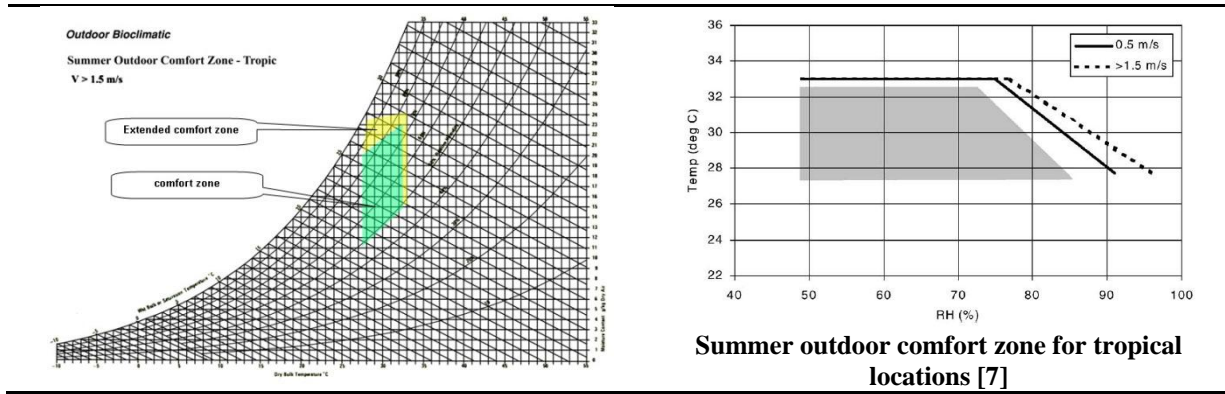


| TSI (°C) | Thermal sensation |
|----------|-------------------|
| 19-25    | Slightly cool     |
| 25-30    | Comfortable       |
| 30-34    | Slightly warm     |

**Tropical summer index [6]**

$$TSI = 1/3 t_w + 3/4 t_g - 2 V^{1/2}$$

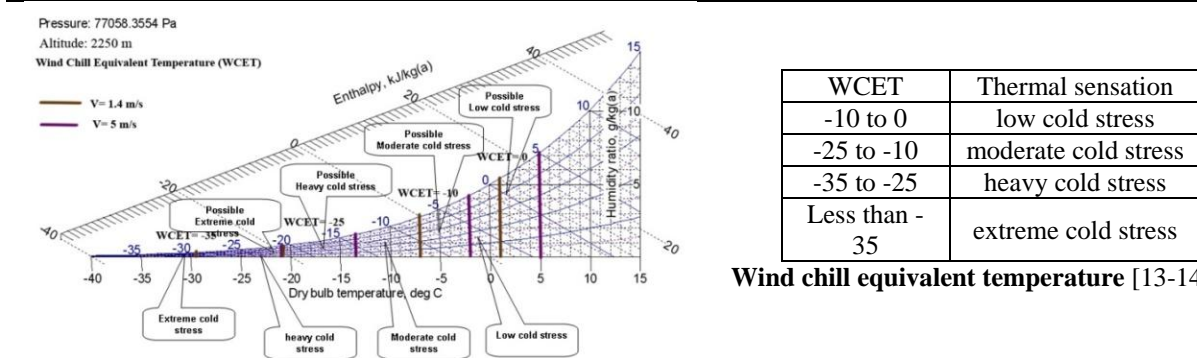
$t_w$  = wet bulb temperature,  $t_g$  = globe temperature,  $v$  = wind velocity



**Wind chill equivalent temperature (WCET):** Wind chill index, the wind chill factor, or just plain wind chill, is the temperature required under no-wind conditions that will equal the cooling effect of the air (the actual air temperature) for a nude person in the shade [10]. Moisture content of the air, visible moisture on the skin or clothing,

presence of sunshine, clothing, and physical activity are not considered [11]. Environment Canada's World Wide Web Site has provided an online calculation for wind chill. The wind chill index does not take into account the effect of sunshine. Bright sunshine may make it feel warmer by 6 to 10 units [12] Table 2.

**Table 2** Cold stress indices for thermal sensation prediction in public spaces [8]



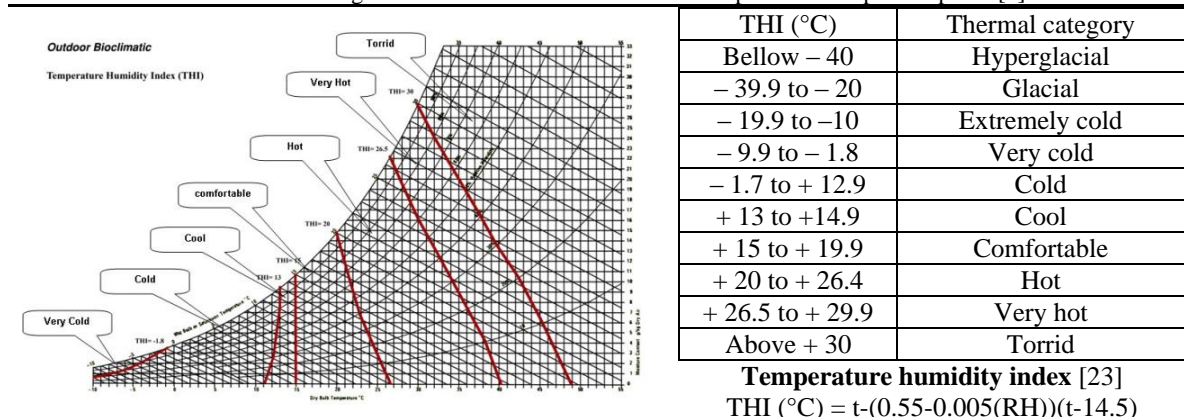
Outdoor indices that are prepared base on heat budget model can evaluate both cold and hot conditions [15] such as, Temperature Humidity Index (THI), Universal Thermal Climate Index (UTCI) and Physiological Equivalent Temperature (PET) [16-17].

**Temperature Humidity index (THI):** It takes into account humidity and temperature and is appropriate for shaded locations that are protected from the wind. It was developed by Thom (1959) called the thermohygroscopic index or temperature humidity index (THI) [18]. THI was

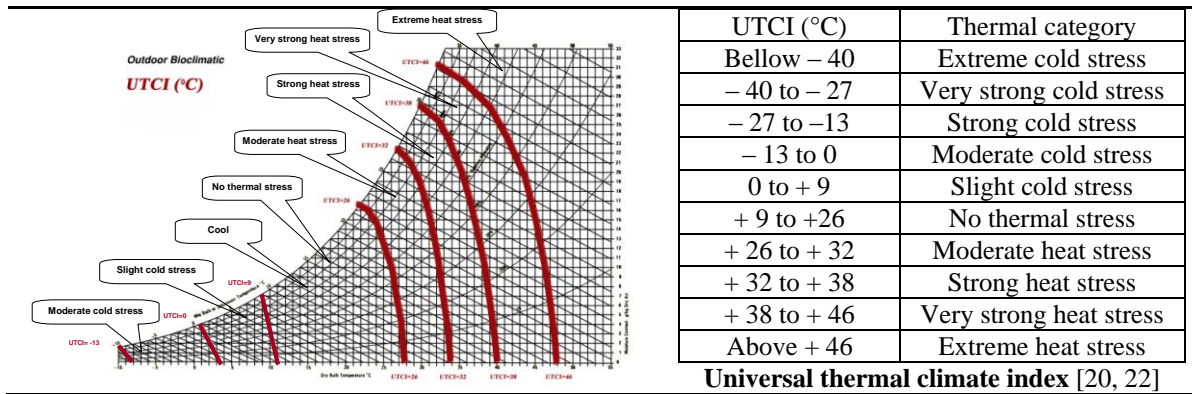
used originally to determine the discomfort due to heat stress, also it has been extended for cold stress conditions [19] Table 3.

**Universal Thermal Climate Index (UTCI):** This index is created to inform the public how the weather feels. It takes into account all four environmental factors of temperature, wind, radiation and humidity [20] and the index is on the temperature scale (in degrees Celsius) [21]. UTCI will be calculated online [22] Table 3.

**Table 3** Heat budget model indices for thermal sensation prediction in public spaces [8]







In a research that was done in Sheffield University in a sabbatical leave by the author, she was able to convert all the above indices on psychrometric chart that gives the advantage of work with data by a comparison opportunity between different indices [8]. A computer software called SIKRON was created to speed up the data input [24]. In this article all the collected microclimate data of the five field study cities are compared related to outdoor thermal indices by this software on psychrometric chart.

### 3. RESEARCH METHOD

Microclimate field data are gathered in five cities of Sheffield (UK), Kuala Lumpur (Malaysia), Kashan (Iran), Ahvaz (Iran) and Tehran (Iran) as the representative of cold climate, tropical climate, hot-arid climate, hot-semi arid climate and moderate-dry climate respectively. In each city the data are collected in midsummer and midwinter that have the most hot or cold weather. The path of observation and the points of data collection are chosen related to the factors such as populous pedestrian walkway

and importance of the place as outdoor coffee shops or restaurants, public building entrances or plazas, arcades, archways and passages. Three factors are in consideration for data collection: 1-Choosing the days of a normal weather condition compare with long term climate data. 2-Choosing the hottest or coldest weather condition of summer or winter. 3-Cover important times for people activities in outdoor places such as morning, noon, afternoon or night.

The data of temperature, humidity and wind are collected by two Kestrel personal weather station kits [25] Fig. 1. The fixed Kestrel-that is mounted on the roof of a building as a reference point-collects the local climate data each 30 minutes. As the representative of microclimate changes another Kestrel is moved in the path of observation and collects data each 30 seconds. These data show the changes of microclimate in each outdoor place. The thermal condition of observed places is drawn on the psychrometric charts that are drafted by SIKRON software [24]. Each chart shows thermal zones of one of the outdoor thermal indices.

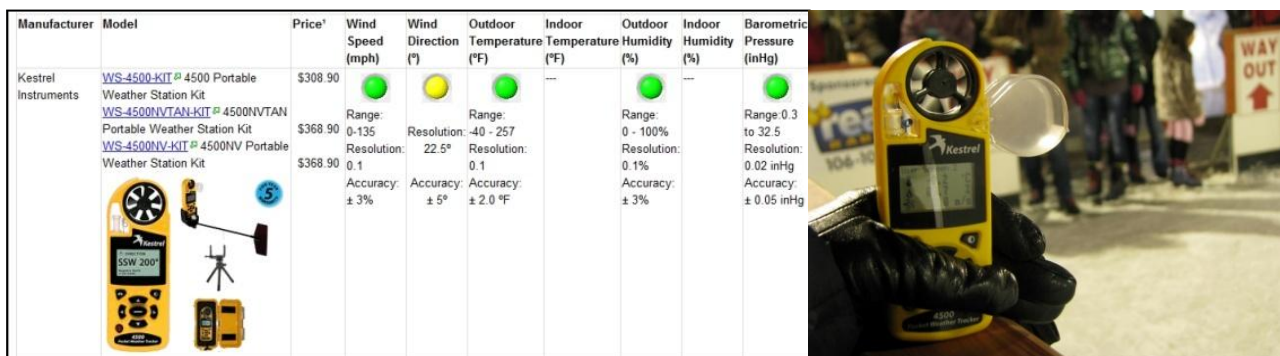




















Fig. 1 Kestrel portable weather station data logger WS-4500 [26]

To classify the factors of age, clothes' clo value, activities' met value and exposure time, table 4 is provided using nominal observation scale. People's activities and behavior in outdoor places is observed carefully and is recorded by photography. Spending more time in a place (more exposure time) such as standing or

sitting relax or walking slowly for shopping and so on, and presence of children, ages and disables among the crowd is the sign of tolerable weather. Wearing more or less clothes than normal clothes in winter or summer is a sign of more cold stress or heat stress in the place of observation.

**Table 4** Nominal observation scale for age, clothes, activity, exposure time and health

| Age  | Clothes (clo)  | Activity (met)   | Exposure time  | Health  |
|--|--|--|--|---|
| <br>Under 2 years | <br>Light Summer clothes                            | <br>Calm standing | <br>Fast passing             | <br>Healthy  |
| <br>Child         | <br>Normal summer clothes                           | <br>Calm sitting  | <br>Short time waiting       | <br>Disables |
| <br>Youth         | <br>Normal winter clothes                           | <br>Slow walking  | <br>Relax passing            |   |
| <br>Aged         | <br>Heavy winter clothes:<br>shawl, gloves and hat | <br>Sporting     | <br>Relax long time sitting |   |

To analyze the sensitivity and accuracy of each thermal outdoor index, the activity and behavior of people in the same thermal condition is studied regarding to predicted heat stress or cold stress condition that is proposed by the index. For example if ages and children are attending and spending some time in outdoor places, it shows that the thermal condition is not so bad. Therefore it is expected that the index predict this condition as slight heat stress or slight cold stress zone. By this way the most accurate index that will better predict thermal zone of different conditions will be distinguished.

#### 4. CASE STUDY CITIES

Here a short explanation of the geographic and climatic condition of each studied cities is provided.

**Ahvaz** is a city of Khoozestan province in the south west of Iran in 31° 19' north latitude and 48° 40' east longitude by 22.5 meters height above the sea level. It has very long, hot and mild summers and very short and moderate winters. Normally Ahvaz is one of the hottest cities in the world with more than 45 degrees Celsius temperatures in summer days with sandstorms and dust storms common during the summer period [27].

**Kuala Lumpur** is a city in the centre of Selangor state of Malaysia that is located in the 3° 12' north latitude and 101° 55' east longitude with less than 100 meters height

above the sea level [28]. It has a tropical rainforest climate with warm, sunny and rainfall weather from October to March. Temperatures remain constant by very low swing during the year. Maximums hover between 31-33°C and minimums hover between 22-23.5°C.

**Kashan** is a historical city in central part of Iran located between the mountains on the west and the Central Desert on the east in 33° 59' north latitude and 51° 27' east longitude with elevation of 982 meters. It has a four season desert climate with high temperature swing during the year that may cover a range of 50° C. Hot summer's temperature increases to 47°C by dusty hurricane and cold winter's temperature decreases to -10°C by chill winds that have caused very harsh climate [29].

**Tehran** is the capital of Iran in the south foothill of Alborz Mountain range. It is located in 35° 41' north latitude and 51° 25' east longitude with elevation of 1190-1548 meters. Tehran has a semi-arid climate with continental climate characteristics and a Mediterranean precipitation pattern. It has a four season climate with mild weather in spring and autumn, hot and dry weather in summer, and cold and wet weather in winter. The hottest temperature in summer is normally around 36 °C, while the coldest temperature in winter will fall below -1 °C [30].

**Sheffield** is a city in the central part of United Kingdom. It is located in 53°23' north latitude 1°28' west longitude. It is a geographically diverse city by several hills and five rivers. Most part of the city has the elevation



between 100 and 200 meters. Sheffield has generally temperate climate with cool, gloomy and wet environment in the mountains and hills that also provide shelter from the prevailing westerly winds. The average maximum temperature in summer is around 20.8 °C and the average minimum temperature in winter is around 1.6 °C [31].

### 5. DATA ANALYSIS IN OUTDOOR PUBLIC SPACES

In this research the climatic data are collected from three sources. The weather data of the cities are available at EnergyPlus website [32] and Iran Meteorology Organization [33]. The microclimate data are gathered by Kestrel personal weather station kit in the paths of observation. All these information are shown on the psychrometric charts of the outdoor indices that are generated by SIKRON software [24]. The psychrometric charts of each index shows thermal condition zones according to main heat or cold stress zones that are distinguished by rainbow colors. Red colors refer to “extreme” and “very strong” heat stress that may cause “heat stroke” [34-35]. Orange and yellow colors refer to “strong” and “moderate” heat stress that may cause “heat exhaustion” [34,36]. Green colors refer to “no thermal stress”. It means that long term exposure<sup>1</sup> in outdoor is tolerable or pleasant [37]. 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” and “frostbite” [38]. Thermal conditions are distinguished visually and easily by using these colors. Fig. 2 shows the charts’ legend of the UTCI index.

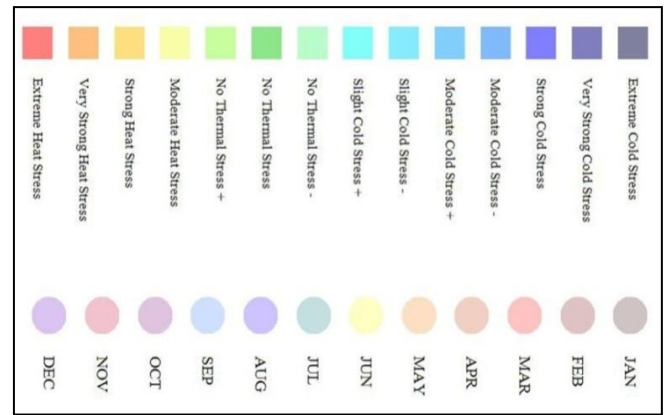


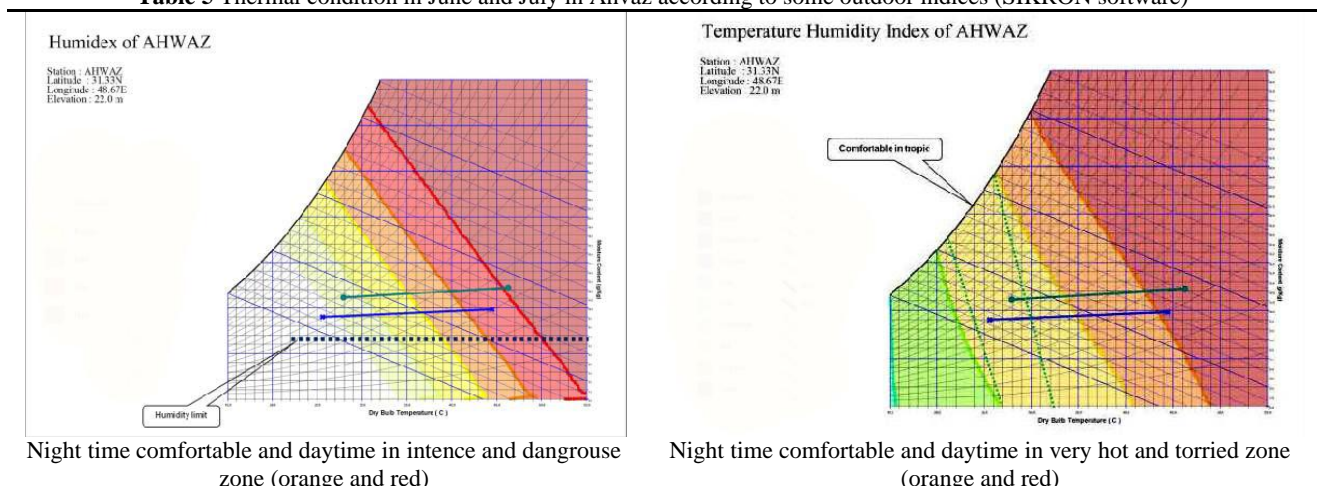
Fig. 2 The legend of the UTCI index for thermal condition zones (SIKRON software) [24]

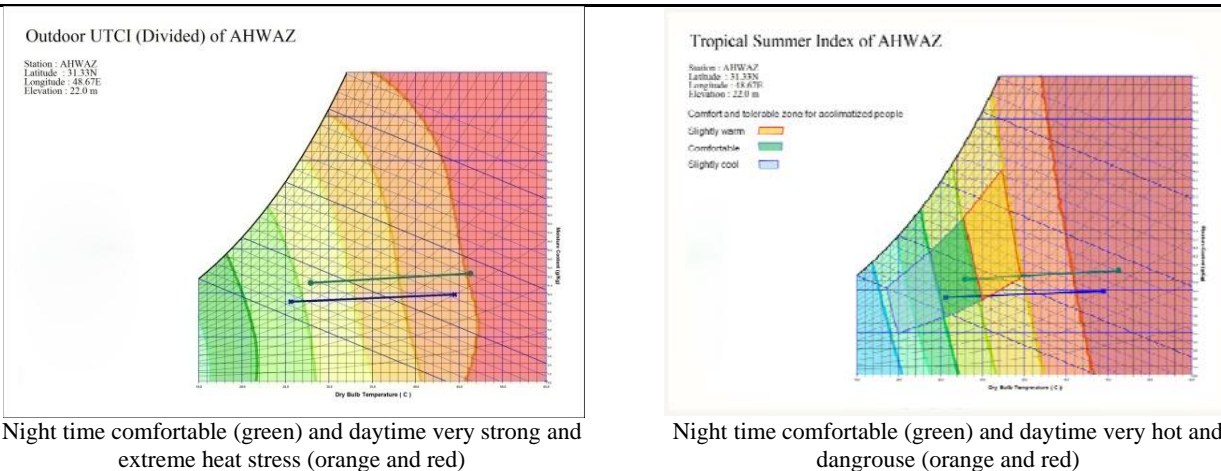
The microclimate observation was performed in these 5 cities in the chosen days. The results are compared with outdoor thermal indices and people’s presence and behavior in public spaces.

#### Ahvaz

Ahvaz with very hot and semi humid weather in summer is the hottest place among the chosen cities. Table 5 shows the weather condition in June and July in Ahvaz on Psychrometric chart according to some outdoor indices. Humidex, Tropical Summer Index (TSI) and Temperature Humidity Index for tropics (THI) predict night time as comfortable for local people. UTCI predicts night time by low heat stress. Wet Bulb Globe Temperature (WBGT) predicts night and day as heat stress while daytime by temperature more than 43-45°C is predicted as the worst and dangerous thermal condition by all indices.

Table 5 Thermal condition in June and July in Ahvaz according to some outdoor indices (SIKRON software)





**Ahvaz - field data collection**

The field study had been done in Amanieh region in Ahvaz for two hot days of 15 June and 28 July in summer 2010. The blue dots on Fig. 3 show the path of observation and chosen public spaces. Weather Data of microclimate

condition was collected from 7:30am to 1pm and from 5pm to 9pm. Because of the extreme heat load in the period of 1-5pm (temperature more than 50°C) the research team was not able to collect the data in this period [39] Fig. 4.



Fig. 3 The observation points in Amanieh region in Ahvaz [39]

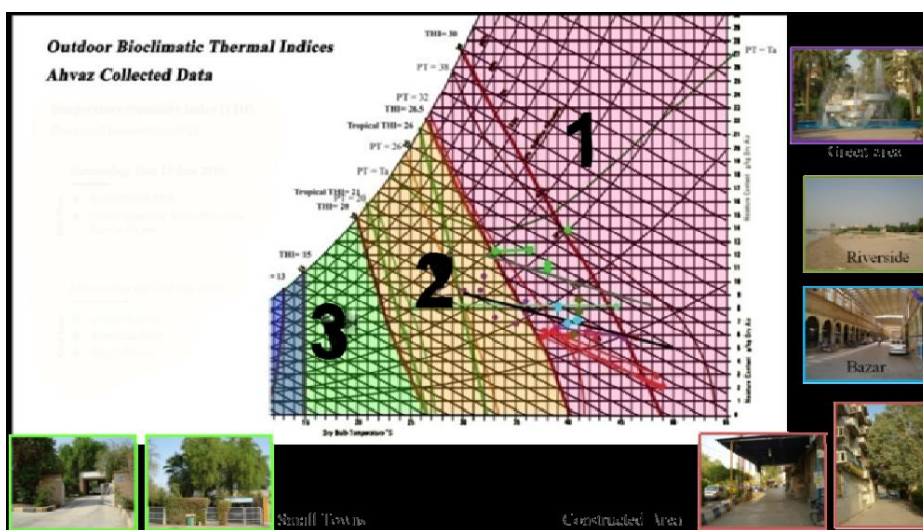


Fig. 4 Outdoor thermal condition in Ahvaz [39]

Fig. 5 shows a local man sleeping on the grass when the temperature is 46°C in the afternoon. People are seen in public places and shopping areas in afternoon and night. The

most populated busy time shows a night life in this city. The presence and behavior of people will be a reason of better adaptation of local people to sever hot climate of this city.



Fig. 5 people's presence in 40-47°C in the afternoon is a normal behavior [39]



Time: 18.43  
 Temperature: 46°C  
 Humidity: 8.6%  
 Wind speed: 2.4m/s



Time: 18.44  
 Temperature: 45.2°C  
 Humidity: 10.2%  
 Wind speed: 2.1m/s



Time: 18.56  
 Temperature: 46.5°C  
 Humidity: 7.9%  
 Wind speed: 2.3 m/s



Time: 18:05  
 Temperature: 48.9°C  
 Humidity: 4.3%



Time: 18:52  
 Temperature: 46.5°C  
 Humidity: 8.2%



Time: 17:15  
 Temperature: 40.4°C  
 Humidity: 12.9%  
 Wind speed: 2.5 m/s



Time: 17:25  
 Temperature: 41°C  
 Humidity: 17.5%

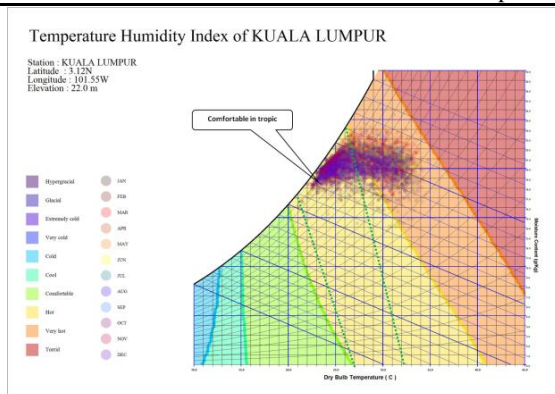
It seems that local people are more adapted to the climate than the prediction of the indices. All indices predict daytime dangerous while it was not such harsh for local people and they were able to live and walk in the city as normal. None of these indices are suitable for acclimated local people for such hot and semi-humid climate and they need to be modified according to the effect of humidity and wind flow in hot conditions.

**Kuala Lumpur**

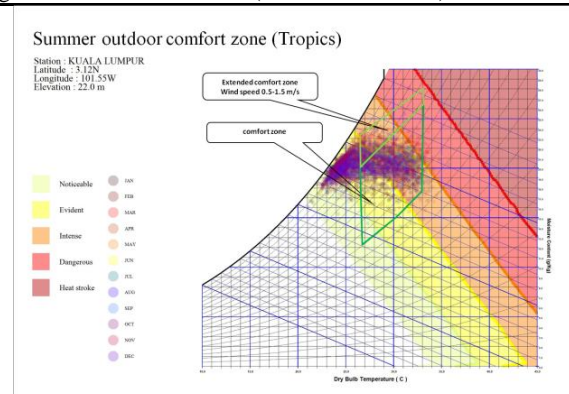
Kuala Lumpur climate with tropical condition is shown

in Table 6 with very low temperature swing and humid weather that cause heat stress most of the time. Thermal analyses of the indices are as below: 1- Heat Index defines the warmest condition as dangerous. 2-UTCI and Humidex and Temperature Humidity Index (Tropics) analyze the warmest condition as intense or strong heat stress. 3- Tropical Summer Index and Summer Outdoor Comfort Zone (Tropics) interprets the warmest weather as slightly warm. At night the weather is interpreted comfortable especially by wind flow.

Table 6 Thermal condition in Kuala Lumpur according to some outdoor indices (SIKRON software)



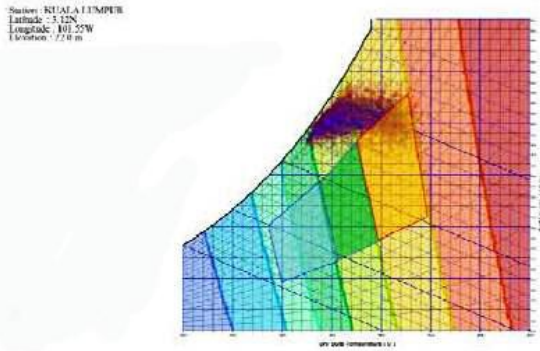
Night time fomfortable and daytime very hot (orange)



Night and day comfortable by wind flow

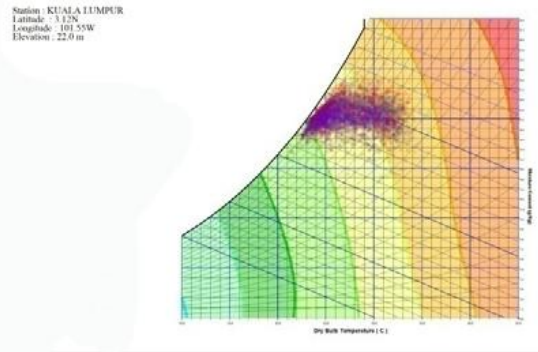


Tropical Summer Index of KUALA LUMPUR



Night and day slightly warm and sultry

Outdoor UTCI (Divided) of KUALA LUMPUR



Night and day moderate to strong heat stress

**Kuala Lumpur - field data collection**

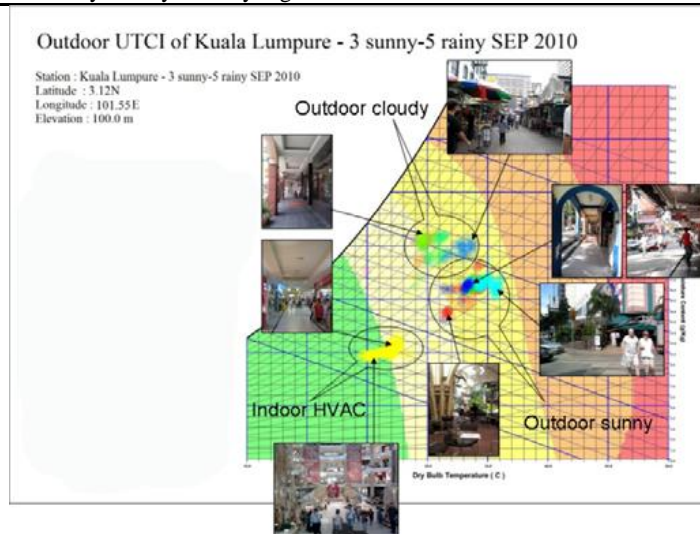
The field study was done in the summer of 2010 in city center of Kuala Lumpur. The data was gathered in two days of 3rd and 5th September as a sunny and a rainy day respectively [40]. The path of observation is shown in Fig 6. Table 7 shows that the sunny days have the warmest condition and may reach the strong heat stress situation

(dark yellow zone). Rainy and cloudy days have better thermal condition. Some changes like providing shelter will drop thermal sensation one level to moderate heat stress (light yellow zone). Observation shows that several outdoor activities are done at night as a costume of night life. Therefore moderate heat stress is tolerable in tropical climate night.

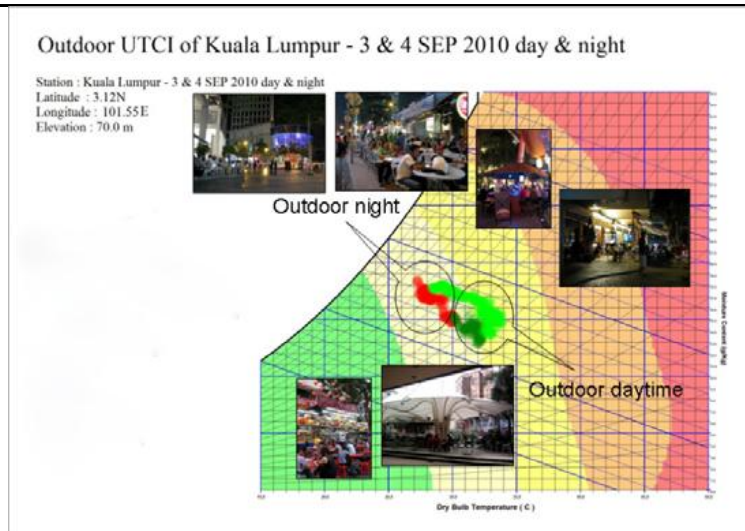


Fig. 6 The path of observation in city centre and a sample of observed points [40]

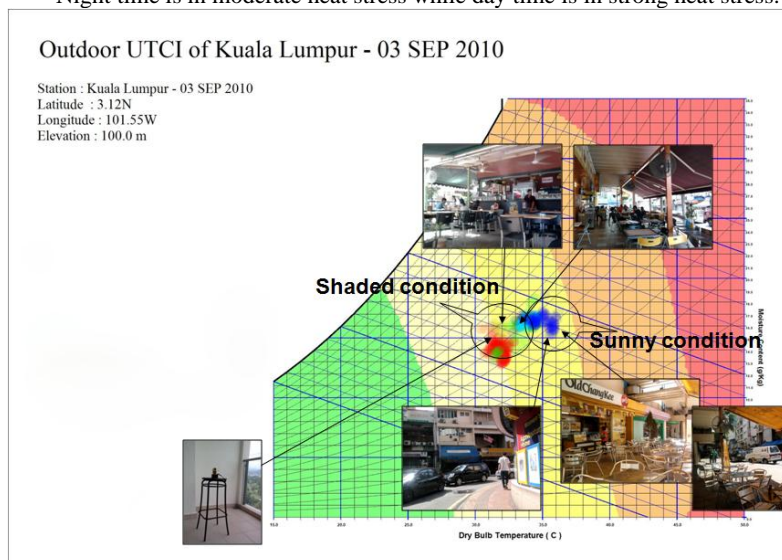
Table 7 Sunny/cloudy and day/night thermal sensation on UTCI index - SEP 2010 [40]



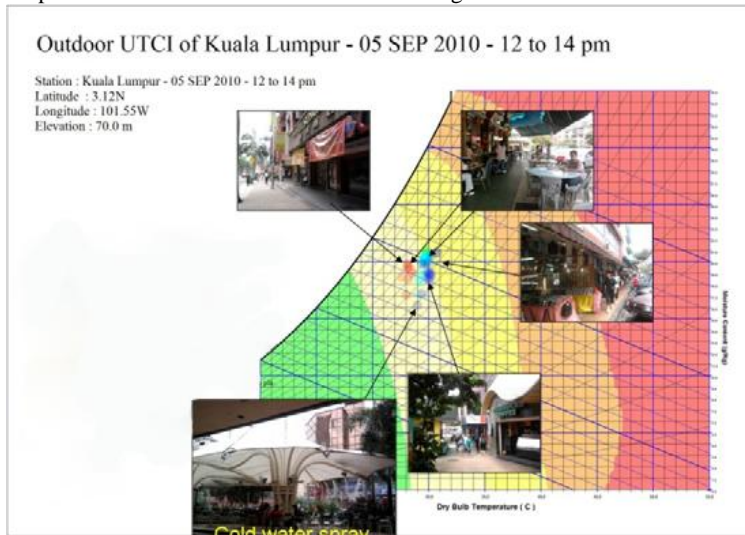
Cloudy days have better thermal condition with lower temperature.



Night time is in moderate heat stress while day time is in strong heat stress.



Shaded places reduce thermal condition from strong heat stress to moderate heat stress.



Cold water spray under a sunshade will modify microclimate one level.

According to Table 7, daytime is defined as moderate and strong heat stress. In spite of this, outdoor areas are populated and lots of long term activities (such as eating

and shopping) are done in this thermal condition. In sunny days by very hot thermal condition, outdoor spaces with shelter and cold water spray will modify the intolerable



microclimate condition one level which helps to be populated, while the spaces without these facilities will remain empty. These facilities will reduce thermal

condition from strong heat stress (dark yellow) to moderate heat stress (light yellow) that provide appropriate places for outdoor long term presence Fig. 7.

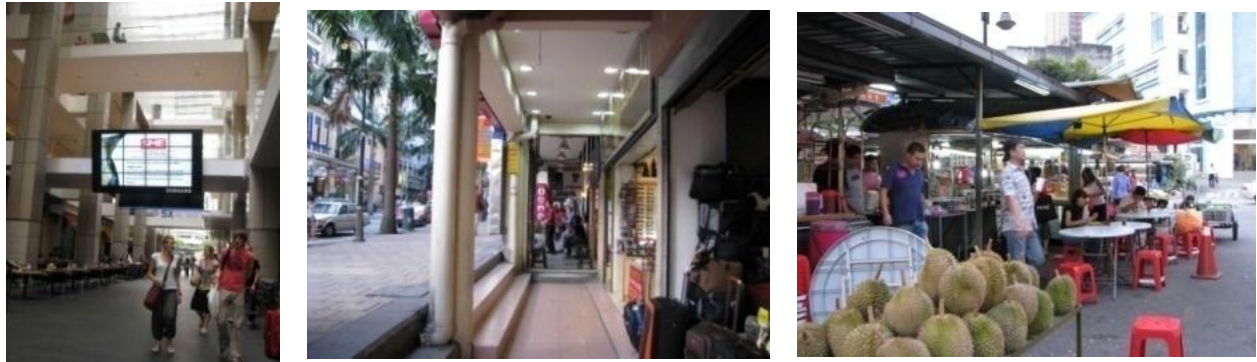


Fig. 7 Permanent and temporary sunshades provided by shopkeepers and hawkers in walkways [40]

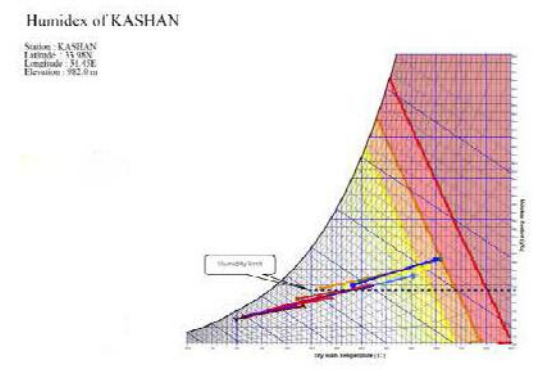
Among outdoor indices, those that are modified for tropical areas, such as tropical summer index and summer outdoor comfort zone (tropics) have good prediction for this climate. Related to local people’s behavior in tropical climates, windy shaded places are capable to provide better thermal condition for outdoor long term presence.

**Kashan**

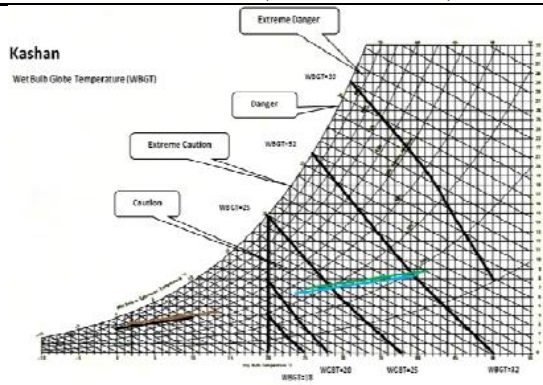
Kashan with hot-arid climate has hot summers and cold winters that are shown in Table 8. According to Heat

Index and WBGT in midsummer it has dangerous thermal condition. According to Humidex and Tropical summer index it is in intensive warm zone. According to UTCI and Temperature Humidity Index at summer midday it has strong heat stress and at night it has no thermal stress. In winter midday according to UTCI and WCET it has no thermal stress or slight cold stress while at night, it may reach the slight cold stress in wind less than 1 m/s. By blowing winds more than 5 m/s it may reach even moderate or strong cold stress condition.

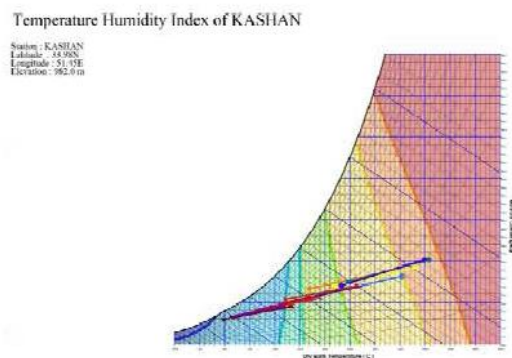
Table 8 Thermal condition in Kashan according to some outdoor thermal indices (SIKRON software)



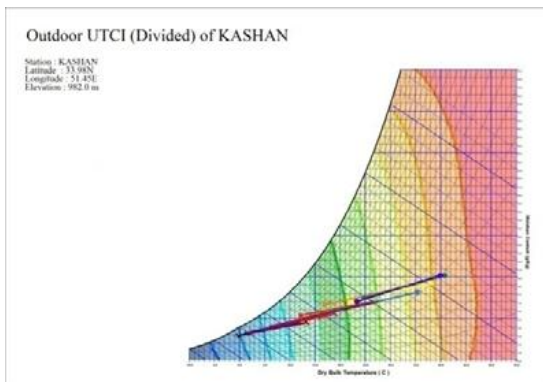
Night time comfortable and daytime evident and intense heat stress in summer (yellow and orange).



Night time caution and daytime extreme caution



Night time hot and daytime very hot in summer (yellow and orange). Day and night cold in winter (blue)



Night time comfortable (green) and daytime strong and very strong heat stress (yellow and orange) in summer. Slight cold stress in winter (blue).



**Kashan - field data collection**

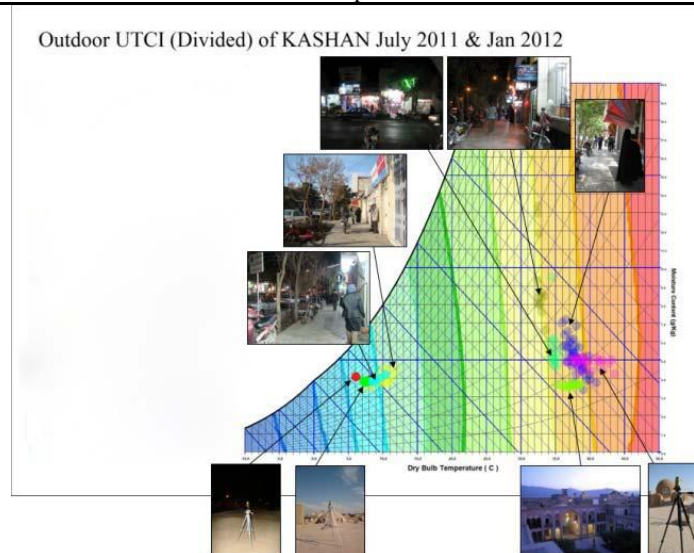
The field study was done in 12 July 2011 and 11-12 Jan 2012 in different passages of the traditional part of Kashan city from 10 am to 9 pm Fig. 8. When the collected data of the different places in the path of observation are plotted on the Psychrometric chart of UTCI index, the results are as below: 1-Although the local climate of hottest hours in summer are in the strong heat stress zone, microclimate thermal stress of different places are not the same. Narrow north/south passages and covered passages (Sabat) that are more shaded, have one level lower heat stress than narrow west/east or wide passages with more sunlit areas Table 9. In this case covered low height passages have the lowest thermal heat stress in summer days. In brief, covered or narrow passages will modify strong heat stress to moderate heat stress that is one level more tolerable. 2-Winter observation shows that the architecture of the historical part of the city helps to provide a better thermal condition in day and night. In Table 9 it is shown that the microclimate of covered passages like “Bazar” and “Sabat” that are shaded and wind protected by high

thermal mass, will cause the cold stress of the local winter midday modify from no thermal stress to no thermal stress zone and the local climate of winter nights modify from slight cold stress to no thermal stress zone. Therefore covered passages are appropriate for outdoor long term stay in summer and winter Fig. 9 [41].



**Fig. 8** The path of observation in the historical part of Kashan [41]

**Table 9** Thermal condition of outdoor spaces in Kashan summer and winter [41]



In summer days outdoor areas are in strong heat stress (orange). At night they are in moderate heat stress (yellow). Sunny and wind protected places in winter are comfortable (green) but at night they are in slight cold stress (blue)



Summer midday, shaded palce



Winter midday, sunny place for long term stay



**Fig. 9** Outdoor long term presence according to appropriate shaded and sunny places [41]

Observation show that sunshine has the most important effect in microclimate thermal condition in this climate. In summer preparing shadow and evaporative cooling will

modify thermal sensation. In winter wind control is very important and sunny and leeward places has better thermal condition. Among the outdoor indices UTCI has better

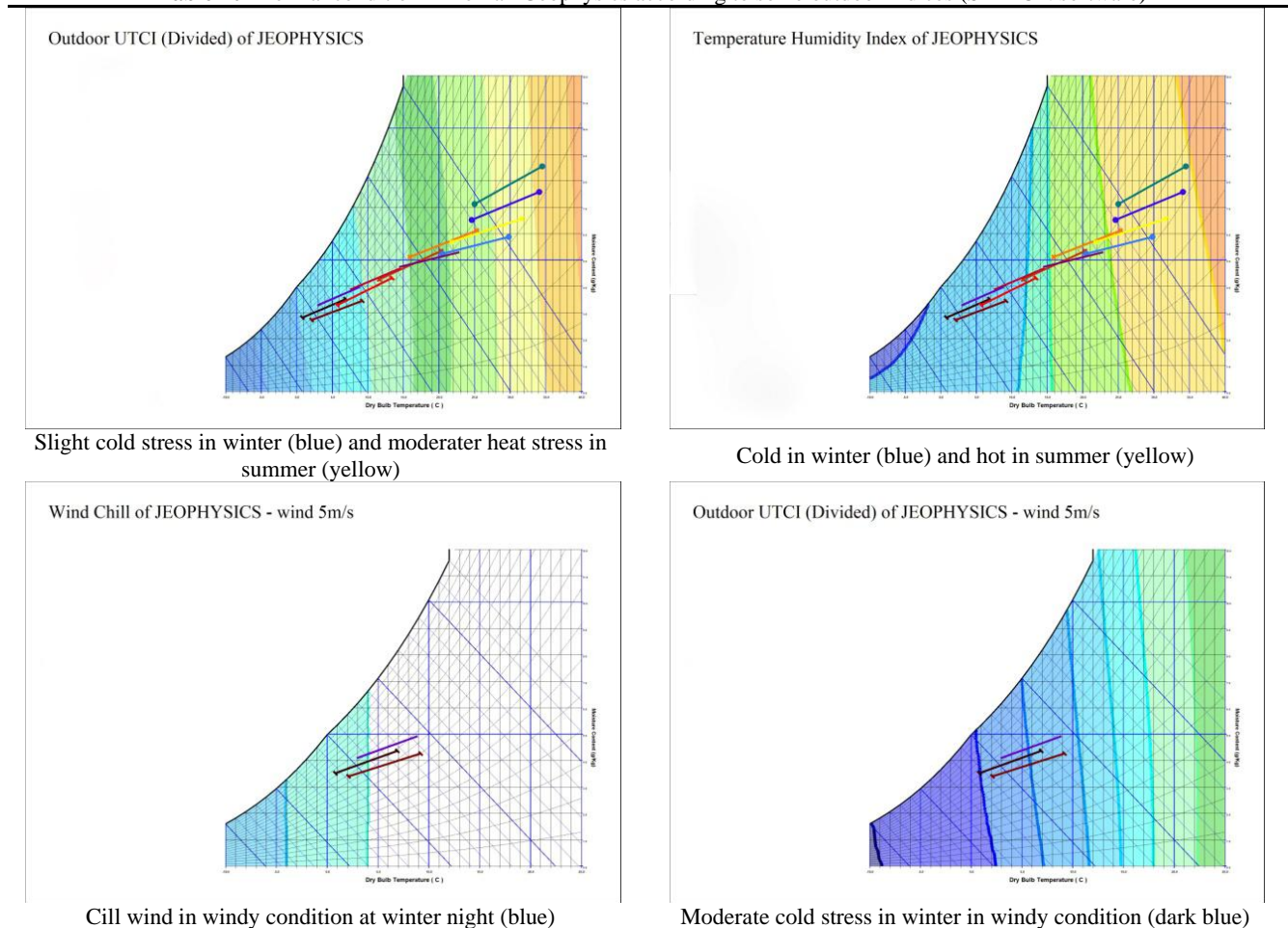
prediction in summer and winter in this climate. UTCI can show the effect of wind speed. According to arid weather, UTCI needs to become more sensitive to evaporative cooling for hot arid summers.

**Tehran-Geophysics**

Tehran-Geophysics in north/center part of Tehran has

hot arid weather in summer and semi-Humid cold weather in winter (Table 10). According to UTCI and Temperature Humidity Index, midsummer has strong heat stress or hot condition. Winter has slight cold stress or cold condition respectively. In windy places (more than 5 m/s) it drops the moderate to strong cold stress condition.

**Table 10** Thermal condition in Tehran Geophysics according to some outdoor indices (SIKRON software)



**Tehran-Geophysics field data collection**

The data were collected in winter from Jan to Feb 2012 in Haghani site of geophysics of Tehran Fig. 10. Plotting the collected data are shown on the Psychrometric chart of UTCI the results will be summarized as bellow: while in leeward condition the thermal sensation is in slight cold stress, in windy conditions it will drop to moderate cold stress condition. Observed places show that in winter, chill wind plays an important role. Table 11 shows that windy places such as B and E will be felt 2-4°C lower because of chill wind and are not suitable for outdoor long term presence. Leeward sunny places such as A and I will be 2-4°C warmer and are the most suitable places for long term stay. Therefore any method to control winter winds such as, trees, walls or glazed wind shelters and providing sunlit places is suitable. At night time people who need to stay out for long time such as hawkers use brazier to make outdoor long term presence tolerable Fig. 11.

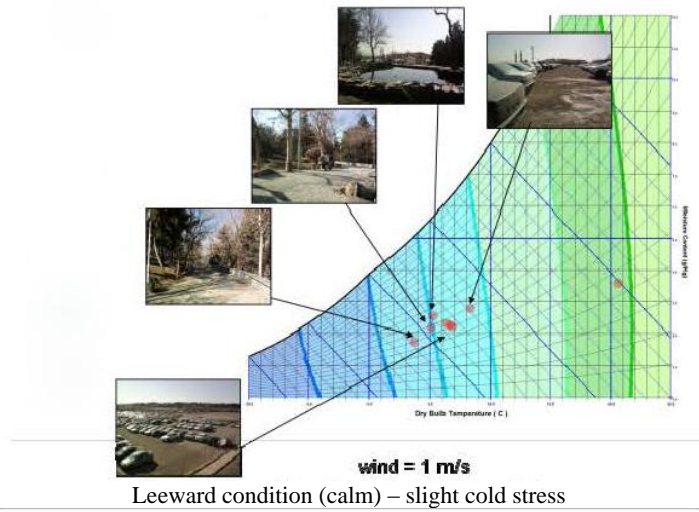


**Fig. 10** Tehran-Haghani observation route

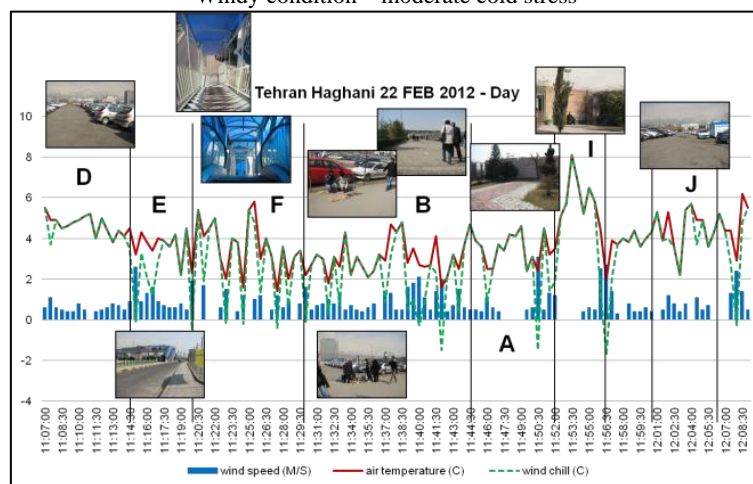
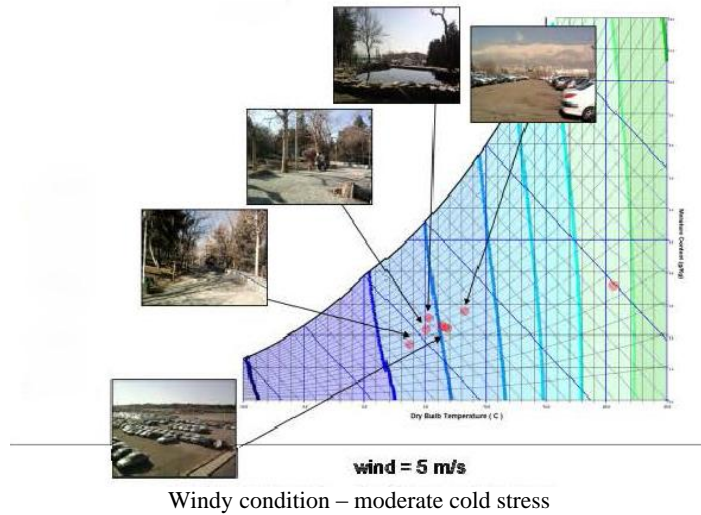


**Table 11** Thermal condition in calm and windy places in winter

Outdoor UTCI (Divided) of Haghani Site 4 JAN 2012 12-13pm

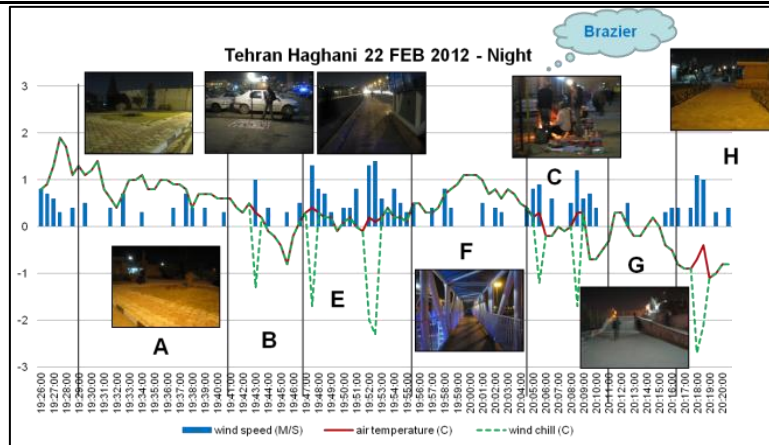


Outdoor UTCI (Divided) of Haghani site-Tehran 4 JAN 2012 12-13pm



Cill wind in slow breeze (E & B), warmer in sunlit lee places (I)





Using brazier for long term presence in moderate cold stress condition (C)



B: Sunny places in winter midday



I: Sunny leeward place



F: Glazed leeward place



C: At night with brazier

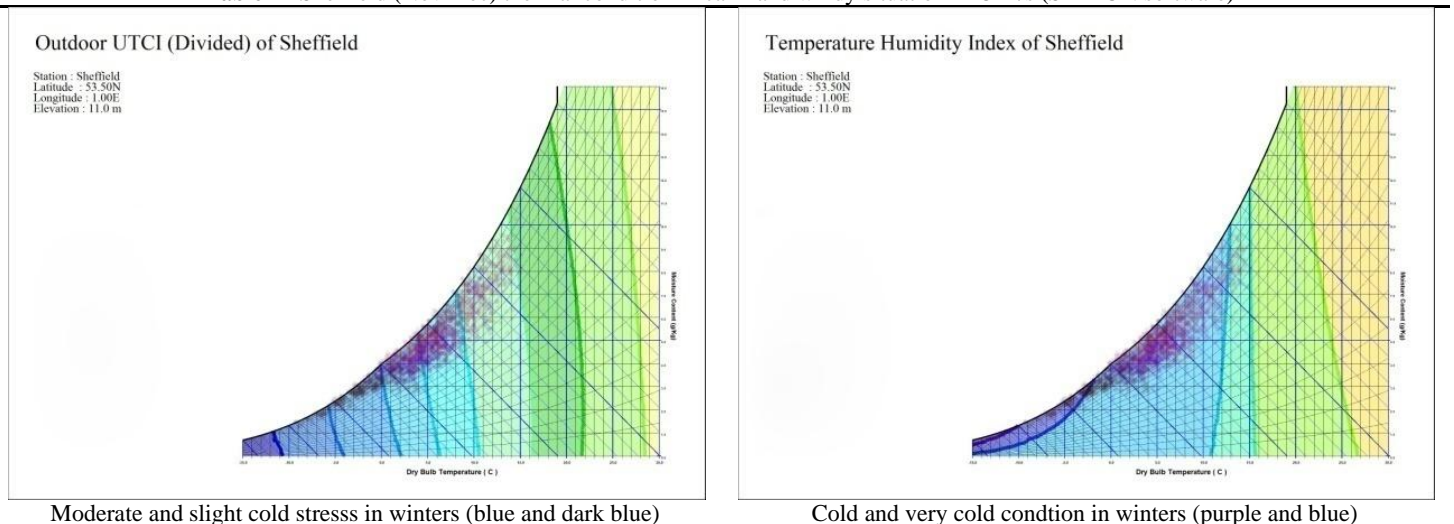
Fig. 11 Different places for outdoor long term presence in midwinter day and night

Observation shows sunlit leeward places have the best microclimate for long term presence in winter. In windy places wind chill is 2-4°C colder than dry temperature. Hawkers use brazier to be able to stay outdoor for a long time. This condition that is around 0°C is predicted slight and moderate cold stress by UTCI. It shows that UTCI has a good prediction for this climate in winters.

### Sheffield

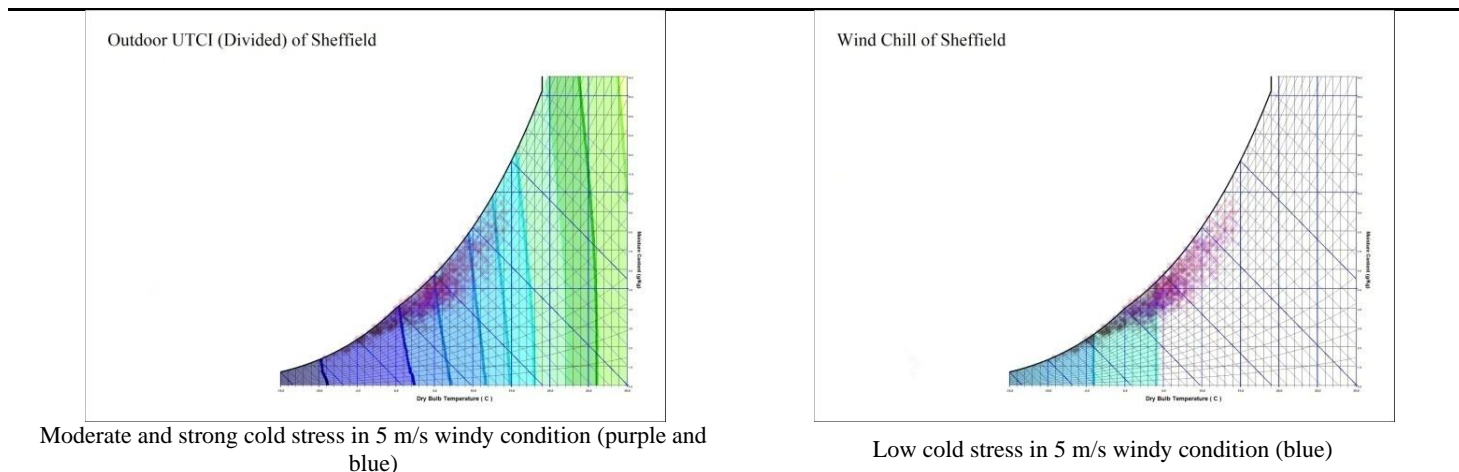
Sheffield with cold and windy weather in winter is shown in table 12. According to UTCI and Temperature Humidity Index midwinter has slight to moderate cold stress. In windy places (by wind speed more than 5 m/s) it riches the moderate to strong cold stress condition. WCET shows windy condition as low to moderate cold stress.

Table 12 Sheffield (Nov-Dec) thermal condition in calm and windy situation 1– 5 m/s (SIKRON software)



Moderate and slight cold stresses in winters (blue and dark blue)

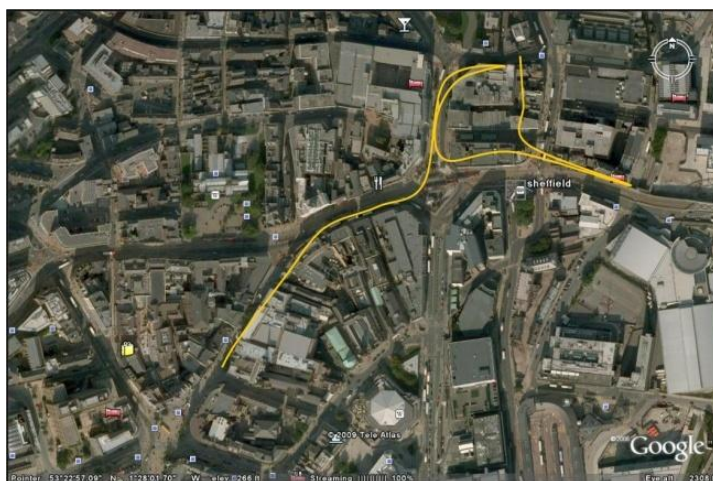
Cold and very cold condition in winters (purple and blue)



**Sheffield - field data collection**

The field study was done in the autumn and winter of 2010-2011 in Sheffield city center in different times of day and night Fig. 12. The local people’s behavior in cold

weather -as a costume of European generation - is studied in this research [42]. According to data collection and observation of people’s behavior, four kinds of thermal sensation were found in this research.

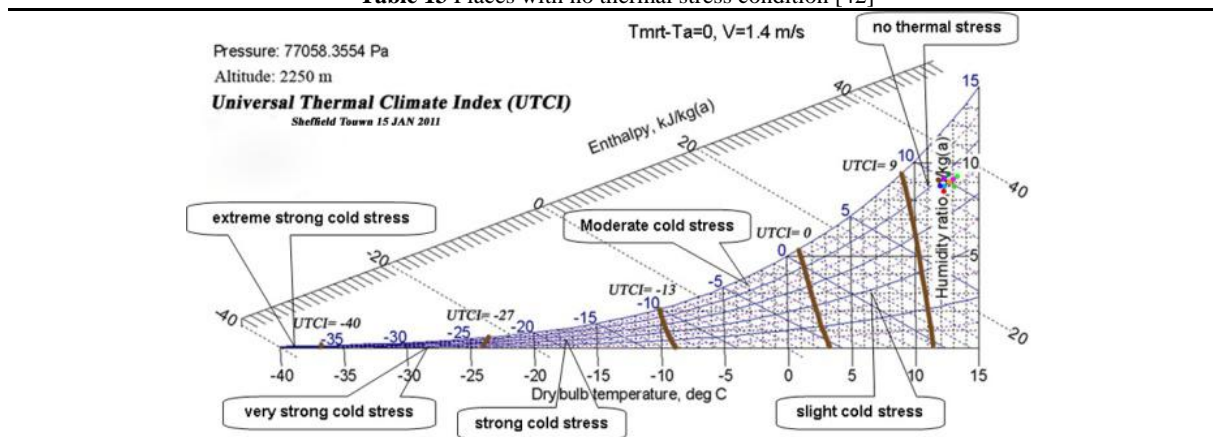


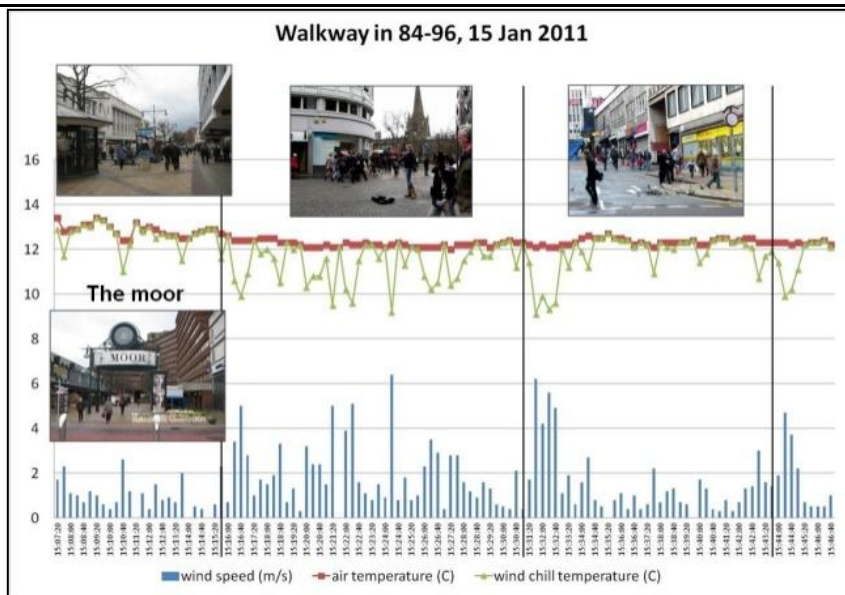
**Fig. 12** The observation path in Sheffield city center [42]

1-The first thermal condition is when the weather temperature of the observed places is more than 12°C with no thermal stress. This condition is appropriate for long term presence in outdoor places. Most of the people even

children, elders and disables spend more time outdoor without special supporting cloths such as gloves or shawl Table 13.

**Table 13** Places with no thermal stress condition [42]





Population spend more time outdoor in no thermal stress condition

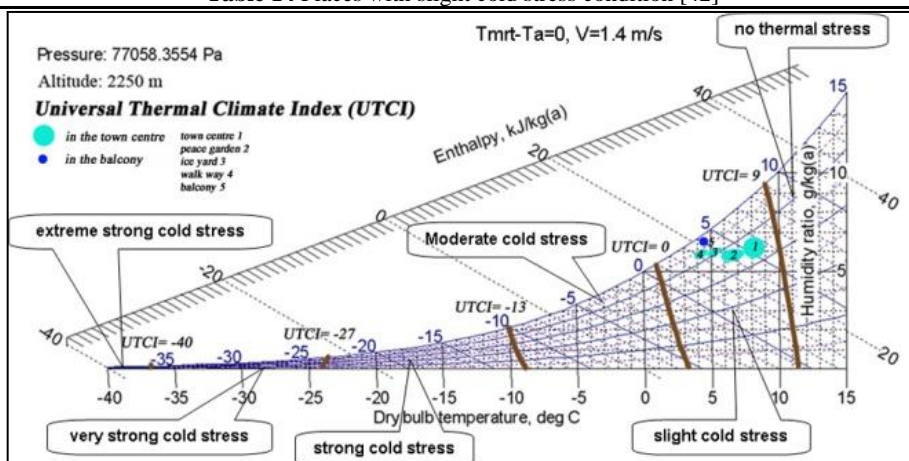


People spend time outdoor without supporting warmer cloths like gloves

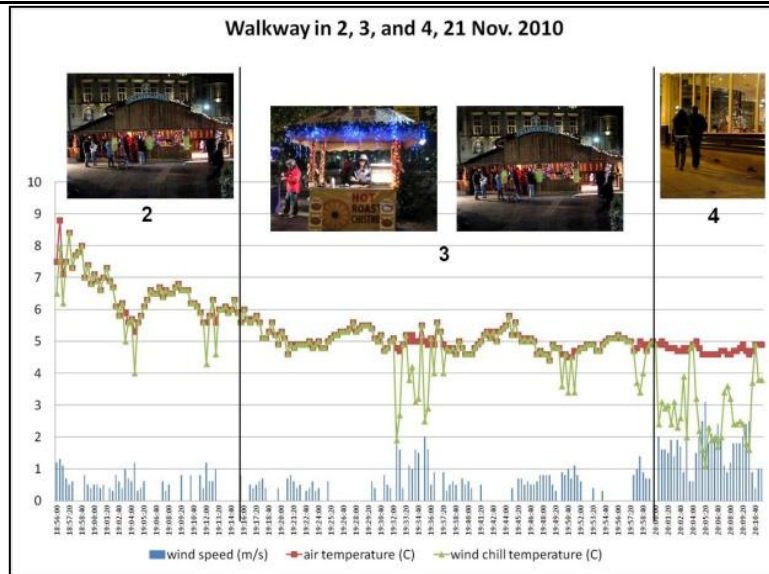
2-The second thermal condition is when the temperature of the observed place is around 5-8°C with slight cold stress condition. Long term presence outdoor is possible with some facilities such as warmer cloths,

hot drinks and food. In windy places wind chill will reduce the feeling temperature from 5°C to 2°C and thermal condition drops from slight cold stress to moderate cold stress Table 14.

Table 14 Places with slight cold stress condition [42]







Population spend time outdoor in slight cold stress condition with some facilities

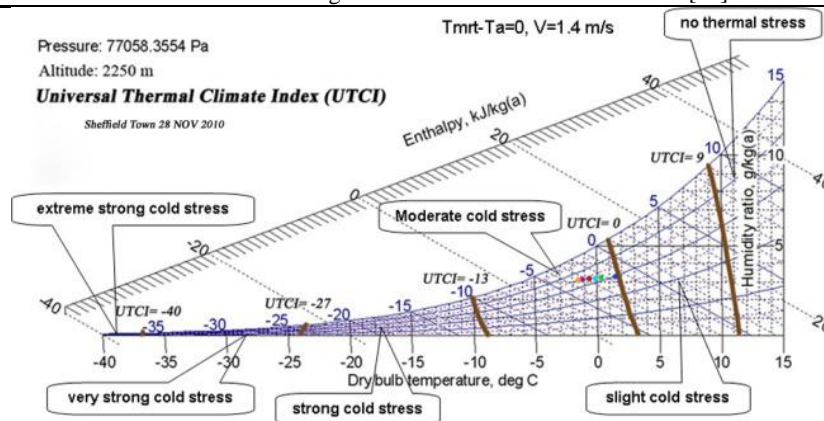


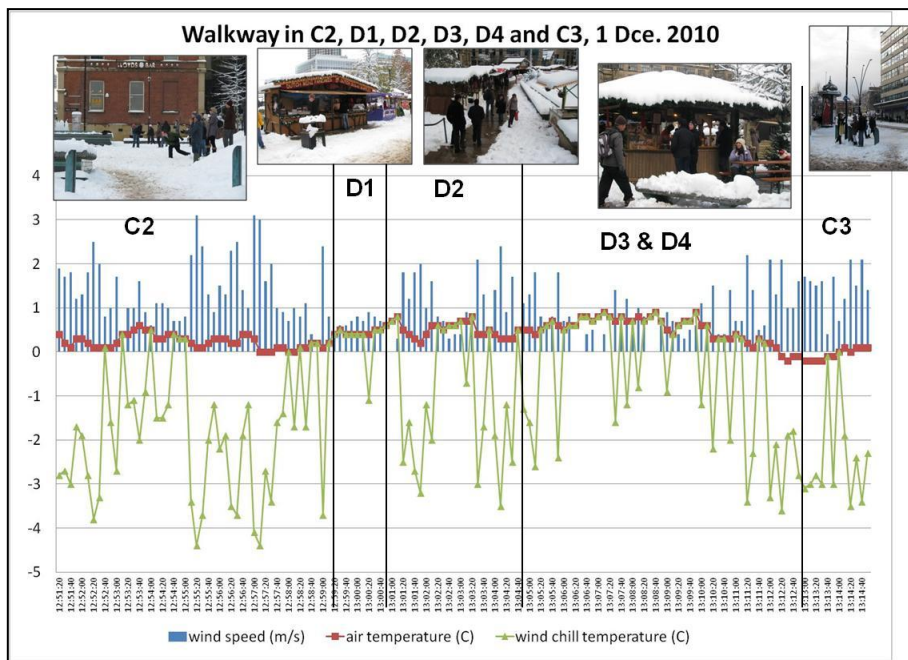
People's presence outdoor with supporting warmer cloths like gloves or facilities like hot drink

3-The third thermal condition is when the temperature of the observed place is around zero (-0.5 to 0.5°C) with slight to moderate cold stress situation depending on leeward or windward condition. Long-term stay outdoor is

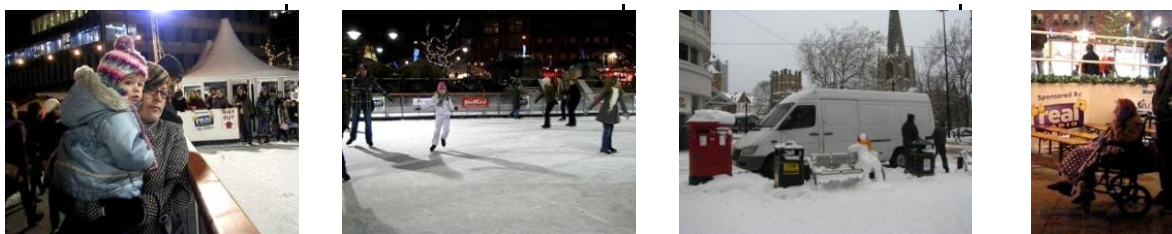
not pleasant except for exciting events with strategies like sunlit areas and wind shelter structures. Children, elderly and disables will present outdoor by more supporting warm clothes like gloves, shawl and hat Table 15.

Table 15 Places with slight to moderate cold stress condition [42]





Population spend more time outdoor because of exciting events

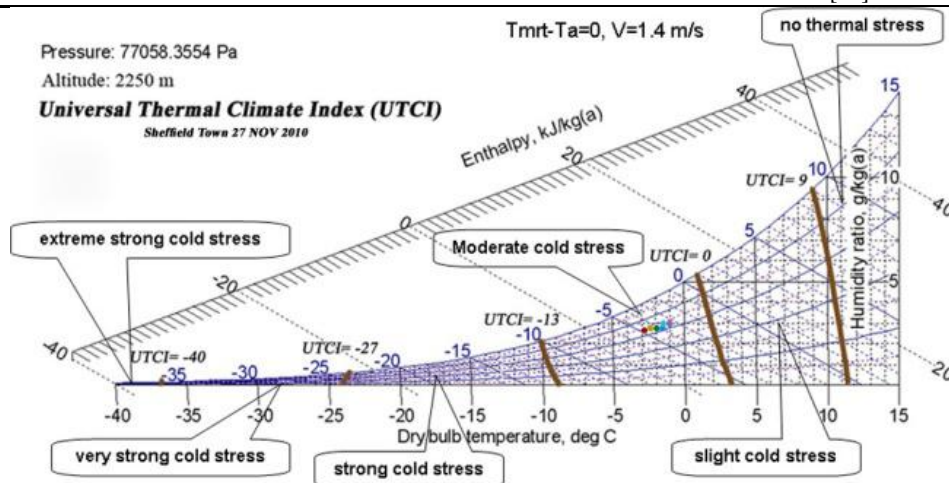


People's presence outdoor with supporting warmer cloths and facilities like sunlit areas or wind shelter

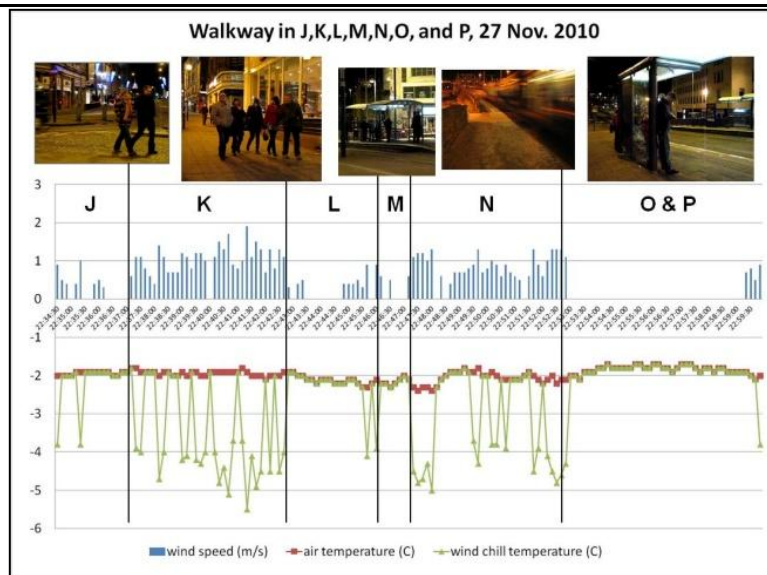
4-The forth thermal condition is when the temperature of the observed place is less than  $-2^{\circ}\text{C}$  and wind chill decreases feeling temperature to  $-6^{\circ}\text{C}$  that is critical

condition for long term exposure outdoor especially for children, elderly and disables. Most of the time only young people are seen outdoor in this condition Table 16.

Table 16 Places with moderate cold stress condition and wind chill effect [42]







Less population passing fast in outdoor areas, wind shelter places will control wind chill effect (O & P)



Few people present outdoor with supporting warm cloths need facilities like sunlit areas or wind shelter

The research of Sheffield shows that how different indices can predict cold stress thermal sensation of local people. It could be summarized that UTCI has more reliable prediction compare to WCET and THI. UTCI has good congruence with thermal behavior of local people in cold condition between zero and 12°C (slight cold stress to no thermal stress). THI is not sensitive enough in cold period although it is prepared for humid conditions. WCET is just prepared for very cold conditions to show wind chill effect for temperatures less than 5°C. It cannot give any prediction for higher temperatures.

## 6. CONCLUSION

This article is the result of some field studies had been done in 2010-2012 in five different climates: tropical (Kuala Lumpur, Malaysia), cold (Sheffield, UK), hot-arid (Kashan, Iran), hot semi humid (Ahvaz, Iran) and moderate-arid (Tehran) in their worst thermal situation. The weather data including temperature, humidity and wind speed, are collected by two portable Kestrel weather station to show weather condition in local and microclimate level. One weather station that is used as a reference is situated in a place like a roof of a building in the observed area, to collect the local climatic data. The other one is used as moving weather station to collect the microclimate data in different points of the observed area. Behavior of the people in outdoor spaces is observed with an nominal scale by special attention to different activities, the length of exposure time and the personal parameters such as clothing, eating and body condition (age and health). Presence of disables,

children and elders in outdoor spaces is a sign of tolerable thermal condition because they are more sensitive to thermal stress. The aim of these observations is to explain the relation between outdoor thermal condition and peoples' behavior. To classify this relationship, different outdoor thermal indices are used.

The results show that outdoor thermal indices are not appropriate for every climatic condition. For example TSI (tropical summer index) and THI for tropics and Summer Outdoor Comfort Zone have better explanation for tropical climates. THI and UTCI have better prediction for cold conditions. THI is more sensitive on wet condition while UTCI has better prediction for wind chill effect. WCET is just suitable for very cold weather. The mentioned indices are not appropriate for extremely hot and semi humid climate like Ahvaz in south of Iran. For hot-arid climate such as Kashan in summer, UTCI have better prediction than THI and WBGT. Although none of them can show the evaporative cooling effect on thermal sensation that has a great role in this climate.

At the end it would be summarized that these indices have acceptable sensitivity to temperature but most of them need to become more sensitive to cooling effect of humidity. UTCI has better prediction for air velocity in summer and winter. Additionally it would be said that although people's outdoor exposure time is related to outdoor thermal condition, some physiological and psychological factors such as acclimatization, expectation or exciting will affect their thermal sensation when they come to outdoor spaces with no tolerable thermal condition. Another important factor is exposure time that

will not be long when the weather is too cold or too hot. Architectural strategies such as providing appropriate sunlit or shaded areas, leeward or windward areas, humidification or water spray facilities will help to modify thermal sensation for long term exposure time.

## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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#### AUTHOR (S) BIOSKETCHES

**Tahbaz, M.**, Assistant Professor, School of Architecture, Shahid Beheshti University (SBU), Tehran, Iran  
Email: [M-tahbaz@sbu.ac.ir](mailto:M-tahbaz@sbu.ac.ir)

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