Int. J. Urban Manage Energy Sustainability, 1(2): 24-33 Spring 2020
DOI: 10.22034/IJUMES.2019.01.01.005

ORIGINAL RESEARCH PAPER

Evaluation of thermal comfort in urban areas

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Received 2 July 2019; revised 29 July 2019; accepted 15 September 2019; available online 1 January 2020

ABSTRACT: This Study introduces the effects of out-door thermal comfort field surveys in the city of Kashan, located in the hot climate zone in the cardinal region of Iran. Approximately 295 data sets by subjects in out-door condition were collected successfully. The answers indicated a friendly relationship between neutral temperature and current temperature, which subjects were exposed to it and also between outdoor temperature and air-speed and comfort temperature. This research has identified several adaptive actions that a soul might contract to reach comfort in outdoor condition. The determinations of the survey exposed that the Iranian citizenry, who are holding out in hot-dry piece of the state could achieve comfort at higher outdoor temperatures compared with the recommendations by some criteria, like Iranian standard for out-door working or existing. They find ways in which to make themselves comfortable in the conditions they normally experienced. It seems, different culture or different climatic zones does not any negative effects in such actions. The paper concludes with this fact that the adaptive model is valid rather than Finger's equations.

KEYWORDS: Adaptive model; Field survey; Finger's equations; Outdoor condition; Thermal comfort.

INTRODUCTION

Thermal comfort of persons staying outside is one of the factors influencing outdoor activities in the streets, shopping centers, playgrounds, urban parks, and so on The amount and intensity of such activities is affected by the level of the discomfort experienced by the inhabitants when they are exposed to the climatic conditions in these outdoor spaces.When staying outdoors, people expect varieability in the exposure conditions: variety of sun and shade, changes in wind speed, and hence along. Outside, wind speeds are much higher than the air speeds common indoor. Wind in summer, up to a certain velocity, may be specifically pleasant, while in winter it may be specifically annoying. Relative humidity also has big effect on outdoor thermal sensation. These elements have to be included in assessing the overall subjective responses to the outdoor environment (Givoni, *et al*., 2003). People staying outdoors usually wear different clothing in different seasons, clothing that is suited to the prevailing mood. In conditions of metabolic rate, there is not much difference between subjects feeling and changing their body processes. While there have been many studies on thermal comfort of people staying indoor environments, relativity few has investigated outdoor thermal comfort and its determinants (Givoni and Noguchi, 2000). Dew dear mentioned that in that location has been an assumption that the conventional theory of thermal comfort developed for indoor applications (Fanger, 1972 ; ASHRAE ,2001) can be generalized to outdoor settings without modification (Spagnolo and de Dear ,2003). Nevertheless, on that point is a lack of empirical thermal comfort data collected in outdoor areas much more study is required, especially if a universally applicable thermal comfort/discomfort index is to be prepared.

Apparently, not only indoor comfort study has a significant impact on energy preservation and carbon emotion, but also outdoor comfort has a cracking force on energy consumption especially in hot and dry zone of the macrocosm. It is because, when people staying indoors, they apply more energy for cool-

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ing and ignition. A typical sitting area of many urban centres generally have paved section, some current water in different form and forms for watering the paved area, thus more humidity, various trees and flowers to make a pleasing environment. The paved section is used for many body processes. Depending on the time of the day there is always a shaded area, enabling people to sway on their activity and at the same time to enjoy nature, water and cool breezes. It also offers a useful seating area for adults and a gaming field for kids. Rational planting of vegetation can offer significant shade, which is important for city temperature reductions (Givoni, 1994).

Some other important factor for lowering the air temperature is the paving in the city floor. In fact, treatment can be applied in walkway to lower the surface temperature by the purpose of suitable paving materials and cooling the paving of the arena itself. Paving heats up quickly causing both painful glare and reflected heat radiation toward the inside of the city. In the early morning the paving receives the diffuse radiation coming from the sky and from the surrounding walls.(VDI,1998).

As the sun lifts the ground surface loses heat to the adjacent cold air layer. The rising heated air is replaced by relatively colder air until the air temperature of inside the courtyard reaches that of the outdoor air. The duration of paving exposure to intense radiation is more capital than that of any vertical wall; this accounts for the criticality of the treatment of its surface.

Yet, for lowering air temperature the material and colour of paving, amount of moisture and shade of pavement is important. In the hot, dry zone of traditional part of Iranian cities burnt clay brick for pavement is one of the most widely used materials. The light coloured, better absorption of water, ability of evaporation of water in time of need and availability is approximately of the burnt clay brick's good properties. On the other hand, surface treatment and the selection of structure wall's colour will determine the thermal behaviour of the city and can aid in diluting the heat load. Role of light colour in traditional roles of hot, dry cities in Iran shows how people experienced the importance of colour (Givoni, 1994).

Lastly, air pollution reduces the transmissivity of the urban air. Part of the solar radiation directed toward the city is retained by the pollution dome over the city.

This study carried out at the facility of Art and Architecture, University of Tehran from May 2016 to October 2016.

Out-door thermal comfort

Outdoor comfort related to three groups of factors, namely physiological and psychological parameters joint with behaviour of people, design of elements in outdoor and the outdoor environment. Achieving comfort conditions requires an understanding of the interaction between these factors. In indoor condition, there are two main methods of determining thermal comfort i.e. through climate chamber experiments or through field studies. Climate chamber experiments are performed in laboratory conditions, while field studies are carried out anywhere as long as the right instruments are available. The comfort temperatures determined from various studies in real world vary notably from one to another and are sometimes difficult to reconcile with the temperatures calculated from the climatic chamber experiments. These two methods can be applied for calculation of neutral temperature and comfort zone. However, comfort is dynamic in character and like many indoor studies of thermal comfort; it may be some more discrepancy between results of two methods in out-door condition (Nicol, 1993).

The functions of cities are basically the same everywhere: to provide a basic and fundamental base for a comfortable living, resting, walking, shopping and working environment and to avoid extreme weather; but the designs and processes for cities in different climates are different according to climate, for example compact shapes in tropical cities. To live in the hot and dry tropical area, the major problem is avoidance of excessive solar radiation(Givoni,1998). urban design should aim, in hot-dry regions, from the climatic point of view, to achieve the following objectives:

- *Choosing locations with the most favourable climate,*
- Avoiding areas prone to severe natural hazards
- Minimizing urban temperature elevation above the surrounding level by reflecting solar radiation from roofs, increasing the areas of green open spaces, etc.
- Enabling good ventilation potential for the buildings, especially in the evenings, and in the open spaces

- Providing shade in summer in the streets, over sidewalks and in open spaces
- Providing "access" to the sun in winter for the buildings and in open spaces, especially in regions with cold winters
- Providing protection from winter winds (in regions with hot summers but cold winters)
- Minimizing the dust level.

Under these conditions, the city should be comfort as expected.

Case study: City of Kashan

The city of Kashan is located in the vicinity of Iran's central desert, i.e. a vast barrier of sand and gravel, namely Bande Rig comprising many sand hills. The desert climate in this area is very hot and dry. The violent winds blown from Bande Rig, distribute huge amounts of dust in the city area, almost throughout the year. The average temperature of the city throughout the year is 19.6ºC, which is close to the temperature in March and September and rapid temperature rise occurs in February to May while temperature drop begins from August. The average maximum temperature exceeds 45ºC in warmer months, particularly in June and July. The average annual rainfall is less than 150mm where the maximum occurs in January and the minimum in June. The average minimum of humidity is %20 in summer compared to the average maximum of %60 in winter, forming very harsh living conditions.

Historically, this city has continued to exert its role as an important population centre connecting the northern and southern cities of the country through the borders of the central desert. The existence of water has been a key factor for the formation of the city, similar to all cities in dry regions. The city of Kashan had some 30,000 populations in a century ago, and now, has more than a million. Fig.1.

Urban design consideration in the city of Kashan

There is no doubt that many urban planning and design issues originate in vast economic, social, cultural and environmental factors. Among these, the role and application of cities are the key factors. However, in deserts and dry regions, and particularly in historical cities, environmental factors are the key and considerable issues. Although climate studies are mainly considered from ecological and agricultural aspects, they are major factors in the existence and formation of cities in dry regions and suitable settlement as a whole. The form and organic environmental shape of cities can be a subsequence of climate indicators. Among important climate indicators are temperature, rain and humidity as well as wind, affected by geographical latitude, topography and altitude above sea level.

The traditional part

The historical and traditional fabric and texture of the Kashan city is a sensitive model of coordination between Architecture and urban design with the natural environment and energy. These aspects can be important lessons and experiences of how such cities in harsh and dry regions have been planned and designed using climate indicators for suitable life and settlement. In the architectural aspect, wind and water have been used to create appealing environments within old houses. The existence of underground reservoirs using the aqueduct system, are some examples. These reservoirs are located in

Fig.1: Geographical location of Kashan City

public open spaces or within private houses forming attractive environments, views and also suitable living conditions, by creating suitable atmospheric humidity. The low storey buildings have also been coherent to climate conditions. Moreover, using special building materials, such as mud and adobe, domes, arches and louvers are other examples of such coherence.

The contemporary part

In contrast to the traditional part of the city, it can be claimed that the new and contemporary parts of the city have neglected such climate conditions. New urban expansion has not only disregarded such climate indicators, but has also made major negative impacts on the old and historical environment. For example, the new land development areas of the city have destroyed agricultural lands, which were the essential factor for city formation and its life throughout the history.

Improving city condition

New technological, economic, social and population requirements may be considered as inevitable factors in such approaches. As it has been recommended in the recent comprehensive and master plans of the city, some approaches can be considered for improving city conditions under contemporary conditions, using climate characteristics, as it has taken place in old and organic parts of the city. Applying metal, plastic and sand material to building front views is prohibited. In contrast, using bricks, cement, mud, wooden doors and windows as well as light colors are recommended.

Another important issue is population and construction density in such regions. It is obvious that under sustainable urban development, compact cities, and increasing densities are widely recommended today. However, as was seen in the case of Kashan city, hot and dry regions require low storey building bases appropriate for their climate conditions. Therefore, urban consolidation approach can be applied in such cities by means of low buildings and low open space per capita.

MATERIALS AND METHODS

The field study of thermal comfort is the methodology used for the present study, which is based on observations in the actual environments. The important advantage of the field studies is that it is an in-situ experiment, which means that the results of the method can be directly applied to similar thermal environments. The environmental parameters and personal parameters cannot be closely controlled, so the results are applicable to the normal conditions encountered by the respondents during the season of study.

During surveys outdoor air temperatures and relative humidity were obtained from Skye Data Hog, data-loggers that gathered and stored results automatically. Its accuracy is 0.2°C (maximum error over 0°C to 60°C). Air velocity past the body also were recorded with an airflow meter, Solomat MPM 500e (accuracy 2% rdg ± 0.15 m/s; -10°C to 70°C). Clothing values as an important individual variable was recorded. The questionnaires contained five questions. They are in order of thermal sensation: using a seven point ASHRAE scale; a three-point preference scale; 5-point air velocity scale and clothing insulation as shown in Table 1.

The field study conducted in July–August 2006, during hot season with 295 subjects in transverse sampling at open spaces on city centre. The start time of the survey in each day was often 10.00 and finish time was about 22.00. The number of subjects was variable in each day from 29 persons to 69 persons and had a mean of about 50 persons in each day (six day).

Distribution of physical and individual data

The summaries of the climatic data in their means, ranges and standard deviation are tabulated in Table 2 for the period of work.

Outdoor air temperatures ranged from a low of 24.6°C to a high of 42.6°C. Mean of air velocity was 0.25 $m/s^{0.5}$ and the mean of relative humidity was 43. Clothing value as physical data has a great effect on thermal comfort. It is individual and has a difference from one person to another. Mean clothing value of subjects was 0.41clo. According to Nicol (Nicol, 1993) the measurement of metabolic rate is not really necessary in field studies, being a function of the social and climatic milieu and of the task for which a comfort temperature is being found. It is also reported by Humphreys (Humphreys, 1976) that variations of activity have not often been recorded in field studies of thermal comfort. Most experimenters have given only a general description of the activity of their respondents. In this study authors ignored from measurement of metabolic rate.

Table 1: Extract from the questionnaire related to the thermal environment

What is your feeling at the moment	Cold Cool Slightly cool Neutral Slightly warm Warm Hot Would you like to be: Cooler No change Warmer What do you think of the wind at this moment: Stale Little wind OK Windy Too much wind

Table 2: Mean and standard deviation of environmental and individual data

	Air Temperature	Relative Humidity	Air Velocity	Clothing
Mean	30.6	43	0.25	0.41
SD	3.70	5.29	0.09	0.07
Min.	24.6	32	0.01	0.30
Max.	42.6	52	0.48	0.64

Distribution of sensation and preference votes

The first and important point is that over 80% of subject votes indicated neutral or slightly warm condition. It is surprising according to the range of air temperature, that this is enough for the range of outdoor comfortable condition. Almost 45% of subjects selected neutral condition (0).

The mean sensation vote on the ASHRAE scale was 0.77 while responses to the McIntyre scale were 24% preferring "no change", 76% for cooler and no vote for warmer. The mean preference vote was (-0.76%).

RESULTS AND DISCUSSION

Relationship between variables

There is a high and positive relationship between air temperature and sensation votes (Fig.2), the higher the temperatures the warmer the sensation. Furthermore, it is interesting that the range of the sensation votes are in the comfort range (slightly cool to slightly warm) while the mean air temperature varied from 24.6°C to 42.6°C. Such a relationship also exists between air temperatures and preference votes but negative.

The correlation of air temperatures and air-velocity was good and negative. According to adaptive model, air velocity does consistently correlate with air temperature in many cases. It is interesting, when the temperatures are highest, the air movement is higher. In this study, we correlated air velocity with sensation vote. The results are in agreement with adaptive model, as shown in Fig. 2. Correlation coefficient of sensation vote and air velocity vote is presented in Fig. 3. Once again, it is interesting. This correlation is highly significant and negative, as adaptive model expected. The correlation between sensation and preference votes is relatively high as might be expected.

Table 3: Mean and standard deviation of sensation and preference votes

	Sensation vote	Preference vote
Mean	0.77	-0.76
SD	0.77	0.43
Min.	0	0
Max.	3	-1

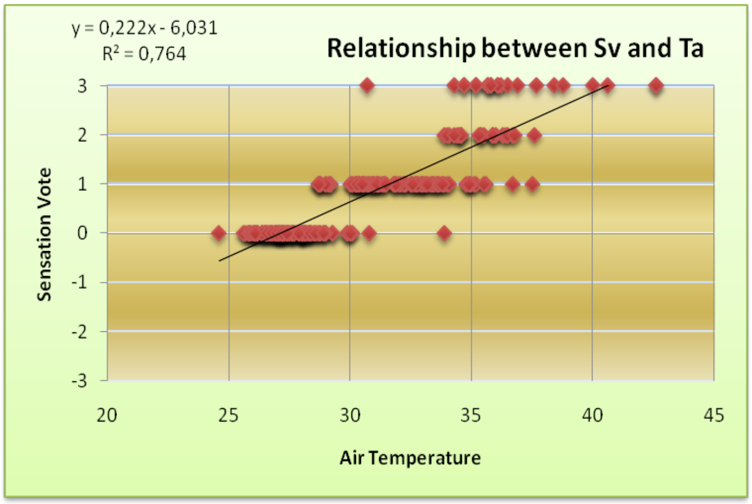

Fig. 2: Relationship between air temperature and sensation vote

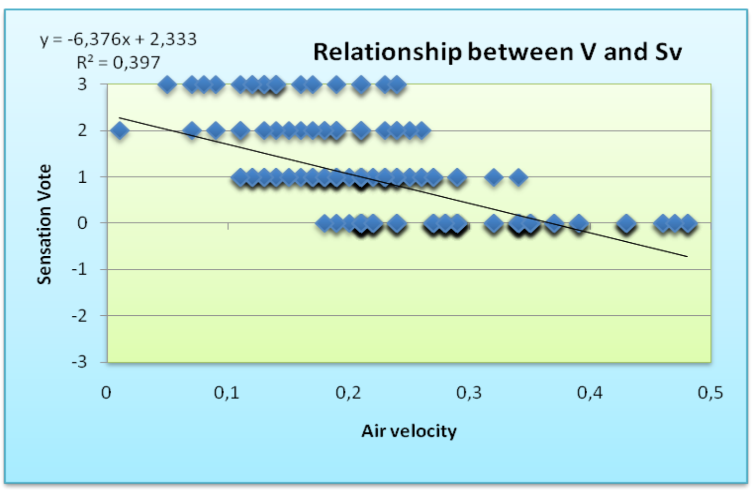

Fig. 3: Relationship between air velocity and sensation vote

Clothing is an important factor contributing to human response. It is not controlled in field studies, but has often been recorded. The highly and negative correlation between air temperature and clothing value shows a very good agreement within these two variables. The warmer, it is the less people wear. It is an indication that the subjects were using clothing as a way of adjusting to the thermal environment. This relationship has been found in other field surveys, among them, Nicol *et al*. (Nicol, 1994). The results indicated that the choice of clothing is not affected by humidity which is not unexpected.

Neutral temperature

One recognised method to predict the subjective comfort which results from a given temperature, or combination of environmental variables, is regression analysis (Nicol, 1994). Simple linear regression was performed of the ASHRAE scale responses versus air temperature to determine the strength of the relationship between them. Table (4) shows the comfort equations during the study. As shown in Table (4) the slope of sensation responses is around 0.22/°C and neutral temperature is 27.2°C.

Relationship between other variables

There is a strong relationship between all variables. We found a good and significant correlation between air temperature and clothing value (Figure 4), air temperature and sensation vote (Fig. 2), air velocity vote and sensation vote (Figure 3), and more importantly between air-velocity and sensation vote (Fig. 3). This point indicated that people are active and these prove: if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort. There is also an interesting relationship between air velocity and air-velocity vote (Fig. 5) which indicated that people are sensitive to air-velocity.

Evidence for adaptation

Some actions relating to changes of environmental conditions included some personal and some non-personal factors. Relationships between such actions and environmental factors were strong and significant in the present study. The correlation coefficients between air temperature and thermal sensation votes are the main point. Relationship between clothing values and air temperature was significant. Clothing insulation, however, had a strong linear dependence on outdoor temperature. We also found a strong relationship between air velocity and sensation vote, between air velocity and air velocity vote, between air velocity and clothing value (Fig. 7).

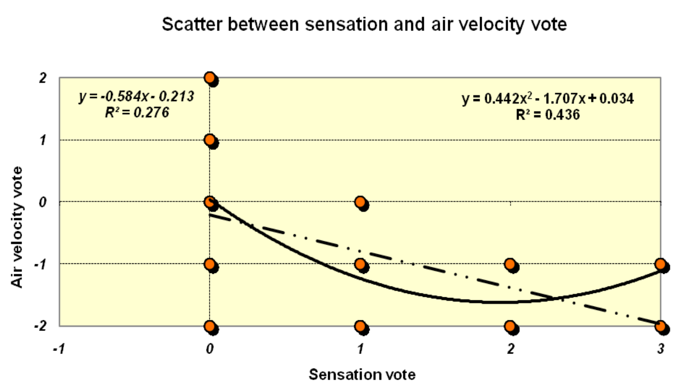

Fig. 4: Relationship between sensation vote and air velocity vote

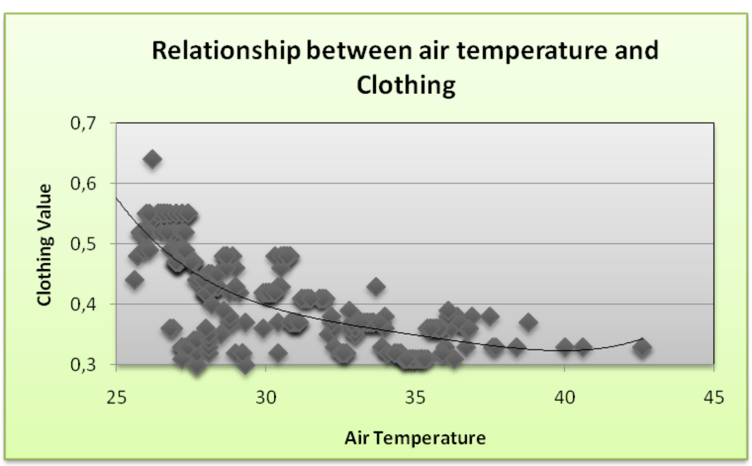

Fig. 5: Relationship between air temperature and clothing value (R^2 = 0,54)

Table 4: Data from simple regression

Slope	Intercept	R^2	T_n (°C)	Equations
0.22	-6.031	0.764	27.2	$= 0.22\, T_a - 6.03$

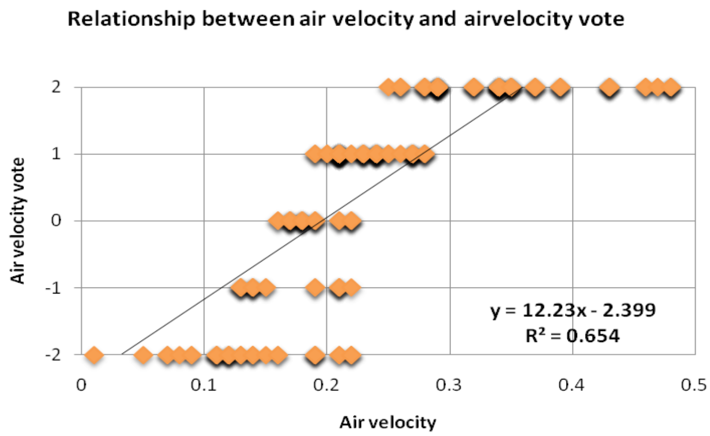

Fig. 5: Relationship between air velocity and air-velocity vote

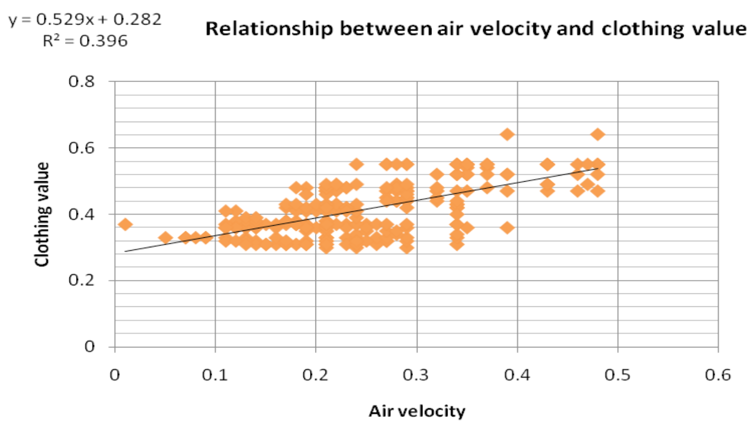

Fig. 7: relationship between air velocity and clothing value

We assumed that 0.1 m/s of air velocity can reduction of 2°C of air temperature to achive comfort condition. According to this statement, a correction for air temperature was made. Fig. 8 shows scatter diagram between the result of the correction and clothing value. Once again it seems there is a very good agreement between clothing insulation and environment variables.

The comfort zone

The comfort zone does not have real boundaries for the comfort condition because it depends on sex, age, acclimatisation according to geographical locations, type of clothing and activity, as well as cultural factors and life style. Thus the range of comfort for building design strategies will be based on field studies at certain locations. By using the conventional method considering thermal sensation votes within the three central points of the seven-point ASHRAE sensation scale and at least 80% of the respondents who were satisfied by their environment, thermal acceptability of present subjects can be established. For this aim a quadratic equation was used to estimate the curves lines.

Limits of air temperatures between 22.7°C to 31.7°C for period of study can be boundaries of ac-

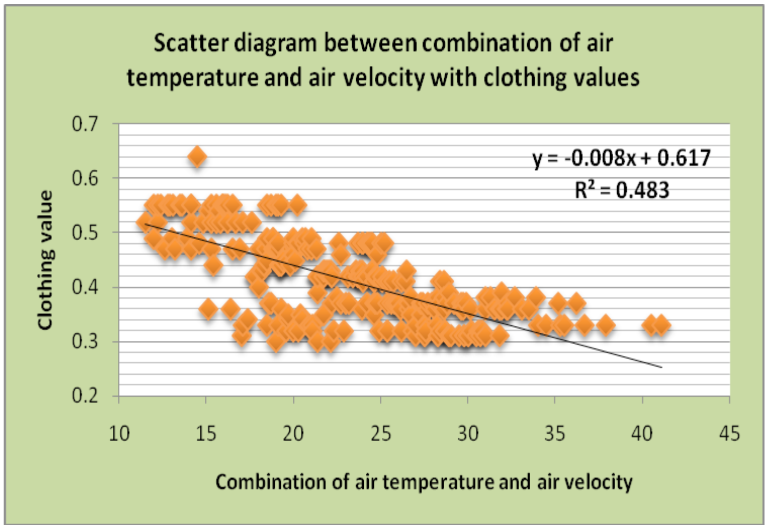

Fig.8: Scatter diagram between combination of air temperature and clothing value

ceptable conditions in Kashan. Mean air velocity votes during the time of questionnaires were about -0.63 which is in the category of still OK air velocity. With increasing air velocity, the upper air temperature limit of the comfort condition can be increased of air temperature. However, the range of acceptable conditions from the present study is much wider than that predicted by standards such as ISO-7730 or ASHRAE standard 55. The findings about air velocity and air temperature indicated that these two variables are important factor in determining outdoor comfort conditions. In the climate of Kashan, it is more often necessary to provide maximum shade and breeze. At the temperature below 43°C, the normal sedentary person is in light clothing will be comfortably warm and it is excellent for designer who is designing outdoor environment.

The work described in this paper presented some of the finding of an extensive project. The finding confirms that there is a strong relationship between microclimatic and comfort conditions, with air temperature, air velocity and relative humidity. The interesting findings of this study, however, were:

Air temperatures are well correlated with thermal sensation votes.

- The neutral temperature was 27.2°C with a thermally acceptable range of 22.7°C to 31.7°C
- The mean sensation vote of all groups of subjects in the present study are in agreement with other outdoor field studies
- The results of this study showed the strong relationship between prevailing temperatures and neutral temperature
- Some behaviour adaptations were identified, such as high correlation between air temperature and clothing value and as well as between air temperature and air movement
- Air temperature alone can be a better indicate of thermal comfort, rather than other indices

ACKNOWLEDGEMENTS

This work supported by the Faculty of Art and Architecture, University of Tehran. Appreciate those collagens in this field.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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