Climatic Range for Comfort Evaporative Cooling

Zahra Ghiabaklou

Abstract—This paper presents the climatic range calculations for comfort evaporative cooling for Tehran. In this study the minimum climatic conditions required to achieve an appropriate comfort zone will be presented.

Physiologically uncomfortable conditions in arid climates are mainly caused by the extreme heat and dryness. Direct evaporative cooling adds moisture to the air stream until the air stream is close to saturation. The dry bulb temperature is reduced, while the wet bulb temperature stays the same. Evaporative cooling is economical, effective, environmentally friendly, and healthy.

Comfort cooling by direct evaporative cooling (passive or fan forced) in the 35. 41 N (such as Tehran) latitude requires design wet-bulb temperature not over 25.4 C. Evaporative cooling outside this limit cannot achieve the required 26.7 ET, and is recommended for relief cooling only.

Keywords—Evaporative cooling, Comfort temperature, Climatic design, Comfort cooling

I. INTRODUCTION

EVAPORATIVE cooling has made summers more bearable for thousands of years and with 21st century technology provides effective, economical, environmentally friendly, and healthy cooling.

When water evaporates it absorbs a large amount of heat from its surroundings. The most familiar example of this is the cooling effect of evaporating perspiration on the human skin. In arid, hot climates body temperature is partially controlled by the rapid evaporation of perspiration from the surface of the skin. In hot climates with high atmospheric moisture the cooling effect is less because the high moisture content of the surrounding air. In both situations, however, the evaporation rate is raised as air movement is increased. Both of these facts can be applied to natural cooling of structures.

Evaporative cooling is healthy and comfortable because it:
1) Brings in outside air and exhausts stale air, smoke, odors, and germs.
2) Helps maintain natural humidity levels, which benefits both people and furniture and cuts static electricity.
3) Does not need an air-tight structure for maximum efficiency, so building occupants can open doors and windows.

The effectiveness of evaporative cooling depends on weather conditions. System design is affected by the prevailing outdoor dry bulb and wet bulb temperatures, as well as the application of the system. Evaporative cooling performs well obviously, only where summer provides adequately dry air. The minimum required weather differs with the type. The

Zahra Ghiabaklou is with the School of Architecture, Faculty of Fine Arts University of Tehran, Tehran, Iran, (e-mail: ghiabaklou@ut.ac.ir).

earliest authorities believed that direct evaporative coolers required a climate having average noon relative humilities in July (for the northern hemisphere) of 40 per cent or less. Those coolers operate best when wet-bulb levels are 23.9°C or less and local dry-bulb temperatures above 32.2°C warrant cooling equipment [1].

Giles [2] has suggested a great range of comfort: three weather zones permitting respective "good", "fair" and "fringe" results. The respective number of hours that dry-bulb temperatures exceed 32.2°C and wet-bulb temperatures exceed 21.1, 22.8 and 24.4°X respectively are combined on the basis that hours of suitable operation in each category should exceed 2/3 of total hot hours. The suggested scales are:

a) Good Results:

$$\{(\text{hours over } 32.2°C \text{ db})-(\text{hours over } 21.1°C \text{ wb})\}/ (\text{hours over } 32.2°C \text{ db})=2/3 \qquad (1)$$

b) Fair Results:

$$\{(\text{hours over } 32.2°C \text{ db})-(\text{hours over } 22.8°C \text{ wb})\}/ (\text{hours over } 32.2°C \text{ db})=2/3 \qquad (2)$$

c) Fringe Results:

$$\{(\text{hours over } 32.2°C \text{ db})-(\text{hours over } 24.4°C \text{ wb})\}/ (\text{hours over } 32.2°C \text{ db})=2/3 \qquad (3)$$

Geographical application of this formula would be valuable, although it lacks clear relation to comfort zone analysis. One assumption is clear; fringe results here require minimum wet-bulb depressions of 7.8°C. This clearly includes some "relief cooling".

II. COMFORT COOLING AND RELIEF COOLING

The real need is for analysis based upon the comfort chart, indicating whether given climates allow evaporative cooling to achieve the comfort zone or not. Suitable climates could then be termed the "comfort range", permitting "comfort cooling"; less advantageous climates would constitute the "relief range", allowing "relief cooling" [1].

Ash [3] suggests that the true measure of evaporative cooling's "comfort range", not its total range, is its ability to maintain conditions below 25.6 ET, near the comfort zone's upper limit. This is the point where perspiration begins in most lightly clothed persons, indicating that body convective and radiant cooling are no longer adequate. He acknowledges that 25.6 ET is achieved by different means in different climates. In dry climates it results mostly from adiabatic saturation based on large wet-bulb depressions.

Accordingly 25.6 ET can be achieved by either *cooling* effectiveness or *ventilating* effectiveness, depending upon the climate. The contrasting conditions below achieve almost identical comfort:

TABLE I
THE CONTRASTING CONDITIONS WHICH ACHIEVE ALMOST
IDENTICAL COMFORT [1]

	Dry Climate	Average Climate
Outdoor dry-bulb °C	44.4	33.9
Outdoor wet-bulb °C	22.2	25.6
Wet-bulb depression °C	22.2	8.3
Washed air enters at °C	26.7	27.2
Room air temperature° C	29.4	28.3
Washed air exhaust °C	32.2	29.4
Room air velocity m/s	0.2	1
Room ET:	25.6	25.6

These nearly opposite conditions create identical sensations of indoor comfort low air movement in the first case being compensated by 50 percent indoor RH, and high velocity in the latter being offset by 80 percent RH. This last humidity may damage some materials but is acceptable for human comfort.

This illustrates that evaporative coolers can improve indoor comfort in almost all climates, provided that high indoor air velocities and relative humidities are acceptable.

III. EVAPORATIVE COOLING COMFORT CHART

Watt proposed to relate local climatic conditions positively to the comfort zone. Evaporative cooling will thus be recommended only where it usually achieves conditions with that area's comfort zone. In this recommended geographical range it will deliver "comfort cooling" and in a limited zone outside it, "relief cooling".

Since no natural definition exists, the following limits for the "comfort range" are proposed. Any locality whose climate allows average evaporative coolers to meet these requirements is thus considered the "comfort range" and its cooling is thus classified as "comfort cooling". The minimum requirements are:

1) That direct evaporative coolers have average saturating efficiencies of 70 percent or more, and the cooled air enters rooms without prior heat gain.
2) That cooled air induces a maximum average indoor air velocity of 1 m/s.
3) That cooled air gains at least 3.3°C indoors before its discharge.
4) That cooled spaces average 1.7°C above cooler discharge temperature and have average humidities of 70 percent RH or below.
5) That cooled spaces average at least 4.4°C below outdoor dry-bulb temperature to counteract entering radiant heat and provide a differential below outside.
6) That cooled spaces average an effective temperature no higher than upper limit of the ASHRAE summer comfort zone adjusted for local latitude. (The final requirement varies with latitude)

For example, in Pittsburgh's 41°N latitude, the comfort chart's origin (Figure 1), the summer comfort zone ranges between 17.8 ET and 26.1 ET, with its centre at 21.7 ET. Thus, in this latitude average direct evaporative coolers must satisfy these requirements and achieve an indoor effective temperature of 26.1 ET or below, to provide "comfort cooling".

With the necessary final indoor conditions known for each region, Figure 1 helps determine the maximum permissible local outdoor wet-bulb temperature and the minimum average outdoor wet-bulb depression required for such performance. The former becomes the maximum permissible design wet-bulb temperature for the locality, and the latter is converted by a simple (and not entirely satisfactory) ratio into the required minimum design wet bulb depression.

IV. DESIGN TEMPERATURES

Design temperatures, published to aid designers of air conditioning systems, consist of dry-bulb and wet-bulb temperatures which form a quick and easy index to local climatic conditions since they represent respectively the hottest and most humid weather commonly encountered. In general, they represent temperatures usually exceeded in only 1 to 5 percent of total hours in average summers, but as matters of local estimate and custom, not of calculation from weather records, they have uncertain accuracy. The ASHRAE Guide's compendium of design temperatures is perhaps the best. Design wet-bulb depression is simply design dry-bulb temperature less the design wet-bulb value.

V. CALCULATING TECHNIQUE

Figure 1 is an adapted thermometric chart showing the interrelation of summer dry-bulb, wet-bulb and air velocity conditions in creating effective temperatures. The ASHRAE old comfort zone for 41°N latitude has been superimposed upon it, its upper limit on 26.1 ET. This zone moves bodily up the curve 0.56 effective temperature (one line) for each 5° reduction in latitude. The theoretical percentage of persons feeling comfortable at any temperature is indicated.

The chart is arranged as a monograph in order to solve comfort problems; straight lines drawn between related dry-bulb and wet-bulb values indicate the resulting effective temperatures where they cross velocity lines.

To solve evaporative cooling's outdoor problems, Watt has added shorter vertical scales indicating direct evaporative cooler washed-air temperatures at saturating efficiencies of 70 to 90 percent. Thus, lines connecting appropriate outdoor values on the dry- and wet-bulb scales indicate on the new ones the temperature of cooled-air entering conditioned rammers.

To calculate the outdoor climatic conditions necessary to achieve comfort cooling as defined, the following method is proposed by Watt [1]:

1) Select outdoor dry-bulb temperature (ODB) and outdoor wet-bulb temperature (WB) from local air conditioning design data.
2) Draw outdoor condition line from ODB to WB.
3) Select cooler saturating efficiency column. Where it crosses outdoor condition line, read the washed air room-entering temperature (WAE).

4) Select washed air indoor temperature gain, usually 2.8-5.6°C (5-10 F), and locate washed air room-exhaust temperature (WAX) on left that far above WAE, and draw connecting line.
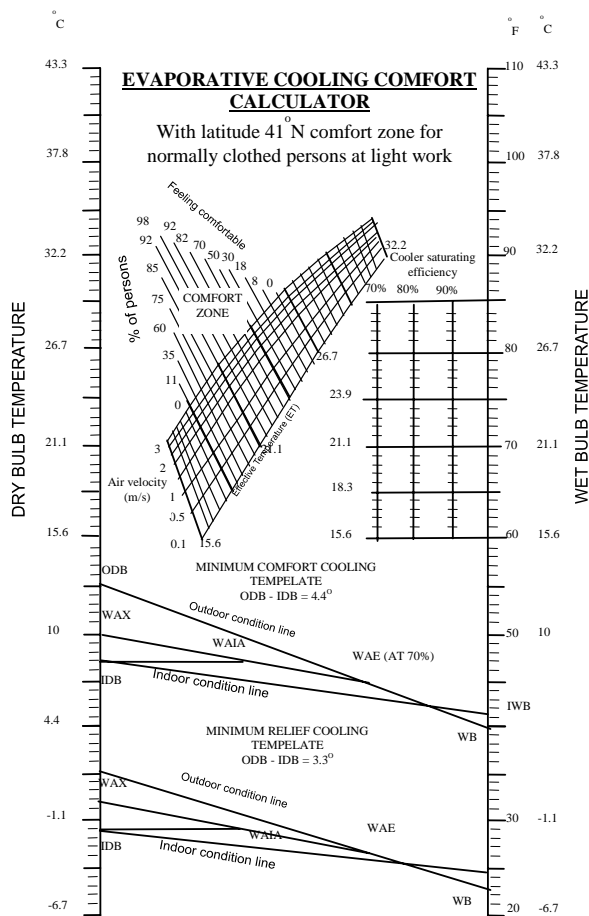

Fig. 1 Comfort evaporative cooling chart [1].

5) Locate washed air indoor mean temperature (WAIA) midway between WAE and WAX.
6) Draw horizontal line left from WAIA to find the average indoor dry bulb temperature (IDB).
7) Select estimated indoor wet-bulb temperature (IWB), usually 1.1°C (2 F) above WB.
8) Draw indoor condition line from IDB to IWB.
9) Select an estimated room average air velocity line.
10) Read indoor comfort level in Effective Temperature degrees, where indoor condition line crosses room air velocity line. Compare with comfort zone adjusted for local latitude.

VI. COMFORT ZONE FOR TEHRAN

In order to calculate the summer comfort zone in Tehran with latitude 35.41°N, the comfort zone in this latitude, has been bodily moved up the curve 0.56 effective temperature (one line). Thus, the summer comfort zone for Tehran, ranges between 18.3 ET and 26.7 ET, with its centre at 22.2 ET.

Design temperatures of dry-bulb and wet-bulb represent respectively the average hottest and most humid weather of the simulation period. Also, air velocity and efficiency of the system are assumed at a conservative averaged minimum level at the hottest time.

The assumptions of calculating comfort zone are:
- Outdoor design dry-bulb temperature = 37.1°C
- Outdoor design wet-bulb temperature = 20.7 °C
- Room air velocity = 0.1 m/s
- Cooling saturating efficiency = 70%

Figure 2 shows the thermal comfort level achieved by the evaporative cooling system and above assumptions in the given climatic condition of Tehran. As can be seen from this figure, the Effective Temperature is 23.9 ET and 70% of people feel comfortable in this climatic region.

In order to determine the geographical performance of evaporative cooling system, Watt presented the minimum climatic conditions allowing average direct evaporative coolers in each region to achieve their appropriate comfort zone. By definition of design temperatures, the localities meeting these requirements probably will enjoy comfort zone cooling at least 80 to 90 percent of all hot hours.

In all cases, comfort cooling requires a minimum design depression of 12.2°C and a maximum wet-bulb temperature based on latitude as presented in Table 2. Comfort cooling by direct evaporative cooling in the 35. 41°N (Tehran) latitude requires design wet-bulb temperature not over 25.4°C. Evaporative cooling outside this limit cannot achieve the required 26.7 ET, and is recommended for relief cooling only.

Similarly, since each change of 5° of North latitude shifts the comfort zone 0.56 ET, evaporative coolers in about 43-47°N, must achieve 25.6 ET, requiring design wet-bulb temperatures of 24.2°C or below. Correspondingly, comfort cooling in the latitudes about 38-42°N, must make 26.1 ET or below for which 24.8°C is the maximum permissible design wet-bulb temperature. In latitudes about 33-37°N, comfort cooling must achieve 26.7 ET or better, requiring a 25.4°C maximum design wet-bulb temperature. At approximate latitudes of 28-32 and 26-27°N, should respectively achieve 27.2 and 27.8 ET, and wet bulb temperatures not over than 25.9°C and 26.5°C.

TABLE II
RECOMMENDED EVAPORATIVE COOLING CLIMATE [1]

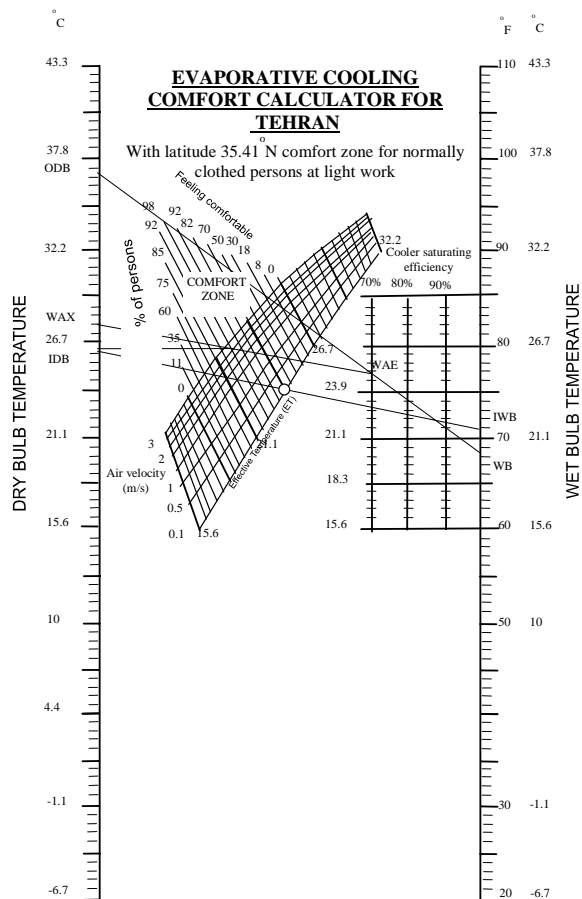| Approximate latitude	For comfort cooling			For relief cooling		
	Maximum indoor ET (°C)	Minimum outdoor design WB depression	Maximum outdoor design WB (°C)	Maximum indoor ET (°C)	Minimum outdoor design WB depression	Maximum outdoor design WB (°C)
47-43°N	25.6	12.2	24.2	26.7	9.4	26.1
42-38	26.1	12.2	24.8	27.2	9.4	26.7
37-33	26.7	12.2	25.4	27.8	9.4	27.2
32-28	27.2	12.2	25.9	28.3	9.4	27.8
27-26	27.8	12.2	26.5	28.9	9.4	28.3

Fig. 2 Comfort evaporative cooling chart for Tehran

VII. CONCLUSION

In this paper, climatic range of effective evaporative cooling was studied. It was stated that evaporative coolers operate best in climatic conditions with wet-bulb temperature of 23.9°C or less and dry-bulb temperature above 32.2°C. Suitable climates were termed as "comfort range", permitting "comfort cooling" and less advantageous climates would constitute the "relief range", allowing "relief cooling". An evaporative cooling comfort chart which proposed by Watt was adopted in order to determine the comfort cooling range in various climatic conditions. The evaporative cooling chart for Tehran showed that, by using this cooling system, 70% of people would feel comfortable in this climatic region. Also a table was presented for recommended evaporative cooling climates for various latitudes and design temperatures.

REFERENCES

[1] Watt, J.R. 1963. *Evaporative Air Conditioning.* The Industrial Press, New York.
[2] Giles, S. 1955. *Evaporative Cooling, A Symposium, Weather Data Limitations.* ASHAE Journal Section, Heating, Piping & Air Conditioning, 141-147, August.
[3] Ash, R. S. 1955. *ASHAE Journal Section, Heating, Piping & Air Conditioning*, 141-147, August.