EVALUATION OF THE POTENTIAL OF EVAPORATIVE COOLING FOR HUMAN THERMAL COMFORT A CASE OF KANO, NIGERIA

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ABSTRACT

In some developing countries like Nigeria, poverty and epileptic power supply are the twin problems impeding people from the use of refrigerated-based air conditioning systems to achieve thermal comfort. Also, the use of some refrigerants has adverse effect on the environment. Evaporative cooling systems are viable options for achieving thermal comfort especially in hot and dry climates. These systems, apart from their low cost and power requirement, they are environmentally friendly. This work attempts to determine the viability of using evaporative coolers to achieve thermal comfort in Kano using the feasibility Index Method. The computed feasibility indices of Kano in the months of January through December are -0.2, 0.1, 0.1, 6.6, 9.5, 14.2, 18, 19.1, 18.2, 10.6, 5.5 and 2.1 respectively. Employing the concept of feasibility index *(FI)* method reveals that comfort cooling can be achieved in the months of January, February, March, April, May, November and December while relief cooling can be achieved in the months of June and October. The method also reveals the unsuitability of evaporative cooling in the months of July, August and September. Considering both the comfort and the relief cooling periods based on the *FI* method, evaporative coolers can therefore be used to achieve human thermal comfort in the study area.

Keywords: *Feasibility index, Evaporative cooler, Thermal comfort, Temperature*

INTRODUCTION

Conventional air conditioning system requires high capital investment and its operating costs often become exponentially high due to its consumption of electricity. Furthermore, the restrictions imposed by protocols limit the type of refrigerants that can be used in these systems. In developing countries like Nigeria, poverty to a very large extent has incapacitated the common man from using air conditioning systems to achieve thermal comfort. The epileptic and interrupted power supply also hinders those that have the conventional air conditioning units from using them as expected. Air conditioning is responsible for the increase of the efficiency of man in his job as well as for his comfort, especially in hot and dry climates. The most commonly used air conditioning systems are the conventional refrigerated-based air conditioning systems. However, in many cases, evaporative cooling can be an economic and healthy alternative and may replace the conventional system in many circumstances.

Evaporative cooling offers an economical, energy efficient and practical means of cooling and can be used to maximum advantage in areas of high dry bulb temperatures, with low outdoor relative humidity. Other benefits of evaporative cooling are:

- Unlike most refrigerated cooling systems that rely on recycled cooled air with partial fresh air replacement, the evaporative cooler enjoys popularity in the introduction of a continuous supply of freshly cooled outdoor air. This creation of healthy invigorating conditions generates a feeling of relaxed enthusiasm, conducive to improve staff concentration and work output. This is due to the naturally cooled, humidified, negatively ionized air which does not dry up nasal passages, eyes or skin, unlike the positively ionized, artificially cooled air from a refrigerant based air conditioning [1].
- Helps maintain natural humidity levels, which benefits both people and furniture and cut static electricity.
- Does not need an air-tight structure for maximum efficiency, so building occupants can open doors and windows.
- Evaporative cooling is also an inexpensive cooling option. It is up to 50% cheaper to install and seven times cheaper to run than refrigerated cooling [2].
- The working fluid, water, does not have negative impact on the environment.

Despite the benefits of evaporative cooling aforementioned, not much work has been done in that area in most developing countries, particularly Africa. This work is therefore geared towards evaluating the feasibility of using evaporative cooling to achieve thermal comfort in Kano, Nigeria.

Recent Work on Evaporative Cooling Systems

In the context of evaporative cooling, several authors dedicated their researches to the development of direct, indirect and combined indirect-direct evaporative cooling systems. Camrago et al [3] worked on experimental performance of direct evaporative cooler operating during summer in Brazilian city, Valesco et al [4] worked on the description and experimental result of semi-indirect ceramic evaporative coolers, Camrago et al [5] discussed three methods to evaluate the use of evaporative cooling for human thermal comfort, Gunhan et al [6] evaluated the suitability of some local materials as cooling pads, Isaac et al [7] reviewed porous evaporative cooling for the preservation of fruits and vegetables. Qun et al [8] worked on the new approach to analyse and optimize evaporative cooling systems, Kulkarni et al [9] theoretically analysed the performance of jute fiber rope bank as media in evaporative coolers, Metin et al [10] determined the relationship among air velocity, cooling efficiency and temperature decrease at cellulose based evaporative cooling pad, Valesco et al [11] discussed the phenomenon of evaporative cooling from a humid surface as an alternative method for air-conditioning, Kulkarni et al [12] theoretically analysed the performance of indirect-direct evaporative coolers in hot and dry climates, Vivek [2] experimentally investigated the performance of evaporative desert cooler using four different cooling pad materials, Metin et al [13] studied the effects of air velocity on the performance of pad evaporative cooling, Kulkarni et al [14] compared the performance of evaporative cooling pads of alternative materials.

Evaporative Cooling Systems

There are basically three main types of evaporative cooling systems:

- Direct evaporative coolers
- Indirect evaporative coolers
- Combined indirect/direct evaporative coolers

Direct evaporative coolers

In direct evaporative coolers, non-saturated air comes into contact with water-saturated cooling pad, and evaporation occurs. The necessary latent heat is provided by the air, which cools down. In addition, the moisture content of the air rises. Direct evaporative cooling is represented on the psychrometric chart in figure 1.0 by a displacement along a constant wet-bulb temperature line AB.

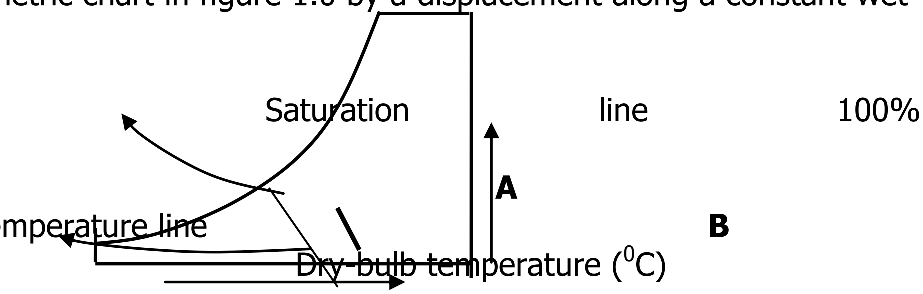

Figure 1.0 Psychrometric Chart of Indirect Evaporative Cooling

Indirect Evaporative Coolers

In indirect evaporative coolers, the evaporation occurs in a primary circuit of a heat exchanger. While the air to be cooled circulates in the secondary circuit, the air temperature decreases but its water content remains constant. Since the humidity content of the cooled air does not rise, indirect evaporative cooling is represented on the psychrometric chart by a displacement along a constant humidity ratio-line CD in figure 2.0.

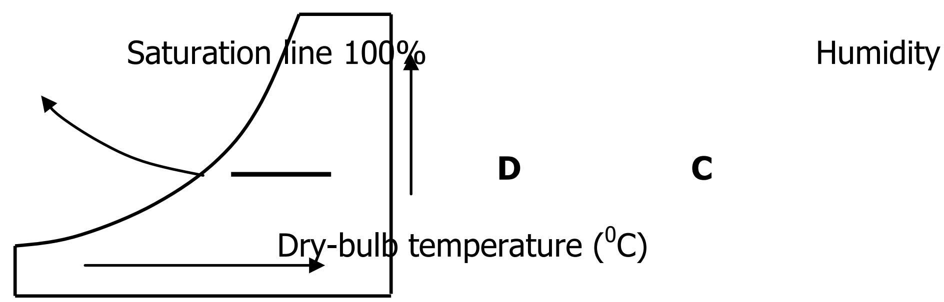

Figure 2.0 Psychrometric Chart of Indirect Evaporative Cooling

Combined Indirect/Direct Evaporative Coolers

The two-stage evaporative cooler combines an indirect cooler in the first stage and a direct cooler in the second stage. The psychrometric chart in figure 3.0 shows the processes involved in this system. Air to be cooled, initially at point A, is sensibly cooled by an indirect evaporative process until it reaches point B, since the water content of the air has not changed, line AB is parallel to the dry-bulb temperature axis. Then the air enters the second stage, where it becomes cooled down by a direct evaporative process to point C. Since this is a constant wet-bulb temperature process, line BC is parallel to the wet-bulb temperature.

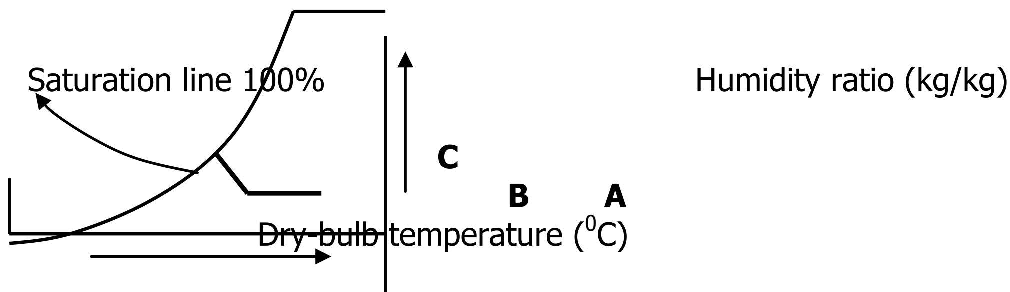

Figure 3.0 Psychrometric Chart of Indirect-Direct Evaporative Cooling

MATERIALS AND METHOD

The potential of evaporative cooling for human thermal comfort using Kano as a case study was evaluated using the method of *feasibility index* (FI). With respect to that, the feasibility indices of the 12 months, January through December, were determined. In this method, the determining parameters used in the analysis were the outdoor dry and wet bulb temperatures. With respect to that, it is customary to consider what the weather will be like in the future. But, even the best weather forecasters cannot help with that. Therefore, there is need to turn to the past instead of the future and bet that past weather data averaged over several years will be a representative of a typical year in the future. Therefore, the past weather data of Kano for four years were considered. The monthly average of the dry bulb temperatures for the past four years is presented in Table 1.0 and the corresponding average wet bulb temperatures were determined using psychrometric chart and the values are presented in Table 2.0.

Table 1.0 Average Maximum Temperature (^{0}C)

MONTH	2008	2009	2010	2011	Average
JAN	24.4	28	30.4	26.9	27.4
FEB	28.8	34	32.9	35.2	32.7
MAR	36.8	36.2	34.6	36.6	36.1
APR	37.2	38.3	38.2	39.4	38.2
MAY	37	36.7	37.6	38.8	37.5
JUN	35.9	36.2	33.6	34.4	35.0
JUL	28.3	32.3	30.1	30.7	30.4
AUG	28.9	30.9	30.2	30.3	30.1
SEP	29.5	31.2	31.6	31.8	31.0
OCT	33.6	35.2	34.1	33	33.9
NOV	31.6	31.6	34.2	31.6	32.3
DEC	31.4	28.8	29	28.8	29.5

Source: WMO [15]

Table 2.0 Average Wet Bulb Temperature (^{0}C)

MONTH	2008	2009	2010	2011	Average
JAN	11.3	14.8	15.5	12.7	13.6
FEB	14.2	16.7	16.2	18.6	16.4
MAR	18.2	18	17.8	18.3	18.1
APR	20.4	22.5	22	22.9	22
MAY	21.5	23.4	25.6	24.1	23.2
JUN	24.4	24.2	25.1	24.8	24.6
JUL	23.6	24.5	24.3	24.3	24.2
AUG	24.4	24.9	24.7	24.5	24.6
SEP	24.1	24.6	25	24.7	24.6
OCT	20.2	21.3	24.3	22.4	22.1
NOV	17.3	18	18.8	21.6	18.9
DEC	17.2	15.2	15.8	14.8	15.8

Description of the Study Area

Kano is located in the Northern part of Nigeria at latitude 12^0 45^1 and longitude 08^0 45^1. It is about 900km from the edge of the Sahara desert and 1140km away from the Atlantic Ocean [16]. The climate is characterized by high temperature and low relative humidity in the dry season. The average maximum temperature is 37.9^0C in April and the coolest average minimum temperature is 29.02^0C in December. The relative humidity ranges from 12.9% in March to 63.5% in August.

The Feasibility Index Method

The feasibility index (FI) is defined by [5] as:

$FI = WBT - \Delta T$

Where

$\Delta T = (DBT - WBT)$ is the wet bulb depression.

$DBT =$ Dry-bulb temperature of outdoor air

$WBT =$ Wet-bulb temperature of outdoor air

This index decreases as the difference between dry and wet bulb temperature increases, that is, as air relative humidity decreases. It shows that the smaller FI is, more efficient the evaporative cooling will be. Thus, this number indicates the evaporative cooling potential to give thermal comfort for human beings [5]. The work of Camrago et al [5] highlights the following ranges of the feasibility indices *(FI)* with respect to cooling for human thermal comfort.

$FI \leq 10$ Recommended for comfort cooling

$11 \leq FI \leq 16$ Recommended for relief (lenitive) cooling

$FI > 16$ Not recommended for the use of evaporative cooling systems

Results

The feasibility index (FI) of Kano was computed by applying the *feasibility index* equation to the values obtained in Tables 1.0 and 2.0. The evaluated values for the twelve months were presented in Table 3.0.

Table 3.0 Monthly Evaporative Cooling Feasibility Index of Kano

MONTH	WBT (^0C)	DBT (^0C)	$\Delta T = (DBT - WBT)$ (^0C)	$FI = (WBT - \Delta T)$
JAN	13.6	27.4	13.8	- 0.2
FEB	16.4	32.7	16.3	0.1
MAR	18.1	36.1	18.0	0.1
APR	22.0	37.4	15.4	6.6
MAY	23.2	36.9	13.7	9.5
JUN	24.6	35.0	10.4	14.2
JUL	24.2	30.4	6.2	18.0
AUG	24.6	30.1	5.5	19.1
SEP	24.6	31.0	6.4	18.2
OCT	22.1	33.6	11.5	10.6
NOV	18.9	32.3	13.4	5.5
DEC	15.8	29.5	13.7	2.1

DISCUSSION

Table 3.0 shows the evaluated feasibility indices of twelve months, January to December, of Kano. From the computed values of the feasibility indices in Table 3.0 and based on the work of Camrago et al [16], comfort cooling for human thermal comfort can be achieved through the use of evaporative coolers in the months of January, February, March, April, May, November and December since their feasibilty indices are -0.2, 0.1, 0.1, 6.6, 9.5, 5.5 and 2.1 respectively. This is so because their values of feasibility indices are less than 11. These periods represent about 58% of the total number of months in a year. During these months, the high temperature and low relative humidities enhance the sensible heat transfer from the incoming air to the water saturated pad and also moisture transfer from the saturated pad to the incoming air. This agreed with the work of Camrago et al [5] that evaporative cooling is viable in regions with relatively low wet bulb temperature.

Relief cooling can be achieved with evaporative coolers in the months of June and October since their feasibility indices are 14.2 and 10.6 respectively. These represent about 17% of the total number of months in a year. In the context of thermal comfort, during the period of lenitive (relief) cooling, the body does not need to activate any of the defense mechanism to maintain normal body temperature. Therefore, the thermal conditions for relief cooling fall at the periphery of the thermal comfort zone. Taking both the comfort and the relief cooling into consideration, evaporative coolers can therefore be used for both comfort and relief cooling for about 75% of the months in a year.

The results show that evaporative coolers may not be suitable for human cooling for thermal comfort in the months of July, August and September, because their feasibility indices are 18, 19.1 and 18.2 respectively. These values are greater than 16 and therefore, fall outside the recommended range. This can be attributed to the high relative humidity during these periods. The higher the relative humidity the slower the rate of evaporation from the saturated pad of the cooler thereby, rendering the cooler insignificant.

CONCLUSION

The potential of evaporative cooling for human thermal comfort in Kano was theoretically evaluated. Employing the concept of feasibility index method for the evaluation shows that evaporative cooling systems have large potential to produce thermal comfort in the study area and in areas with similar climate characteristics. The systems are technically viable in regions where the dry bulb temperature is high and the wet bulb temperature is relatively low. The use of evaporative coolers can provide thermal comfort for people irrespective of their economic status because they are cheaper, simpler to construct and operate, easier to maintain by the local people and also have no negative impacts on the environment compared to the conventional refrigerated-based air conditioning systems. Evaporative coolers can therefore be effectively used in areas such as residences, schools and offices, commercial centres, workshops and industries provided the required conditions for evaporative cooling are met.

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