Theoretical Evaluation Of The Potential Of Evaporative Cooling For Human Thermal Comfort Using Feasibility Index (Fi) Model

Lateef L. Akintunji, Ibrahim U. Haruna, Bello S. Momoh

Abstract: Thermal comfort has a great influence on the productivity and satisfaction of indoor building occupants. In some developing countries like Niger Republic, 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 study attempts to determine the viability of using evaporative coolers to achieve thermal comfort in Niamey using the feasibility Index Model. The computed feasibility indices of Niamey in the months of January through December are -3.6, -4.4, -4.3, 2.8, 6.6, 11.2, 13.7, 17.0, 16.0, 9.8, 0.7 and -5.6 respectively. Employing the concept of the feasibility index (FI) model reveals that comfort cooling can be achieved in the months of January, February, March, April, May, October, November and December while relief cooling can be achieved in the months of June, July and September. The method also reveals the unsuitability of evaporative cooling in the month of August. Considering both the comfort and the relief cooling periods based on the FI model, evaporative coolers can therefore be a suitable alternative to refrigerated-base air conditioning systems.

Index terms: Evaporative cooler, Thermal comfort, Temperature, Feasibility index

1.0 Introduction

Refrigerated-based air conditioning system requires high capital investment and its operating costs often become exponentially high due to its consumption of electricity. Moreover, the restrictions imposed by protocols limit the type of refrigerants that can be used in these systems. In Africa, the use of conventional air conditioning systems to achieve human thermal comfort is largely impeded by the epileptic power supply and high cost of the air conditioning systems. The use of air conditioning systems apart from providing thermal comfort for the occupants of a space, they enhance the efficiency of man in his job. 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.

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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: Natural humidity level is maintained and this benefits both people and furniture and cut down static electricity An air-tight structure is not required therefore building occupants can open their doors and windows. Refrigerated cooling systems rely on recycled cooled air with partial fresh air replacement while the evaporative cooler enjoys popularity in the introduction of a continuous supply of freshly cooled outdoor air.[1]. 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]. Water is the working fluid and it does not have negative influence on the environment There are direct, indirect and combined indirect/direct evaporative cooling systems in use today. But direct evaporative cooling systems are the most widely used because they are relatively cheaper, ease of construction and maintenance, ease of installation and also have better performance especially in hot and dry climates. This paper therefore is an attempt to evaluate the potential of direct evaporative cooler for human thermal comfort in Niamey, Niger Republic, using the Feasibility Index (FI) Model.

1.1 Recent development on evaporative cooling systems

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.

1.2 Direct evaporative coolers

In direct evaporative coolers, non-saturated outside air is blown through a water saturated pad and evaporation occurs. The necessary latent heat is provided by the air which cools down. Therefore, the leaving air temperature reduces while the relative humidity increases. A typical direct evaporative cooler is shown in figure 1.0.

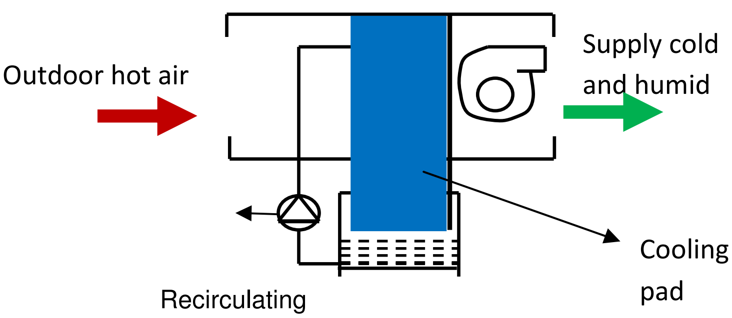

Figure 1.0 Direct Evaporative Cooler

2.0 Materials and method

In this study, the potential of direct evaporative cooling for human thermal comfort in Niamey, Niger republic was evaluated using the Feasibility Index (FI) Model. The feasibility indices of 12 months January through December of the study area were determined. To determine the FI values of the 12 months, the outdoor dry and wet bulb temperatures which are the determining parameters used in the analysis were obtained from the past weather data averaged over five years. The dry bulb temperatures were obtained from World Meteorological Organization [15] and the corresponding average monthly wet bulb temperatures were determined using psychrometric chart. The average monthly dry and wet bulb temperatures are presented in Table 1.

Figure1. Average monthly dry and wet bulb temperatures

Months	Dry bulb (^{0}C)	Wet bulb (^{0}C)
January	32.8	14.6
February	36.4	16.0
March	42.5	19.1
April	41.0	21.9
May	41.7	24.2
June	38.4	24.8
July	34.9	24.3
August	32.8	24.9
September	34.2	25.1
October	37.8	23.8
November	39.1	19.9
December	35.6	15.0

2.1 Description of the study area
Niamey is the capital and largest city of the West African country Niger. Niamey lies on the Niger River, primarily situated on the east bank. It is an administrative, cultural and economic centre. Niamey's population, which was estimated at 774,235 in 2006 is now projected to be much higher. The climate is hot semi-arid (Köppen climate classification BSh), with an expected rainfall of between 500 mm (20 in) and 750 mm (30 in) a year, mostly beginning with a few storms in May, then accelerating to a rainy season usually lasting from sometime in June to early September, when the rains taper off rather quickly. Most of the rainfall is from late June to mid August. There is practically no rain from mid-October to April. Niamey is remarkably hot throughout the year. Average monthly high temperatures reach 38 °C (100 °F) four months out of the year and in no month does average high temperatures fall below 32 °C (90 °F). During the dry season, particularly from November through February, nights are generally cool. Average nighttime lows between November and February range from 14–18 °C (57–64 °F).

2.2 The feasibility index model
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

3.0 Results
The feasibility index (FI) of Niamey was computed by applying the feasibility index equation to the values obtained in Tables 1.0. The evaluated values for the twelve months were presented in Table 2.

Table 2. Monthly evaporative cooling feasibility index of Niamey

MONTH	WBT (^{0}C)	DBT (^{0}C)	FI = (WBT – ΔT)
January	14.6	32.8	-3.6
February	16.0	36.4	-4.4
March	19.1	42.5	-4.3
April	21.9	41.0	2.8
May	24.2	41.7	6.6
June	24.8	38.4	11.2
July	24.3	34.9	13.7
August	24.9	32.8	17.0
September	25.1	34.2	16.0
October	23.8	37.8	9.8
November	19.9	39.1	0.7
December	15.0	35.6	-5.6

4.0 Discussion

The feasibility indices of the twelve months, January through December, of the study area Niamey are shown in Table 2. From this table, it can be seen that thermal comfort can be achieved in the months of January, February, March, April, May, October, November and December because their feasibility indices are -3.6, -4.4, -4.3, 2.8, 6.6, 9.8, 0.7, and -5.6 respectively. This however is in consonance with the work of Camrago et al [5] who stated that feasibility indices less than or equal to ten are suitable for human thermal comfort. These periods represent about 66.6% 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. From Table 2, it can be seen that relief cooling can be achieved with the use of the direct evaporative cooler in the months of June, July and September because their feasibility indices are 11.2, 13.7 and 16.0 respectively. These findings agrees with the work of Camrago et al [5] who stated that lenitive (relief) evaporative cooling for human thermal comfort can be achieved if the computed feasibility index falls within the range 11≤ FI ≤ 16. These periods for relief cooling represent about 25% months in a year. According to Cengel [16], during the period of relief cooling, the body does not need to activate any of the body defense mechanism to maintain normal body temperature. Therefore, the thermal conditions in this case fall on the periphery of the thermal comfort zone. Considering both the thermal and the relief cooling, cooling can therefore be achieved through the use of evaporative cooler for about 91.6% months in a year. Based on the work of Camrago et al [5], the computed feasibility index of August is 17.0 and is greater than 16 and therefore is not suitable for the use of direct evaporative cooling for human thermal comfort, its unsuitability can be attributed to the high outdoor relative humidity. Study have shown that the higher the ambient relative humidity the slower the rate of evaporation from the water-saturated pad of the cooling system.

5.0 Conclusion

The study theoretically evaluates the potential of direct evaporative cooling for human thermal comfort in Niamey, Niger Republic using feasibility index (FI) model. The FI model employed in this study portrays the suitability of using direct evaporative cooling to achieve human thermal comfort in Niamey and by extension in areas with similar climate characteristics. Direct evaporative coolers can therefore be used to ameliorate human thermal comfort in schools, residences, hospitals, commercial centres and industries provided the determining parameters for evaporative cooling fall within the recommended range.

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