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THEORETICAL EVALUATION OF EVAPORATIVE COOLING POTENTIAL USING FEASIBILITY INDEX MODEL

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Abstract: Thermal comfort has a great influence on the productivity and satisfaction of indoor building occupants. 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. Furthermore, 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 cooling to achieve thermal comfort in Mubi-South using the feasibility Index model. The computed feasibility indices of the study area in the months of January through December are – 0.08, - 1.62, 4.04, 13.09, 27.06, 17.36, 18.39, 18.42, 18.24, 3.12, - 0.12 and – 0.28 respectively. Employing the concept of the feasibility index (FI) model reveals that comfort cooling can be achieved in the months of January, February, March, October, November and December while relief cooling can be achieved in the month of April. The model also reveals the unsuitability of evaporative cooling in the months of May, June, July, August and September. Considering both the comfort and the relief cooling periods based on the FI model, evaporative cooling can therefore be a suitable alternative to refrigerated-based air

conditioning systems in Mubi-South and other areas with similar climatic characteristics.

Keywords: Evaporative Cooling, Thermal Comfort, Temperature, Relative Humidity, Feasibility Index
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INTRODUCTION

Conventional 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 thermal comfort is largely impeded by the epileptic power supply and high cost of the air conditioning systems.

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 with high bulb temperatures and 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 rely on recycled cooled air with partial fresh air replacement while the evaporative cooling 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-based cooling [2].
- Water is the working fluid which does not have negative influence on the environment.
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There are direct, indirect and combined indirect/direct evaporative cooling systems in use today. But direct evaporative cooling is 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 is an attempt to evaluate the potential of direct evaporative cooling for human thermal comfort using the feasibility Index model.

Development of 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] evaluate the suitability of some local materials as cooling pads, Issac 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 cellolose 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.

Direct Evaporative Cooling

In direct evaporative cooling, non-saturated outdoor 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 cooling system is shown in fig. 1.0.

Direct evaporative cooling is represented on the psychrometric chart in fig.1.0 by a displacement along a constant wet bulb temperature line AB.

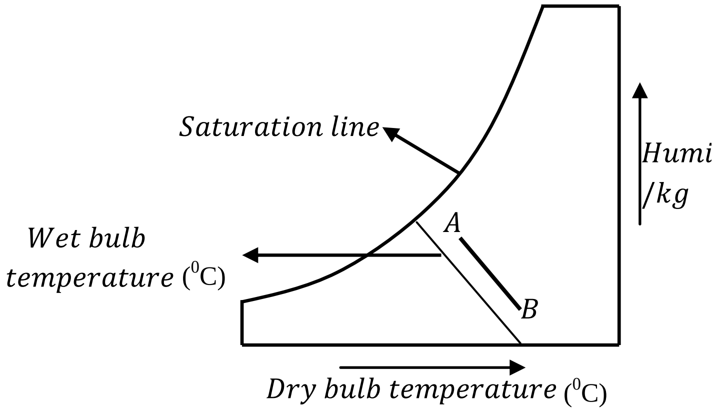

Fig. 1.0 Psychrometric chart of Direct Evaporative Cooling

Materials and Method

In this study, the potential of directive evaporative cooling for human comfort of Mubi-South was evaluated using the feasibility index (FI) model. The feasibility indices of 12 months January through December of the study area determined. To determine the FI values of the 12 months, the outdoor dry bulb temperatures used in the analysis were obtained from the past weather data averaged over 22 years [15][16]. The corresponding monthly average wet bulb temperatures were determined using psychometric chart. The average monthly dry and the wet bulb temperatures were presented in Table 1.0.

Table 1.0 Average Monthly Dry Bulb, Wet Bulb and Relative Humidity of Mubi-South

Month	Dry bulb (^0C)	Wet bulb (^0C)	Relative Humidity (%)
January	24.92	12.42	18.8
February	27.18	12.78	15.8
March	30.16	17.10	25.1
April	29.31	21.20	49.7
May	28.14	27.60	64.6
June	25.86	21.61	75.0
July	24.57	21.48	80.5
August	24.38	21.40	80.0
September	25.00	21.62	75.8
October	26.48	19.80	54.4
November	27.47	13.60	25.0
December	25.84	12.78	20.8

Source [16]

Description of the Study Area

Mubi-South is located in the north eastern part of Nigeria. It situated on latitude 10.5^0 N and longitude 13.5^0 E. It experiences two weather conditions in the year. These are the rainy season which begins around April and runs through October; the dry season begins from November and ends in March. Within these periods, there are brief period of harmattan occasioned by the north east trade wind, with a resultant dusty haze and intense coldness and dryness [17].

The Feasibility Index (FI) Model

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

$$FI = WBT - \Delta T$$

Where $\Delta T = (DBT - WBT) = Wet\ bulb\ depression$

$WBT = W\ et\ bulb\ temperature$

$DBT = Dry\ bulb\ temperature$

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, the more efficient the evaporative cooling will be. Thus, this number indicates the evaporative cooling potential to give thermal comfort for human beings[5].

This model highlights the following ranges of the feasibility indices with respect to cooling for human thermal comfort.

$FI \leq 10 \qquad Recommended\ for\ comfort\ cooling$

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

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

Results

The Feasibility Index (FI) of Mubi was computed by applying the feasibility index model to the values obtained in Table 1.0. The evaluated values for the twelve months were presented in Table 2.0.

Table 2.0. Monthly Evaporative Cooling Feasibility Index of Mubi-South

Month	DBT (^{0}C)	WBT (^{0}C)	ΔT (^{0}C)	FI
January	24.92	12.42	12.5	- 0.08
February	27.18	12.78	14.4	-1.62
March	30.16	17.10	13.06	4.04
April	29.31	21.20	8.11	13.09
May	28.14	27.60	0.54	27.06
June	25.86	21.61	4.25	17.36
July	24.57	21.48	3.09	18.39
August	24.38	21.40	2.98	18.42
September	25.00	21.62	3.38	18.24
October	26.48	19.80	16.68	3.12
November	27.47	13.60	13.87	- 0.27
December	25.84	12.78	13.06	- 0.28

Discussion

The feasibility indices of the twelve months, January through December, of the study area, Mubi-South, are shown in Table 2.0. From this table, it can be seen that thermal comfort can be achieved in the months of January, February, March, October, November and December because their feasibility indices are – 0.08, -1.6, 4.04, 3.12, - 0.12 and -0.28 respectively. This however is in consonance with the work of Camrago et al [5] who stated that feasibility indices less than or equal to 10 are suitable for human thermal comfort. These periods represent about 50% of the total number of months in a year in the study area. During these months, the high temperature and low relative humidity enhance the sensible heat transfer from the incoming air to the water saturated pad and moisture transfer from the saturated pad to the incoming air. This agrees with the work of Camrago et al [5] that evaporative cooling is viable in regions with relatively low wet bulb temperature.

From Table 2.0, it can be seen that relief cooling can be achieved with the use of direct evaporative cooling systems in the month of April because its feasibility index is13.09. This finding agrees with the work of Camrago et al [5] who stated that relief (lenitive) cooling can be achieved if the computed feasibility index falls within the range $11 \leq FI \leq 16$. This period for relief cooling represents about 8.3% number of months in a year in the study area. According to Cengel[18], 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 comfort and the relief cooling, cooling can therefore be achieved through the use of evaporative cooling for about 58.3% months in a year.

Based on the work of Camrago et al [5], the computed feasibility indices of May, June, July, August and September are 27.06, 17.36, 18.39, 18.42 and 18.24 respectively are greater than 16 and therefore are not suitable for the use of direct evaporative cooling for human thermal comfort. Their unsuitability can be attributed to the high outdoor relative humidity as seen in Table 1. 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.

CONCLUSION

The study theoretically evaluates the potential of direct evaporative cooling for human thermal comfort of Mubi-South using the feasibility index model. The FI model employed in this study portrays the suitability of using direct evaporative cooling to achieve human thermal comfort in Mubi-South. Direct evaporative cooling 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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