Advances in Engineering Research, volume 207
Proceedings of the 2nd International Seminar of Science and Applied Technology (ISSAT 2021)

Using Feasibility Index Model to Investigate Human Thermal Comfort Under Weather Data of Mubi, Adamawa State, Nigeria

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ABSTRACT
Thermal comfort in the world has created interest for renewable energy researchers due to the increase in the world population and in trying to make the environment friendly to every community. This study determines the thermal comfort of the Mubi metropolis in Adamawa state, Nigeria. The data used in this present study were taken from Meteonorm file through TRNSYS Software for 22 years. The sought data were Dry bulb temperature and 100% relative humidity which were used as the input parameters to determine the feasibility index values. The results of the research show the thermal comfort (cooling) in January, February, March, October, November and December because their FI values are less than ten. It also revealed that only the month of April achieved the lenitive cooling whereby the other months in a year did not, hence we, recommend the use of evaporative cooling because their values are greater than sixteen. The study concludes that direct evaporative cooling can be used in the Mubi metropolis to improve human comfort. It will also serve as an alternative to refrigeration-based air conditioning systems to achieve thermal comfort which is not environmentally friendly because some refrigerants affect the daily FI index values with other areas that have similar climate weather data.

***Keywords**: Evaporative cooling, Thermal comfort, Dry bulb Temperature, Wet bulb Temperature, Relative humidity.*

1. INTRODUCTION

The energy demand for thermal comfort in the world has increased due to the increase in world population which has continuously increased over the decades. This global population has been predicted by [1] to be eight billion in year 2025. The economic rise is major concern of majority of populous countries in the world such as Brazil, Chaina, Egypt, India and Nigeria which affect their standard of living in terms of living in terms of thermal comfort i.e heating and cooling system. Thus, the translate of agricultural perspective rise the real thermal confort demand throughout the world [2, 3]. [3] reported that due to inadequate supply of electrical energy in Nigeria, designers should think of designing devices that would be reducing the electrical power consumption or any alternative devices that are not even using electricity for heating/cooling purposes because most of the devices for heating and cooling have maximum power consumption.

An evaporative cooling system mostly used water and air has working fluid through induced processes of heat and mass transfer. This system operates when the induced water is evaporating as when its flows, this makes environment air temperature decreasing, this process referred to "direct evaporative cooling" when its thermal process is adiabatic saturation (condition). The direct evaporative cooling has more efficient when air cooling is used for thermal comfort. In addition, it has lower energy consumption and is easy to maintain [4, 5]. [6] reported that the lack of this power supply to some of the communities in Nigeria set people back in economic and social development in terms of thermal comfort. Because of this, engineers are expected to come out with new technology that will aid people to meet thermal comfort demand base on increasing global population and also producing the lower the price thermal comfort devices/systems. Literature reviews show that most of the researchers in developed countries have focused on the convectional system for thermal comfort in terms of cooling. The first analysis of evaporative cooling for both direct and indirect system carried out by Watt, 1963, and also his mathematical model used today for all evaporative cooling devices was formulated and presented by Halaz, 1998 as cited in [4].

In the early stage, an evaporative cooler referred to as passive design type which later called swamp/desert/wet air cooler. The Persian Gulf such as Iran and Kuwait countries called desert coolers because of their weather conditions where the air is hot with lower humidity [7,8]. Evaporative cooling techniques are old in terms of temperature reduction but it gains their popularity again in the twentieth century especially in the USA and Asia countries [2]. There are similar report shows that installation and the operating cost of an evaporative cooler is 50% lower than the refrigerator or air conditioners. United Nation had advocated through Food and Agriculture Organization (FAO) for lower cost and energy-saving storage system using principle of evaporative cooling during favourable climate conditions. In addition, in 1999, world bank suggested the benefits of evaporative cooling such as energy cost reduction, negligible carbon emission if there are no hydrocarbon gases utilized. Therefore, the system improves indoor air quality, humidity and regional energy independence [8,9]. [10] worked on three performance natural fibres to be used as wetted pads in the evaporative cooling system such as palm fibre, jute and luffa. Similarly, [11] evaluated two performance evaporative heat exchanger that works under same weather condition of airflow and water inlet temperatures.

[12] study the basic principles of the evaporative cooling systems for human thermal comfort and also present the mathematical expression of the thermal exchange's equations, that can be used to determine the effectiveness of saturation. [13,14] reported that used evaporative cooling started 4521 years ago (2500 B.C) during that time an ancient Egyptians used water container porous clay jars to cool air. The authors further, explaining that after this mechanism had been used many years in Egyptian's buildings, it was later adopted across the Middle East regions where their climates were the same (hot/arid state). Later, many similar systems of these system were built up later like porous water pots, water pond pools etc. and sometimes combined in buildings constructions to create the buildings cooling effect. According to [15] the use of swamp coolers in the United States(US) may be due to the odour of algae produced by the early system. [2] reported on an extensive review of evaporative coolers used in some countries to preserve any fresh agricultural products. They further explained that most of these designs used for cooling is direct evaporative cooling because it is very simple in design but had low thermal performance. The authors concluded that in their comprehensive review that cooler evaporative revealed that climatic weather adjustments favour operation of the systems at lower relative humidity in tropical countries in both harmattan and dry season periods.

An investigation of a direct evaporative air cooler (DEAC) was carried out under Algerian weather conditions in Bechar city [16]. The DEAC and simulated it in TRNSYS software through three consecutive months (June, July and August). The weather dates used were also generated from Meteonorm weather viewers. Their results show the higher depression of dry bulb temperature to be 18.86℃. The authors concluded that their evaporative cooling equipment's works well in the hot and dry periods of arid southern regions of Algeria. [4] three methods to be used to validate the efficient of evaporative cooling systems. The author stated that these three methods had been applied in Brazilian cities that have different weather climates conditions. Similarly, [12] worked on the basic principles of the authors come out with the thermal exchanges models which will be used to determine the effectiveness of saturation of the evaporative cooling.

An investigation to performance two difference evaporative operation heat exchangers system under same weather condition using flow air and inlet temperature as a working fluid was conducted by [11]. [17] investigated the potential application of downdraught cooling in the United State. The authors claimed that their study would aid designers in terms of identifying the correct cooling strategy for geographic area of their interest. The authors used two related climatic indexes such as dry bulb temperature and their results identify some climate zones for down-drought cooling application in the USA. They finally, suggested the appropriate design strategies to be used for each location selected. [13] worked on the review of indirect evaporative cooling technology by looking at various aspects of it such as background, history, system configuration, operational prospects. The authors concluded through investigation that indirect evaporative cooling is an alternative to conventional mechanical vapour compression refrigeration systems using buildings cooling. Presentation on desiccant and evaporative cooling system based on livestock(animal) comfort was carried out by [18]. The authors investigated the study utilizing experiments and thermodynamic, the authors used the ambient condition of Multan city in Pakistan and also suggested three kinds of air-conditioning (AC) combination; Standalone Maisotsenko-cycle evaporative cooling (SMEC), Standalone desiccant AC and M-cycle based desiccant

(MBD) AC system. They found out that SMEC and MBD systems can provide thermal comfort for animals from March to June and March to September respectively while (SD) AC systems cannot provide any thermal comfort throughout the year.

[19] presented the feasibility of the direct and indirect evaporative cooling system for residences in arid regions of Israel, the authors based their studies on a desert cooler. They concluded that such a system can provide a significantly higher level of thermal comfort for any residence in Israel. Effectiveness enhancement and performance evaluation of the indirect and direct evaporative cooling system was conducted in Iran. The ISO 7730 thermal comfort standard was used to evaluate their evaporative cooling system through capability and performance at different climates weather conditions [20]. An experiment was set up to integrate parallel chiller and a cooling tower with a panel-based Radiant Cooling System (RSC) in Jaipur, Rajasthan, India. The authors found that the wet-bulb temperature (WBT) is suitable for integration if cooling tower system is RSC. The authors stated that cooling tower-operated of RSC has higher annual total savings of 7% in hot climate, 20% in temperature climate when compared with the chiller-operated RSC [20].

The recent researches showed favorable results on the feasibility index model as applied in many engineering fields for the prediction of direct evaporative cooling for human thermal comfort. Thus, study aims to determine the potential of direct evaporative cooling for human thermal comfort under Mubi metropolitan through minimum input parameters by using the feasibility index model.

2. MATERIALS AND METHODS

2.1 Study Area

Mubi is one of the major towns in Adamawa State. It is the headquarter of the Mubi North local government Area. Its geographical location lies between latitude 10.27^0N and 13.28^0E and is also situated in the Noth Eastern zone of Nigeria with 580m above sea level (a.s.l) as reported by National Atmospheric Surface Administration [21] and [22]. The town (Mubi) has tropical Wet and Dry climate. Dry season fall between November to March i.e last for five months while wet season starts from April to October [23]. It has a land area of 4728.77km^2 and a population of 759045 in 2003 (1991 projected census figure) as described by [24].

2.2 Weather Data Resources

Secondary data was used for the study of potential direct evaporative cooling in Mubi metropolitan for human comfort which evaluated by feasibility index (FI) model. The data used include the climate elements, the dry bulb temperature, wet bulb temperature (WBT) and relative humidity (RH) of the study area. All these data were sourced from Meteonorm 8 vision through the TRNSYS Software throughout a year, hourly, as presented in figure 1.

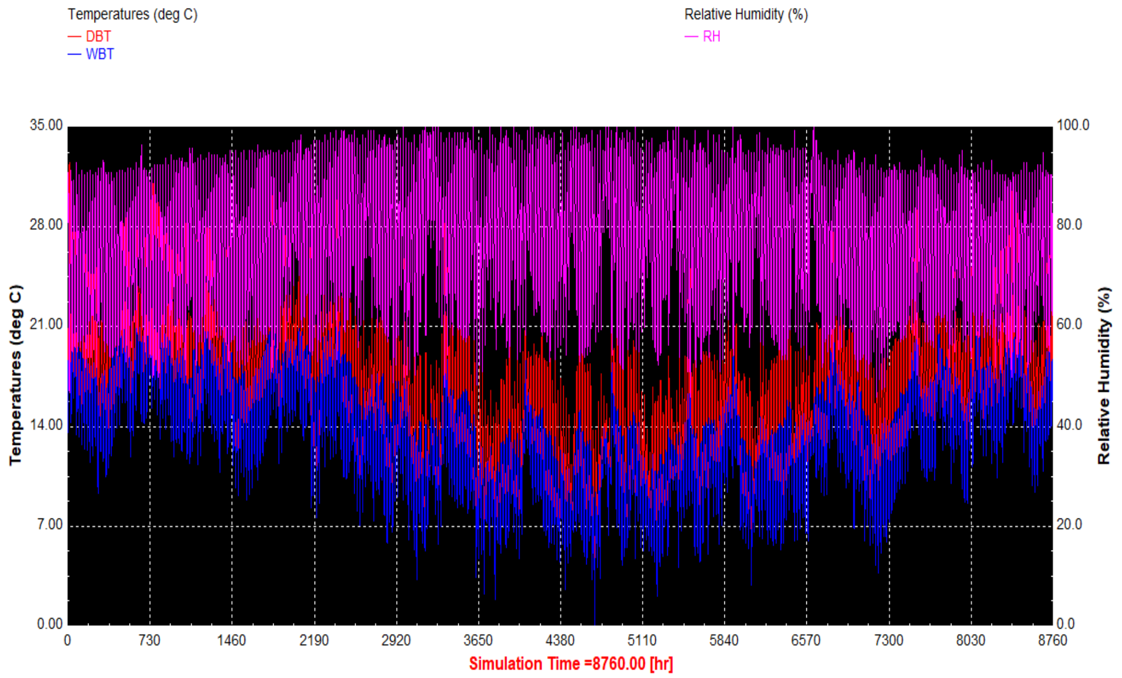

Figure 1: Hourly DBT, WBT and RH of Mubi Metropolitan

To evaluate the FI values of the 12 months, the outdoor data of DBT and its corresponding WBT used in the analysis was obtained from the past weather data for 30 years. The average monthly DBT, WBT and RH were generated from Microsoft Excel (2016) and later presented in table 1

Table 1. Average monthly of DBT, WBT and RH of Mubi Metropolitan

Months	DBT(^{0}C)	WBT(^{0}C)	RH%
January	24.91	12.43	18.90
February	27.18	12.77	15.80
March	30.15	17.11	25.10
April	29.30	21.21	49.70
May	28.14	27.60	64.61
June	25.87	21.60	75.01
July	24.57	21.48	80.50
August	24.38	21.41	80.01
September	25.10	21.61	75.80
October	26.49	19.81	54.41
November	27.48	13.61	25.01
December	25.83	12.77	20.78

2.3 Feasibility Index (FI) model

According to [16,25] FI model method is faster method presently to verify the feasibility of evaporative cooling for human thermal comfort as given in equations 1-3. They further explained that if the difference between DBT and WBT increases, their effect makes the index decreases as relative humidity. Their report revealed that the smaller the FI value, the higher evaporative cooling will be. However, the number indicates the evaporative cooling potential to give thermal comfort.

$$FI = WBT - \Delta T \quad (1)$$

$$\Delta T = DWT - WBT \quad (2)$$

Where ΔT is the Wet Bulb Depression (WBD) in ^{0}C.

$$Therefore, FI = 2WBT - DWT \quad (3)$$

[5] reported and recommend that any indices that are less than or equal to 10 (i.e $FI \leq 10$) indicated for comfort cooling, indices that fall between 11 and 16 (i.e $11 \leq FI \leq 16$) is for lenitive/ relief cooling and lastly, indices which above sixteen (i.e $FI > 16$) is a place that not recommended for the of evaporative cooling systems.

2.4 Economic benefit

In this study, of economic benefit of evaporative cooling for human comfort can be evaluated as follows:

- The costs used to fabricate and maintain the evaporative cooling system for human comfort is lesser than the conventional cooling system i.e. air-conditioning.
- The working fluid in the evaporative cooling system is water which is available everywhere with less cost even if it is to buy but the working fluid of the convectional system is refrigerated which is expensive to buy and it may not available in some parts of the location where to use it.
- Direct indirect evaporative cooling system for human comfort is promising owing to its significant electricity cost saving over the conventional system.
- The cooling load of most buildings can adapt this evaporative cooling system (direct /indirect) in order to replace conventional mechanical vapour compression refrigeration device system which will cause annual energy saving and also reduce carbon dioxide emissions.
- Lastly, the natural humidity level is maintained in human beings, furniture, and fruits & vegetable which cut down electricity bills used to maintain the cooling system is at any domestic.

3. RESULTS AND DISCUSSION

The main purpose of applying the *FI* model is to determine the possibility of obtaining cooling for comfort, relief or not use for evaporative cooling for Mubi Metropolitan. The *FI* of Mubi metropolitan was computed by using the empirical *FI* model to obtain the values as shown in table 2. The physical characterization of the *FI* model has two inputs: *DBT* (^{0}C) and *WBT* (^{0}C) were used as the input and the values of *FI* obtained is input in this study.

Table 2. Monthly evaporative cooling of *FI* index of Mubi metropolitan.

Months	*DBT*(^{0}C)	*WBT*(^{0}C)	ΔT (^{0}C)	RH%	*FI* index
January	24.91	12.43	12.49	18.90	-0.08
February	27.18	12.77	14.40	15.80	-1.60
March	30.15	17.11	13.05	25.10	4.02
April	29.30	21.21	8.11	49.70	13.10
May	28.14	27.60	0.54	64.61	27.05
June	25.87	21.60	4.25	75.01	17.38
July	24.57	21.48	3.09	80.50	18.37
August	24.38	21.41	2.97	80.01	18.42
September	25.10	21.61	3.38	75.80	18.24
October	26.49	19.81	16.69	54.41	3.12
November	27.48	13.61	13.86	25.01	-0.27
December	25.83	12.77	13.07	20.78	-0.28

The average of the months in a year i.e from January to December of the study area had been computed as shown in table 2. It revealed that thermal cooling can in the month of January, February, March, October, November and December because their *FI* values are less than or equal to ten (*FI* ≤10). Therefore, these months had good agreement with the work of (watt and brown 1997) which stated that any *FI* values obtained that less than or equal to 10 in a place is good for thermal human comfort. These periods (months) represent half (50%) of the total months in a year area of the study. The results obtained during these months also revealed that the temperature/wet-bulb depression with low relative humidity values enhances the sensible heat transfer from the incoming air to the water-saturated pad and moisture transfer from the saturated pad to the incoming air [16]. This agrees with the work of [4] who stated evaporative cooling is feasible in place that has low relatively WBT.

It can be seen that only the month of April showed the lenitive (relief) cooling with the use of a direct evaporative cooling system because its *FI* is 13.09. This value shows the good agreement with the work of [4], which stated that relief cooling can be achieved if the values obtained in *FI* descent within the range of 11 ≤ *FI* ≤ 16. the period for relief cooling in this month (April) in a year in the study area represents 8.33%. [26] stated that during the period of lenitive cooling, the body does not need to activate any of the body defence mechanisms to maintain its normal body temperature, therefore, the thermal condition in this month. (April) fall in the periphery of the thermal comfort zone. In this case, both thermal comfort and relief cooling can be achieved through the use of evaporative cooling of about 8.33% of months in a year.

Lastly, the computed values of *FI*; May, June, July, August and September are greater than sixteen i.e *FI* > 16 and therefore, they are not suitable for the use of direct evaporative cooling for human thermal comfort according to the report of [4]. Their unsuitability can be attributed to the high outdoor relative humidity with low WBD as shown in table 2. This study shows the higher relative humidity, the lower the rate of evaporative from the water-saturated pad of the cooling system.

4. CONCLUSION AND RECOMMENDATION

A climate classification of the potential for thermal comfort in the metropolis has been presented in this paper. The thermal comfort has been based on DWT and WBT, cooling degree hour/average months and *FI*. The results show that January, February, March, October, November and December are recommended for comfort cooling. The month of April only showed the lenitive cooling for direct evaporative cooling system but the remaining months from May to September are the months that are not recommended for the use of the evaporative cooling system because their values are greater than the recommended values from past temperature. FI model used in the study describes the suitability of using direct evaporative cooling to achieve human thermal comfort in Mubi town. Therefore, direct evaporative cooling can be employed to improve human thermal comfort in any of our social amenity's place(s) in Mubi such as schools, hospitals, residences, business centres, factories/industries provided that the evaluated parameters for evaporative cooling are within the recommended range values of *FI*.

The study recommended further investigation on the daily *FI* index values, also here, the weather data of Mubi was used, one can take the courage (challenges) to look at the behaviour of the *FI* model at various locations across the other political zones in Nigeria, to boost the confidence in the *FI* model in term of human thermal comfort.

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