Theoretical Evaluation Of The Potential Of Evaporative Cooling For Human Thermal Comfort In West Africa

Ibrahim U. Haruna, Ishaq Musa, Muhammad I. Tikau, Unwaha J. Ibrahim

Abstract: The realization of thermal comfort through the use of refrigerated-based air conditioning systems is largely impeded by poverty and epileptic power supply. Furthermore, the use of some refrigerants has negative effect on the environment. Evaporative cooling systems are viable options for achieving thermal comfort because, apart from their low cost and power requirement, they are environmentally friendly. This paper attempts to determine the viability of using direct evaporative coolers to achieve human thermal comfort in several West African cities characterized by different climates using the feasibility index method. Employing the concept of the feasibility index reveals the suitability of using evaporative coolers in Agadez, Bamako, Diffa, Jos, and Nema while Conakry, Gagnoa and Port Harcourt are not recommended for the use of evaporative coolers. Evaporative coolers are therefore suitable alternative to refrigerated-based air conditioning systems for achieving human thermal comfort in these areas and in similar areas with high evaporative cooling potentials.

Index terms: Thermal comfort, Feasibility index, Evaporative cooler, selected cities, Climate

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Introduction

Thermal comfort has a great influence on the productivity and satisfaction of indoor building occupants. Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment. It is difficult to define thermal comfort because of the range of environmental and personal factors that need to be taking into account when deciding what will make people comfortable; the combination of these factors make up what is known as 'human thermal environment. There are many ways of achieving thermal comfort. Some of these ways are active, passive or hybrid.

The passive ways of achieving thermal comfort such as the use of natural ventilation, nocturnal thermal radiation, shading devices, etc, to a reasonable degree can only provide relief (lenitive) comfort for the occupants of a space [1]. During unfavourable weather conditions, especially when the weather is hot, conventional air conditioning systems are used to condition the air suitable for human thermal comfort. But the use of these conventional air conditioners is associated with problems such as:

- ➢ They are detrimental to the ozone layer because of the release of CFC and HCFC
- ➢ They are relatively expensive for the common man
- ➢ Their maintenance require the service of a skilled personnel
- ➢ They are not fully utilized in areas where the power supply is epileptic and constantly interrupted
- ➢ Their high electric power consumptions translate to high operational cost.
- ➢ They are characterized by poor indoor air quality because of the use of recirculated air

Evaporative coolers have been found to be suitable alternative to the conventional air conditioning systems especially in hot and dry climates because of the following reasons: Natural humidity level is maintained which benefits both people and furniture and cut static electricity Occupants can open their doors and windows because it does not require an air-tight structure for maximum efficiency Refrigerated cooling systems rely on recycled cooled air with partial fresh air replacement while evaporative cooler enjoys popularity in the introduction of a continuous supply of freshly cooled outdoor air [2]. The technology of evaporative cooler is simpler, the cooler costs about 80 per cent less than refrigerated based air conditioner that will cool the same area [3]. The installation costs of evaporative coolers are comparable to conventional air conditioning The working fluid, water, does not have adverse impacts on the environment and it is relatively available

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- ***Ibrahim U. Haruna***
- *Qualifications: M.Eng (Energy Engineering)*
- *Status/Rank: Lecturer II*
- *Affiliation: Department of Mechanical Engineering, Federal Polytechnic Mubi, Adamawa State. E-mail: heldabuk@yahoo.com*
- ***Ishaq Musa***
- *Qualifications: M.Eng (Energy Engineering)*
- *Affiliation: Department of Mechanical Engineering, Bayero University Kano, Kano State, Nigeria.*
- ***Muhammad I. Tikau***
- *Status/Rank: Assistant Lecturer*
- *Affiliation: Department of Mechanical Engineering, Federal Polytechnic Mubi, Adamawa State.*
- ***Unwaha J. Ibrahim***
- *Status/Rank: Lecturer III*
- *Affiliation: Department of Mechanical Engineering, Federal Polytechnic Mubi, Adamawa State.*

and cheap Considering these aforementioned reasons, the use of evaporative coolers for achieving human thermal comfort is imperative. Therefore, this paper attempts to evaluate the potential of direct evaporative coolers for achieving human thermal comfort in West Africa.

Recent development on evaporative cooling systems

Many researchers have dedicated their researches to the development of direct, indirect and combined indirect-direct evaporative cooling systems. Camrago et al [4] worked on experimental performance of direct evaporative cooler operating during summer in Brazilian city, Valesco et al [5] worked on the description and experimental result of semi-indirect ceramic evaporative coolers, Camrago et al [6] discussed three methods to evaluate the use of evaporative cooling for human thermal comfort, Gunhan et al [7] evaluated the suitability of some local materials as cooling pads, Isaac et al [8] reviewed porous evaporative cooling for the preservation of fruits and vegetables. Qun et al [9] worked on the new approach to analyse and optimize evaporative cooling systems, Kulkarni et al [10] theoretically analysed the performance of jute fiber rope bank as media in evaporative coolers, Metin et al [11] determined the relationship among air velocity, cooling efficiency and temperature decrease at cellulose based evaporative cooling pad, Valesco et al [12] discussed the phenomenon of evaporative cooling from a humid surface as an alternative method for air-conditioning, Kulkarni et al [13] theoretically analysed the performance of indirect-direct evaporative coolers in hot and dry climates, Vivek [3] experimentally investigated the performance of evaporative desert cooler using four different cooling pad materials, Metin et al [14] studied the effects of air velocity on the performance of pad evaporative cooling, Kulkarni et al [15] compared the performance of evaporative cooling pads of alternative materials.

Description of 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 psychrometric chart by a displacement along a constant wet-bulb temperature line [2].

The study area

West Africa, also called Western Africa and the West of Africa, is the westernmost region of the African continent. In line with the current membership of the Economic Community of West African States (ECOWAS), West Africa has been defined in Africa as including the fifteen countries of Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. The following climatic types abound in the study area: Sahara, Tropical wet climate, Montane, Sahel and Tropical savanna

Methodology

The potential of direct evaporative cooling for human thermal comfort for some selected cities in West Africa was evaluated using the method of feasibility index (FI). The selected cities are: Diffa (Niger republic), Agadez (Niger republic), Port-Harcourt (Nigeria), Jos (Nigeria), Bamako (Mali), Conakry (Guinea), Gagnoa (Cote D'Ivoire), Banjul (Gambia) and Nema (Mauritania). These were cities are characterized by different climates. The determining parameters used in the analysis were the outdoor dry-bulb and wet-bulb temperatures. In designing any cooling system, it is axiomatic to consider the climate scenario of the study area. Therefore, the average dry-bulb temperatures of the selected cities for the past four years were considered [16] and there mean values based on the 97.75% coincident level as proposed by [1] are presented in Table 1.0. The corresponding average wet-bulb temperatures of the selected cities were determined using the psychrometric chart and their values are presented in Table 2.0.

Table 1.0: Mean Dry-bulb Temperature of the Selected Cities

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agadez	29.2	33.0	34.1	40.2	42.5	42.8	39.6	39.7	40.4	38.9	33.4	28.6
Bamako	34.1	34.5	38.9	39.9	38.3	35.1	32.4	31.8	33.2	35.5	36.6	32.8
Banjul	30.6	32.6	36.0	32.2	34.4	32.4	31.0	30.8	30.8	33.0	32.7	32.5
Conakry	30.8	32.7	32.1	31.8	32.6	30.2	28.2	27.3	28.9	29.5	30.6	31.5
Diffa	29.7	34.0	35.8	41.8	40.7	38.0	33.6	32.4	34.1	39.7	37.8	33.1
Gagnoa	33.8	35.0	35.2	34.4	34.0	31.3	29.9	29.3	32.5	32.0	32.4	32.0
Jos	33.2	36.6	38.0	40.2	37.8	35.9	31.8	31.2	32.0	35.0	33.0	33.0
Nema	34.4	37.4	39.2	43.1	43.0	42.8	37.2	35.6	37.0	39.2	37.0	34.3
P/Harcourt	31.9	33.0	32.2	30.6	29.4	29.5	27.8	27.0	29.0	27.9	32.0	33.2

Table 2.0: Mean Wet-bulb Temperature of the Selected Cities

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agadez	13.2	14.9	15.1	18.8	21.0	22.3	22.8	24.2	21.4	17.7	14.8	13.3
Bamako	16.6	16.4	19.7	20.4	24.4	24.8	25.3	25.1	25.2	24.3	19.4	15.2
Banjul	16.4	17.9	19.7	21.7	24.3	25.3	26.0	25.9	26.1	26.7	235.1	19.9
Conakry	22.0	24.6	25.0	24.8	25.1	25.7	25.1	24.8	25.2	25.8	26.0	24.7
Diffa	13.8	16.0	16.2	21.2	25.4	25.3	25.4	25.1	25.8	24.5	19.2	17.1
Gagnoa	22.7	25.3	26.7	26.2	26.0	25.1	23.9	23.8	24.9	25.2	25.6	25.0
Jos	13.5	16.4	15.2	17.9	21.0	21.7	20.6	20.2	19.9	19.5	14.3	13.5
Nema	15.1	17.4	18.1	20.0	21.2	23.2	24.3	24.6	25.2	21.0	17.5	15.9
P/Harcourt	24.3	26.6	25.8	25.6	26.1	25.2	24.4	24.3	24.7	24.6	25.2	23.3

The Feasibility Index Method

Feasibility index (FI) is defined as [6]:

$$FI = WBT - \Delta T$$

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 [6]. Camrago et al [6] 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

Using equation 1.0 and Tables 1.0 and 2.0, the feasibility index (FI) of the selected cities in West Africa for twelve months, January through December, were computed and presented in Table 3.0.

Results and Discussion

Table 3.0: Monthly Evaporative Cooling Feasibility Index of the Selected Cities

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agadez	-2.8	-3.2	-3.9	-2.9	-0.5	1.8	6.0	8.7	2.4	-3.5	-3.8	-2.0
Bamako	-0.9	-1.7	0.5	0.9	10.5	14.5	18.2	18.4	17.2	13.1	2.2	-2.4
Banjul	2.2	3.2	3.4	11.2	14.2	18.2	21.0	21.0	21.4	20.4	17.5	7.3
Conakry	13.2	16.5	17.9	17.8	17.6	21.2	22.0	22.3	21.5	22.1	21.4	17.9
Diffa	-2.1	-2.0	-3.4	0.6	10.1	12.6	17.2	17.8	17.5	9.3	0.6	1.1
Gagnoa	11.6	15.6	18.2	18.0	18.0	18.9	17.9	18.3	17.3	18.4	18.4	18.0
Jos	-0.2	2.4	-0.9	4.7	14.9	17.2	16.5	17.1	14.6	13.3	3.0	0.2
Nema	-4.1	-2.6	-3.0	-3.1	-0.6	3.6	11.4	13.6	13.4	2.8	-2.0	-2.5
P/Harcourt	16.7	20.2	19.4	20.6	22.8	20.9	21.0	21.6	20.4	21.3	18.4	13.4

Based on the recommendation of [6] and the computed feasibilty indices of the selected cities presented in Table 3.0, the periods for comfort cooling and relief cooling as well as periods not recommended for the use of direct evaporative coolers were sorted out and presented in Table 4.0.

Table 4.0 Evaporative cooling status of the selected West African cities

Cities	Comfort Cooling	Relief Cooling	Not Recommended
Agadez	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sept, Oct, Nov, Dec	-	-
Bamako	Jan, Feb, Mar, Apr, Oct, Nov, Dec	May, Jun	Jul, Aug, Sept,
Banjul	Jan, Feb, Mar, Dec	Apr, May	Jun, Jul, Aug, Sept, Oct, Nov
Conakry	-	Jan	Feb, Mar, Apr, May, Jun, Jul, Aug, Sept, Oct, Nov, Dec
Diffa	Jan, Feb, Mar, Apr, Oct, Nov, Dec	May, Jun	Jul, Aug, Sept
Gagnoa	-	Jan	Feb, Mar, Apr, May, Jun, Jul, Aug, Sept, Oct, Nov, Dec
Jos	Jan, Feb, Mar, Apr, Nov, Dec	May, Sept, Oct	Jun, Jul, Aug
Nema	Jan, Feb, Mar, Apr, May, Jun, Oct, Nov, Dec	Jul, Aug, Sept	-
P/Harcourt	-	Dec	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sept, Oct, Nov

Discussion

The monthly evaporative cooling feasibility indices of the selected cities in West Africa are shown in Table 3.0. Considering the work of [6] and the sorted months presented in Table 4.0, it can be seen that 100%, 58.3%, 33.3%, 0%, 58.3%, 0%, 50%, 75%, 0% of the periods in a year of Agadez, Bamako, Banjul, Conakry, Diffa, Gagnoa, Jos, Nema, P/Harcourt, are recommended for the use of direct evaporative cooling for human thermal comfort. It is axiomatic that Conakry, Gagnoa, P/Harcourt are not recommended for the use of direct evaporative cooling which can be attributed to the high relative humidity and low wet bulb depression in these areas. It can be seen from Table 4.0 that Jos and Nema have relative high relief cooling potential of about 25%, 25% respectively. 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. Table 4 also shows the combination of comfort and relief cooling of the selected cities. It can therefore be seen that Agadez, Bamako, Diffa, Jos, and Nema have high direct evaporative cooling potential. This can be attributed to the low relative humidity in these areas. This agreed with the work of [17] and [6] that low relative humidity and high wet bulb depression characterize an area as having high potential for the use of direct evaporative cooling for human thermal comfort.

Conclusion

The potential of direct evaporative cooling for human thermal comfort in West Africa was theoretically evaluated. Employing the concept of the feasibility index (FI) method for the evaluation shows that Agadez, Bamako, Diffa, Jos, and Nema have high potential for the use of direct evaporative cooling for human thermal comfort Conakry, Gagnoa and Port Harcourt are not recommended for the use of direct evaporative cooling. Therefore, due environmental friendliness, low power requirement, low cost, ease of construction and maintenance, the use of direct evaporative coolers in areas with high evaporative cooling potential can be a suitable alternative to conventional air conditioning systems.

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