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Performance of Evaporative Cooling Pads Made from Different Plant Materials of Sub-Saharan Area (NIGER)

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ABSTRACT— A thermal comfort zone is sought by all living beings for their optimum life activity, production or reproduction. In hot environment, direct evaporative coolers are often used as cost-effective thermal comfort providing-devices. This paper presents performance analysis of newly proposed accessible and cost-effective evaporative cooling pads from local plant materials (herbs and fibers) from Niger, a sub-Saharan country. Experiment was run in an experimental duct exposed to ambient pressure and temperature conditions, with different fan speed (5.11 and 5.52 m/s) and constant pad thickness (5 cm). Saturation efficiencies, mass and heat transfer coefficients, pressure drop, permeability, increase in relative humidity as well as coefficient of performances (COP) and cost-to-efficiency ratios (CER) were obtained for all the pads locally made. Compared to commercially available Celdek pad with tested efficiency of 70.02% and 79.80% at low and high fan speed respectively, local pads efficiencies ranged from 16.50% to 69.88% at a frontal velocity of 5.11m/s and from 22.73% to 78.80% at 5.52 m/s frontal velocity. Most of the local pads had better CER than the commercial one. Pad made from local wood wool emerged to be an excellent candidate providing thermal comfort and outlet temperature close to that of commercial pads. Controlling physical parameters such as arrangement, flute size and packing pattern can help to improve some of thermodynamic properties of locally made pads.

Keywords—Direct evaporative cooler, cellulosic pad materials, heat stress, saturation efficiency, Sahelian plant fibers

I. INTRODUCTION

Hot environment limit activities and productivities of living organisms (Fournel et al., 2017). Heat stress is said to reduce cow health, production and reproduction performance. Food intake of such animals begin to decline under ambient temperature beyond 26oC (Fournel et al., 2017). Excessive heat within poultry houses are responsible for 25% losses in terms of poultry weight and even responsible for 15% of poultry mortality in hot zones (Laknizi et al., 2018; Lara and Rostagno, 2013). In the case of humans living in hot areas such as Sahelian and some sub-Saharan zones, many researches have shown a reduction of activity affecting the economy. Even heat-adapted people were observed to have limited activity capability under ambient wet bulb temperature of 32oC equivalent to a heat index of 55oC (Raymond et al., 2020). Therefore, an optimum environment, neither so hot nor so cold is necessary for living being's optimum activity. Various methods are used to create a convenient temperature drop for comfortable living zone. Among these methods, conventional air conditioning devices and evaporative cooling devices are often used. Sub-Saharan areas facing such heat are mostly populated by inhabitants with middle to low income pads (Arbel et al., 2003; Kachhwaha and Prabhakar, 2010). Therefore, they cannot, in average, afford those cooling devices although evaporative coolers appear cheaper and are more promoted due to their environmental friendliness. However, the dusty state of the environment oblige a regular change of cooling pads (Arbel et al., 2003; Kachhwaha and Prabhakar, 2010). Not everyone can afford to change regularly a pad that is relatively expensive. Getting locally a replaceable pad could help solve this issue. Evaporative cooling devices or direct evaporative coolers mostly work under evaporative cooling process in which dry and hot air comes into contact with water. Water retrieves latent heat of evaporation from the air stream and evaporates while the outlet air gets sensible heat and drops in terms of temperature; hence getting cooler for better comfort (Khobragade and Kongre, 2016; Manuwa and Odey, 2012). The most efficient pad to date is Celdek pad attaining a saturation efficiency of up to 90% (Khobragade and Kongre, 2016). Many local plant-based cellulosic materials from hot and dry regions were investigated in view to finding cheaper alternative, yet minding the cost-effectiveness aspect. Jain and Hindoliya (2011) worked on pads made from Aspen, Khus, Coconut and Palash fibers. From his experiment, Palash fibers got a relatively higher saturation efficiency of 81.04% against 71.59% for the Aspen fibers which are another commercial pad fibers (Jain and Hindoliya, 2011). Moreover, Manuwa and Odey (2012) found that Jute pad produced the highest cooling efficiency of 93.5% with a hexagonal cross-section cooler compared to wood shavings (African cordia-Cordia millenii), khrus-grass, charcoal and latex foam (Manuwa and Odey, 2012). Furthermore, palm leaves fibres, cotton wastes, wood wool, luffa, so on and so forth were also investigated as cooling materials by several authors (Barzegar et al., 2012; Khobragade and Kongre, 2016; Manuwa and Odey, 2012). In fact, researchers are pushing up research in order to come up with more cost-effective cooling pads and devices.

This research seeks to search for alternative cooling pads from locally accessible and affordable plant materials for the development of cost-effective cooling pads.

II.METHODOLOGY

2 Materials and Methods

2.1 Materials

2.1.1 Pads

Pads were made using aluminium perforated sheet (aluminium net) worked into a rectangular volume shape. Local pants materials were used to fill up the volume of this pad. Plant materials were obtained from local market (Katako market) and used directly in their dry state.

2.1.2 Measuring instruments

Thermodynamic parameters (temperature, pressure, relative humidity and wind velocity) about inlet and outlet conditions were taken using digital instruments: Anemometer HoldPeak HP-856A for wind velocity and inlet dry bulb temperature; two digital multimeters HoldPeak HP-90EPC with a thermocouple probe. One of them is used for measuring outlet dry bulb temperature and the other had its probe covered with a wet cotton wool in order to measure wet bulb temperature. Two hygrometer HTC 1 were used for relative humidity measurement and a TP101 thermometer was used for measuring water temperature.

2.1.3 Experimental setup

The experimental setup is made up of a hollow square duct made up aluminium sheet insulated by a 4 mm glass wool as a lagging material. It has four sections: the first section is a fan blower with changeable speed; a second section is comprised of a slot for temperature, humidity and wind measuring device; the third section is comprising a slot for interchanging the various pads with a water drip system and a water collecting/recycling tank; a fourth section for another set of thermometer and hygrometer and a fifth section which is an outlet. More details are giving in figure 2.

(a)Commercial pad: Celdek pad	(b)Local pad: Kaba pad	(c)Local pad: Wood wool pad

Figure 1: Commercial pad (a) against some of the locally made pads (b) and (c).

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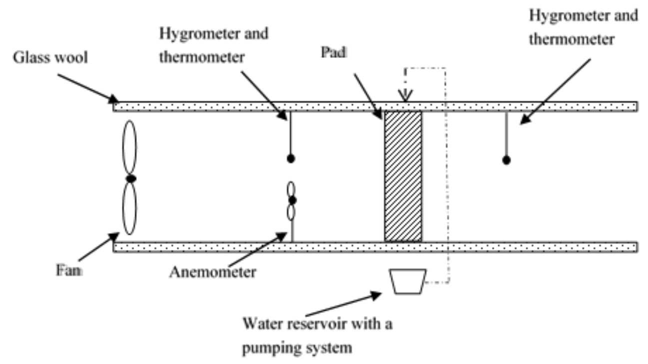

Figure 2: Schematic diagram of Cross-sectional view of experimental setup.

2.2 Methods

Pads made from indigenous plants parts were tested as candidates for new a cost-effective evaporative cooling pad. The pads were characterized under two different inlet velocities with water being recycled and its temperature being measured. The saturation efficiency of each of them was derived as long as their cooling capacities.

Saturation efficiency is given by: $eff = \frac{T_{db1}-T_{db2}}{T_{db1}-T_{wb}}$ Equation 1

Cooling capacity is given by: $Q = m_a Cp_a(T_{db1} - T_{db2})$ Equation 2

Where eff = Evaporative saturation efficiency, % ; T_{db} = dry bulb temperature with 1 and 2 being inlet and outlet conditions, °C; T_{wb} = wet bulb temperature, °C; Q = Cooling capacity, kW; ma = air mass flow rate, kg/s;

Cross sectional area or wetted area: A = H x L = 0.00193 m^2;

Thickness of pads is constant: Ɛ = 5 cm; Pump power = 18W ;

Fan velocity = v_{high} 5.522 m/s and v_{low} = 5.110 m/s

Some assumptions were made such as:

1. Steady state system
2. Heat transfer to surrounding is zero, heat radiation is ignored
3. Fluid flow at entry is uniformly distributed in the plane perpendicular to the flow
4. Mass and heat transfer direction is normal to the flow
5. Complete surface wetting of the pads is assumed
6. Resistance to heat transfer from water layer core to its surface is neglected

2.3 Balance around the pads

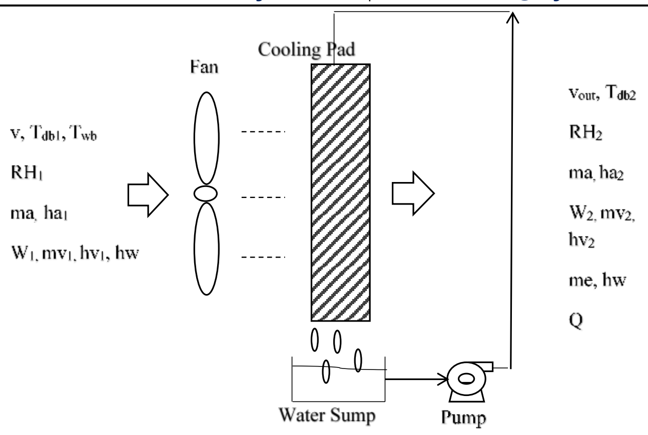

Figure 3: Diagram of a balance around the pad.

2.3.1 Energy balance

When thermal equilibrium is reached, the energy balance for air/water vapour mixture across the pads can be written as follow:

maha1 + mv1hv1 + mv1hw = maha2 + mv2hv2 +mv2hw + Q

Equation 4

where the indices 1 and 2 indicate inlet and outlet parameter respectively,

mv = mass flow rate of water vapour, kg/s;

W = humidity ratio, kg of air/kg of water;

ha = enthalpy of air, kJ/kg of dry air;

hw = enthalpy of water, kJ/kg of dry air and;

Q = heat loss by the pads, kJ/s;

RH = relative humidity, %;

v = frontal/inlet velocity, m/s; v_{out} = outlet velocity, m/s; Let me = mass of water evaporated, me = mv2 – mv1→Equation 5

W = humidity ratio, W = mv/ma →Equation 6

Q = heat loss, Q = ma Cpa (Tdb1 – Tdb2) →Equation 7

Applying equation 5 into equation 4, we obtain:

ma (ha1-ha2) + mehw + mv1hv1 + mv2hv2 = Q →Equation 8

Dividing equation 4 by ma, we get:

$ha_1 + W_1hv_1 + W_1hw - ha_2 - W_2hv_2 - W_2hw = \frac{Q}{ma}$ →Equation 3

Applying equation 7 into 4, we obtain:

$ha_1 - ha_2 + W_1(hv_1 + hw) - W_2(hv_2 – hw) = Cpa(T_{db1} – T_{db2})$ →Equation 4

2.3.2 Heat and mass transfer coefficients

The heat loss (Q) is also known as the heat transferred which is carried by the cool air serving as a comfort. The heat transferred can also be expressed as:

$Q = h_H A_s \Delta T$ Equation 5

And the mass of water evaporated (me) or mass transferred through the evaporative cooling process can be expressed as:

$me = h_M A_s \Delta\rho_v$ Equation 6

Where h_H, is the heat transfer coefficient, h_M is the mass transfer coefficient, A_s is the total wetted surface area of the pad used, ΔT is the log mean temperature difference and $\Delta\rho_v$ is the log mean mass density difference of water vapour.

$\Delta T = \frac{T_{db2}-T_{db1}}{ln((T_{db2}-T_{wb})/(T_{db1}-T_{wb}))}$ Equation 7

$\Delta\rho_v = \frac{\rho_{v2}-\rho_{v1}}{ln((\rho_{v2}-\rho_{wb})/(\rho_{v1}-\rho_{wb}))}$ Equation 8

Where the indices 1, 2 and wb are used to represent parameter taken at inlet, outlet and wet bulb conditions.

2.3.3 Pressure drop

Evaporative cooling process causes a Pressure drop across the pads which can be expressed as

$\Delta Pv = Pv_2 - Pv_1$ Equation 9

Where Pv_2 and Pv_1 are vapour pressures at outlet and inlet temperature respectively.

$Pv_2 = Ps_2 \times RH_2$; $Pv_1 = Ps_1 \times RH_1$

Ps is the saturated vapour pressure obtained from air properties table while RH is relative humidity (Alvarado and Klein, 1970)

2.3.4 Permeability of pads

Knowing the capacity of the pads to retain water for the mass and heat exchange long enough for a better efficiency is a good information in the design of an effective pad. This function is expressed in terms of the permeability coefficient, k as first proposed by Darcy through Darcy's law and restudied by Pal et al. (2006). The permeability of a porous media for single phase and multi-phase flow describes the kinetics of fluid flow though porous media in terms of driving force and permeability of the medium (Pal et al., 2006). It is expressed as:

$Q = \frac{K}{\eta}\frac{\Delta P}{\Delta L}A$ Equation 10

where Q is volumetric flow rate (m^3/s), K is permeability coefficient (m^2), ΔP is pressure drop, ΔL flow length of thickness, A is cross section area to flow and η is fluid viscosity.

This formula can be adapted for evaporative cooling pad as:

$Q = \frac{K}{\eta}\frac{\Delta Pv}{\mathcal{E}} As \Rightarrow K = \frac{\frac{me}{\Delta\rho v}\eta \times \mathcal{E}}{\Delta Pv \times As}$ Equation 11

where me is mass flow rate of water evaporated, Δρv is log mean mass density of water vapour, η is dynamic viscosity obtained from air properties table, Ɛ is thickness of the pad and ΔPv pressure drop (Alvarado and Klein, 1970).

The greater the K value, the higher will be the rate of fluid flow through a material. K is dependent on the fluid and porous material used (Pal et al., 2006)

2.3.5 Coefficient of performance (COP)

This parameter contributes in evaluating the energy efficiency aspect of the cooling pads. The higher the COP value, the more efficient is the cooling pad.

$COP = \frac{Q_{pad}}{P_{fan} \times P_{pump}}$ Equation 12

Where Q_{pad} is the cooling capacity of the pad, P_{fan} and P_{pump} represent power of fan or blower and pump respectively. P_{pump} = 18W given by the manufacturer.

$P_{fan} = \frac{ma \times \Delta Pv}{\rho a \times \eta_{fan} \times \eta_{motor}}$ Equation 13

Where ma and ρa are mass flow rate and density of air respectively; ΔPv pressure drop; η_{fan} and η_{motor} are fan and motor efficiencies. $\eta_{fan} = \eta_{motor} = 80\%$

2.3.6 Cost to efficiency ratio (CER)

This parameter helps to get the optimum material taking into account the cost of the pad using the plant cellulosic material and its efficiency when used. The higher the CER value, the better the material.

$$CER = \frac{Cost}{eff} \qquad \text{Equation 14}$$

III. RESULTS AND DISCUSSION

3.1 Overall analysis

Different cellulosic cooling pads locally made were characterised under measured and controlled two different fan speed 5.110 m/s and 5.522 m/s keeping the pad thickness constant (Ɛ=5 cm) throughout the experiment. Average values of the various thermodynamic data were used for the purpose of a comparative analysis.

In Table 1 and table 2 are presented the various performances of the pads exposed to a frontal velocity of 5.110 m/s and 5.522 m/s respectively. Compared to the commercial Celdek pad used in conventional evaporative coolers, wood wool pad from the leaves stipulates of Hyphaene thebaica had saturation efficiency closer to that of Celdek and performed much better than the other local plant made pads. Indeed, with saturation efficiencies varying from 16.50% (Kuriya pad - Ceba pentandra fibers) to 69.88% (wood wool pad) at lower fan speed and from 22.73% (Gamba pad - Antropon gavanus) to 78.80% (wood wool pad) at higher fan speed, local materials' pad challenged the commercial Celdek pad which could reach as saturation efficiency of 70.02% at lower and 79.80% at higher frontal velocity. This comparison is better seen through the histograms presented in the figure 4. It is observed that saturation efficiency increased with increasing frontal velocity as also mentioned by Laknizi et al. (2018). To the best of our knowledge, no data on these plants' performances as cooling pads are available in the literature.

3.1.1 Effect of pad packing materials on outlet velocity

For an air or wind to provide comfort, it is supposed to come fast enough to be better appreciated or to cool down an enclosure such as a room. Because all the local pads were made through packing, filling and rearrangement to attain a certain volume (in this case, L x H x Ɛ = 9635 cm3), this situation affects the velocity at which the outlet comfortable air should come out and could probably affect the efficiency and other thermodynamic properties (see table 1 and 2). The outlet winds ranged from 0.1 (over packed pads) to 0.657 m/s (Kaba pad – leaves of Hyphaene thebaica) and from 0.333 to 0.825 m/s (wood wool pad). Wood wool is in a coil form and arrangement, Kaba is straight while the rest are randomly packed (see figure 1). While the water is running, all disordered and unstable packing becomes more condensed to the extend to make obstruction to air flow. This situation reduces the outlet and could affect the efficiency and other thermodynamic parameters. In fact, the cooling efficiency of the cooling pad was reported to be affected by the flute size, the porosity and the water absorption capability of the pad; some physical characteristics similar to packing density of local pads (Barzegar et al., 2012).

3.1.2 Effect of frontal velocity on saturation efficiency, cooling capacity and heat transfer coefficient

Figure 4, 5 and 6 show the saturation efficiency, cooling capacity and heat transfer coefficient of various pads. In fact, all these parameters increase with increasing frontal velocity. This is because these parameters are temperature driven which is an intrinsic property, not proportional or affected by the size of the material. From these histograms, it can be observed that at lower frontal velocity, Celdek, wood wool, Kaba and wood shavings pads had the four best efficiencies (70.02, 69.88, 47.19 and 45.03% respectively), cooling capacities Q pad (0.1477, 0.1496, 0.0985 and 0.0912 kW respectively) and heat transfer coefficient hH (3.1400, 3.1150 and 1.6794 kW/m2.oC respectively). However, for higher frontal velocity, the same order in terms of performance is observed with, in this case, wood shavings pad having higher parameters. This sudden performance of wood shavings can be allocated to the fact that at a lower velocity, wind cannot penetrate the packing easily to be detected well by temperature and humidity sensors. Hence, more force was needed to penetrate this pad wall (see figure 9). Also, according to Barzegar et al. (2012) and Laknizi, et al. (2018), more time is needed for materials to absorb enough water allowing more heat and mass transfer (Barzegar et al., 2012; Laknizi et al., 2018).

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Table 1: Characteristics of various cooling pad at a lower fan speed

Pad type	Scientific / Common names	Frontal Velocity v (m/s)	Mass flow rate ma (kg/s)	Average inlet dry bulb temperature T_{db1} (°C)	Average wet bulb temperature T_{wb} (°C)	Average outlet dry bulb temperature T_{db2} (°C)	Average saturation efficiency (%)	Average RH of inlet wind	Average RH of outlet wind	Outlet velocity V_{out}, m/s	Velocity decrease, %decr
Celdek pad	'Trade name'	5.110	0.0113	34.82	16.42	21.92	70.02%	10.00%	38.00%	1.166	77.18%
Baata pad	Ctenium elegoms	5.110	0.0113	35.85	17.17	31.83	21.69%	10.50%	21.69%	0.100	98.04%
Gamba pad	Antropogon gayanus	5.110	0.0113	36.32	17.00	32.58	19.37%	10.17%	12.33%	0.100	98.04%
Kaba pad	Hyphaene thebaica (leaves)	5.110	0.0113	34.35	16.08	25.75	47.19%	10.00%	26.67%	0.657	87.14%
Kaikai pad	Pennisetum glaucum (husk)	5.110	0.0113	35.30	16.33	30.17	27.10%	10.00%	20.67%	0.100	98.04%
Kuriya pad	Ceba pentandra (fibers)	5.110	0.0113	34.22	15.83	31.17	16.50%	10.00%	12.33%	0.100	98.04%
Wood shavings pad	'Red and white wood'	5.110	0.0113	35.38	17.67	27.42	45.03%	10.00%	22.50%	0.335	93.44%
Wood wool pad	Hyphaene thebaica (leaves stipulates)	5.110	0.0113	35.65	16.92	22.58	69.88%	10.00%	37.17%	0.448	91.23%

Table 2: Characteristics of various cooling pad at a higher fan speed

Pad type	Scientific / Common names	Frontal Velocity v (m/s)	Mass flow rate ma (kg/s)	Average inlet dry bulb temperature T_{db1} (ºC)	Average wet bulb temperature T_{wb} (ºC)	Average outlet dry bulb temperature T_{db2} (ºC)	Average saturation efficiency (%)	Average RH of inlet wind	Average RH of outlet wind	Outlet velocity v_{out}, m/s	Velocity decrease, %decr
Celdek pad	'Trade name'	5.522	0.0122	34.5833	17.4167	20.9167	79.80%	13.50%	50.00%	1.166	78.88%
Baata pad	Ctenium elegoms	5.522	0.0122	32.2833	14.7500	26.7500	31.54%	10.33%	15.00%	0.659	88.07%
Gamba pad	Antropogon gayanus	5.522	0.0122	35.2500	15.4167	30.7500	22.73%	10.33%	12.50%	0.659	88.07%
Kaba pad	Hyphaene thebaica (leaves)	5.522	0.0122	34.7500	16.5000	26.1667	47.01%	10.00%	24.17%	0.803	85.46%
Kaikai pad	Pennisetum glaucum (husk)	5.522	0.0122	36.6833	17.0000	30.8333	29.71%	10.67%	19.67%	0.335	93.93%
Kuriya pad	Ceba pentandra (fibers)	5.522	0.0122	34.5500	18.0000	30.7500	23.18%	10.00%	25.17%	0.333	93.97%
Wood shavings pad	'Red and white wood'	5.522	0.0122	33.6500	18.3333	21.8333	75.88%	14.33%	35.67%	0.680	87.69%
Wood wool pad	Hyphaene thebaica (leaves stipulates)	5.522	0.0122	35.6667	17.8333	21.8333	78.80%	13.83%	33.00%	0.825	85.06%

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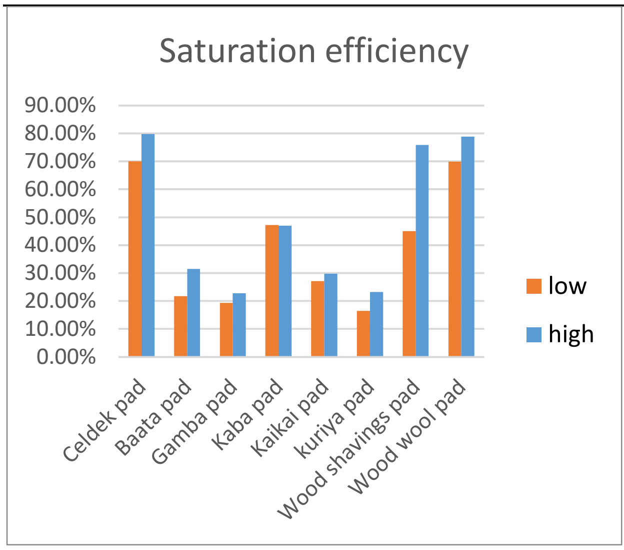

Figure 4: Saturation efficiency of various pads.

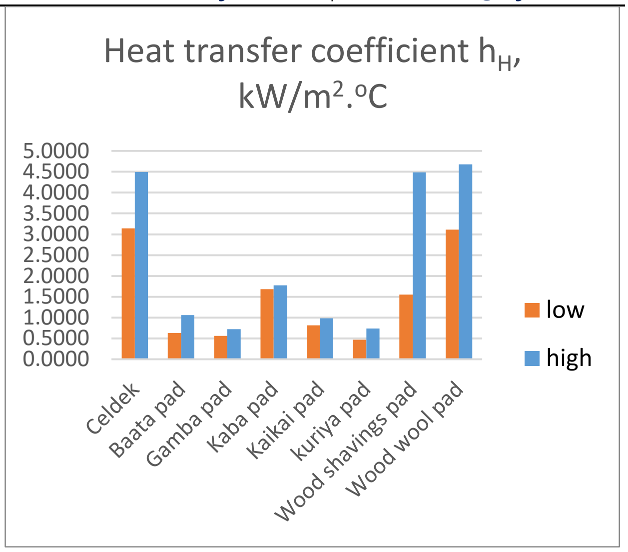

Figure 6: Heat transfer coefficient hH, kW/m2.oC Cooling

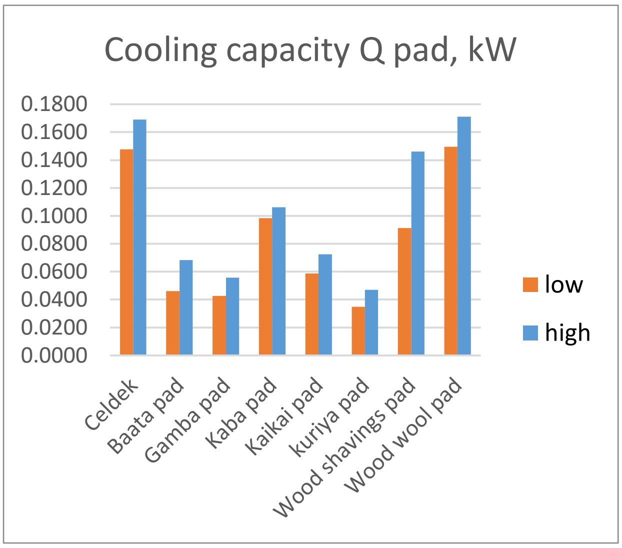

Figure 5 Cooling capacity of various pad 1

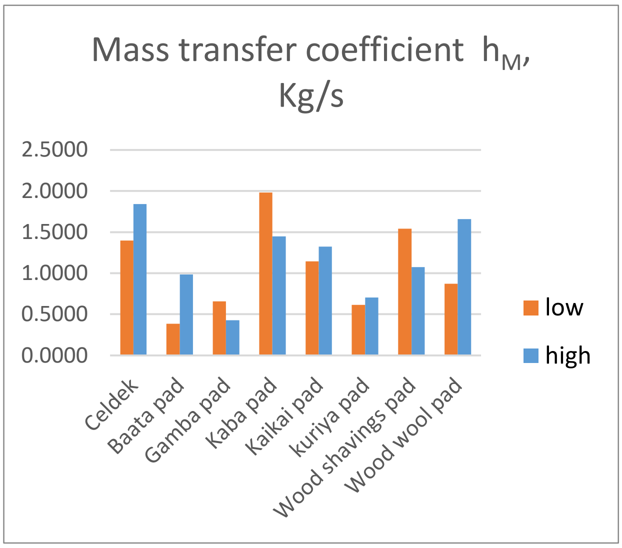

Figure 7: Mass transfer coefficient hM, kg/s

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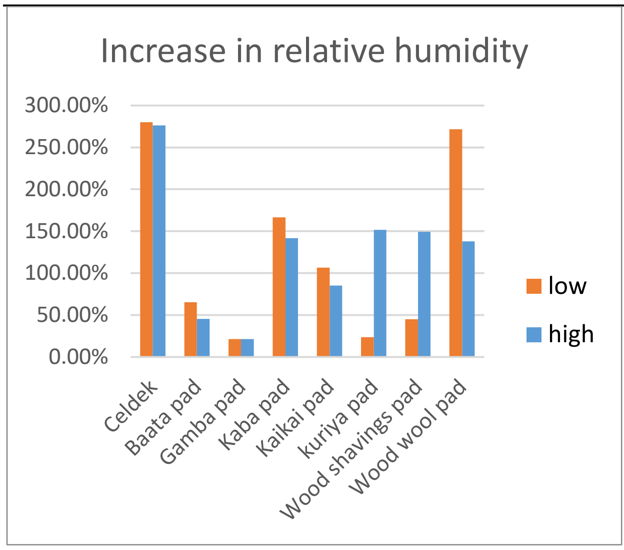

Figure 8: Increase in relative humidity

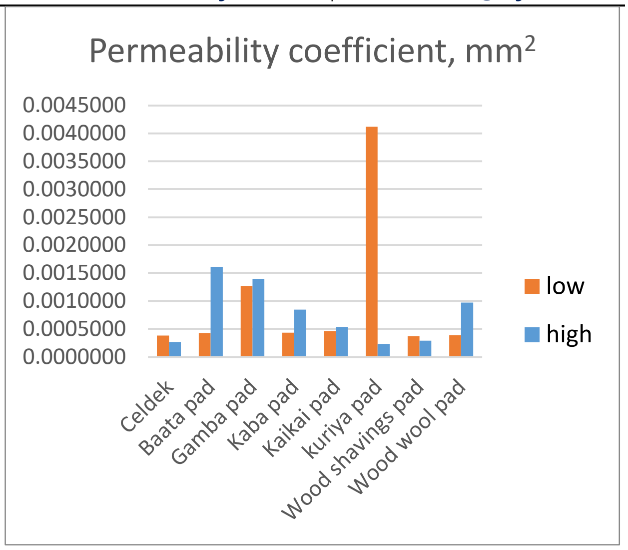

Figure 9: Permeability coefficient

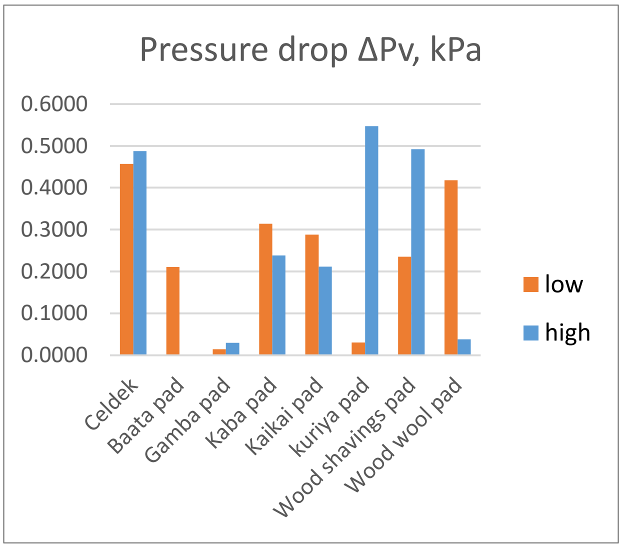

Figure 10: Pressure drop

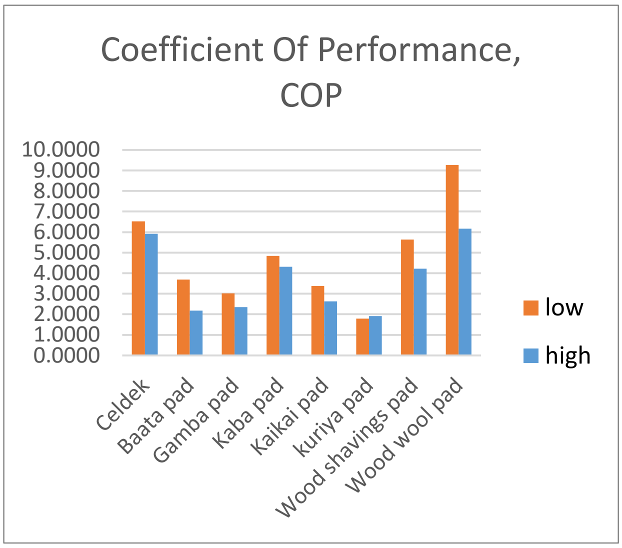

Figure 11: Coefficient of performance

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3.1.3 Effect of frontal velocity on mass flow rate and permeability coefficient

At the same pad size and mass flow rate, the pads from Celdek, wood wool, Kaba, wood shavings and Kaikai (Pennisetum glaucum) transferred more mass of water vapour than the rest of local materials (see figure 7). The higher the frontal velocity, the higher the mass transfer coefficient hM except some anomalies observed in Gamba pad, Kaba and wood shavings. Besides, pad from Ceba pentandra fibers (Kuriya pad) and Antropon gavanus (Gamba pad) are the ones not performing well due to the impermeable shell protecting the various materials. These shells reduce the mass and heat transfer rate and affecting the other thermodynamic properties.

The permeability coefficient k pad is presented on figure 9. This parameter depends on the combination of the fluid and porous materials used. The higher this parameter is, the higher the fluid flow rate through a material. In this figure, it can be observed that all the materials with lowest performance (saturation efficiency and cooling capacity) had the highest permeability coefficient which is the cases of Baata, Gamba and Kuriya pads in this order. In fact, this is because, the materials do not allow a better moist air-cellulose mass and heat exchange.

3.1.4 Effect of relative humidity on pad performance

Figure 8 and 10 show the increase in relative humidity and the pressure drop across the pad. Materials with higher efficiencies, that exchanged more heat and which allowed better mass transfer led to a higher increase in relative humidity and more pressure drop. We could observe the high stability of Celdek pad which has stable characteristics irrespective of the wind velocity contrary to Kuriya and wood wool. However, Materials presented a higher increase in relative humidity at a lower frontal velocity. Among the local material pads, wood wool pad could create an increase of 271.67% at lower fan speed against 140.57% at higher speed whereas wood shavings could create a 149.40% increase. Here again, highly packed materials such as wood shavings perform well at higher speed whereas the opposite is observed in the case of well-performing pads such as wood wool and Celdek. Of course, the other thermodynamic parameters limit the extent to which a pad can increase the relative humidity.

From figures 8 and 9 we can see materials with lower permeability coefficient allow more time for water absorption and, hence, can create a higher increase in relative humidity. The coefficient of performance of various pads are presented in the figure 11 The COP at lower frontal velocity is observed to be higher (range of 1.9064-6.1570 for lower and 1.7908-9.0074 for higher frontal velocity) than the one at higher COP and the same trend is observed with the relative humidity (figure 8). This shows that relative humidity affects the performance of a system as also observed by (Laknizi et al., 2018).

3.1.5 Cost effectiveness analysis

The financial analysis based on cost to efficiency ratio using CFA (XOF) and USD (United States Dollars-$) was presented in figures 12 and 13. The lower the ratio the better and the most recommended the pad material is in order to optimize cost and efficiency especially when thermal comfort is becoming a luxury. On local market, a Celdek pad costs about 10 000 CFA ($18) against 2500 CFA ($3.60) for the wood wool pad. The two pads gave saturation efficiencies up to 79.8% and 78.8% at high frontal velocity respectively. By doing the cost-to-efficiency ratio as shown in figures 12 and 13, Celdek pad which is the most effective happen to be less cost effective, hence, less recommended than wood wool pad especially our contest where not all households could afford regular change in pad materials. This high cost of material from Celdek is because the material is imported from overseas whereas wood wool and the rest are locally available and accessible, hence, much cheaper. Besides, wood shavings pad whose efficiency is relatively acceptable compared to Celdek and wood wool, shows promising cost-effectiveness. Indeed, with a cost of 2500 CFA ($3.60) to make the pad and a maximum efficiency of 75.88%, wood shavings are the second local pad materials for replacement from our local market.

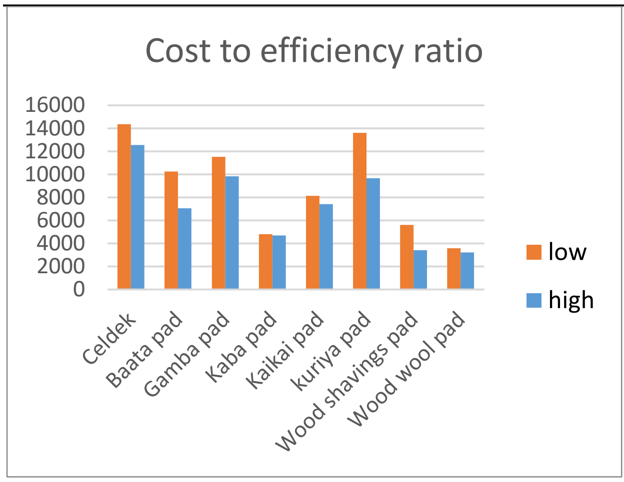

Figure 12: Cost to efficiency ratio CER based on CFA (XOF).

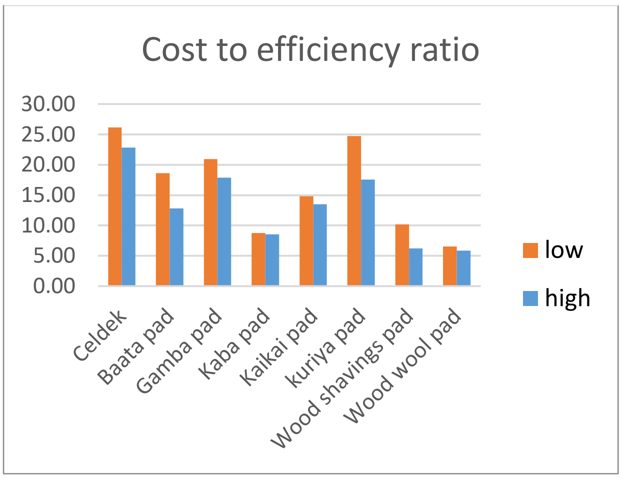

Figure 13: Cost to efficiency ratio CER based on USD

IV. CONCLUSION

The experiment on local cellulosic material as alternative cooling pad materials has been successful. Wood wool pad from the fibres of the stipulates of Hyphaene thebaica emerged to be the most performing pad with thermodynamic characteristics challenging those of the commercial Celdek pad and, having the best cost-to-efficiency ratio. It could be derived from this experiment that, pads with higher the efficiency are able to provide the higher relative humidity a more humid (30 to 60% relative humidity) and cool air (up to 20oC). Besides, physical structure as well as physicochemical properties of plants materials forming various pads affects the overall performance of pads. Optimizing these parameters can help improve pads saturation efficiency, performance and outlet temperature as well as outlet wind velocity.

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