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RESEARCH ARTICLE

EXPERIMENTAL STUDY OF A MOBILE SOLAR AIR COOLERWITH A CLAY-BASED COOL WATER RESERVOIR

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Abstract

This paper focuses on the simulation in SolidWorks and experimental study of a mobile solar air cooler using clay as the base material.This device is an energy-autonomous and economically viable response to the challenges of climate change and limited access to conventional air conditioning in developing countries. The methodology used incorporat es specifications and the optimal choice of components necessary for the prototype (clay, a 1 W DC fan, four 500 Wp photovoltaic panels with a 2 kVA / 1.6 kW 48 ,V converter and a 48 V 200 Ah battery bank)as well as the experimental characterisation of the prototype. The results show a temperature reduction of 5°C (indoor temperature of 25°C for 30°C outdoors) with relative humidity of 55%, autonomy of one day and daily consumption of 7 kWh. The cost of producing the device is 221,500 CFA francs.

Introduction:-

In sub-Saharan Africa, temperatures can exceed 40°C for long periods of time, and conventional cooling solutions remain largely inaccessible to a large part of the population (Lufu et al., 2025). Evaporative cooling technologies using local materials and renewable energy are promising alternatives. These systems, based on the physical principle of water evaporation to absorb latent heat, have the advantage of being economically affordable and energy sustainable (Workneh, 2010). The use of clay as a base material for evaporative cooling systems has been the subject of growing interest in scientific literature. The intrinsic properties of clay, including its high porosity, water retention capacity and local availability, make it a particularly suitable material for passive cooling applications (Mondal et al., 2009). Recent studies have shown that water-saturated porous clay structures can significantly reduce ambient temperature, with particularly remarkable performance in hot and dry climates (Mustafa et al, 2025). The integration of solar energy into evaporative cooling systems represents an innovative approach that combines environmental sustainability and energy efficiency. In this paper, an experimental study is carried out on a mobile solar air cooler with a clay-based cool water reservoir designed on the basisof adopted specifcations, specifically adapted to the climatic conditions and socio-economic constraints of developing countries such as Benin. The

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originality of this approach lies in the synergistic integration of three key elements: the use of local clay as the base material, the incorporation of a water pre-cooling system through storage, and the mobility of the device for flexible use.

Materials and Methods:-

This section presents the equipment and materials used to build the air cooler, the research methodology and the associated sizing. The main objective of this research is to develop an accessible, sustainable and effective technological solution to improve thermal comfort in enclosed spaces, while promoting local resources and renewable energies.

Equipment/materials used:-

The equipment and measuring devices used during the design phase are described in the table 1 below:

Table 1: List of equipment/materials

Equipment/Materials	Technical specifications
Temperature sensor	○ Brand: MCP Healthcare ○ Temperature range: -50 °C to +110 °C ○ Accuracy: ± 1 °C ○ Resolution: 0.1 °C
Humidity sensor	○ Measuring range: 0–100% RH ○ Accuracy: 20–80%: ±3% and 0–20% / 80–100%: up to 5%
Clay canaries	○ Apparent density: 1800-2200 kg/m^3 ○ Porosity: 25-45% (microporous structure) ○ Water permeability: 1×10^{-12} to 1×10^{-10} m^2 ○ Thermal conductivity: 0.8-1.5 W/(m·K) ○ Specific heat capacity: 800-1000 J/(kg·K) ○ Water retention coefficient: High (absorption up to 20-30% of its weight)
Mist marker	○ Model: Mist marker ○ Nominal voltage: 24 V ○ Nominal current: 1 A ○ Water flow rate: 250 ml/h ○ Temperature range: 5°C – 45°C ○ Ceramic membrane size: 16 mm
Fan	○ Diameter: 12 cm ○ Rotation speed: 800 rpm ○ Maximum airflow: 43 cfm ○ Nominal power: 1 W ○ Maximum air pressure: 1 mm H_2O ○ Bearing type: Fluid bearing
Casing	○ Materials: wood ○ Dimensions: 40 * 40 * 50 cm^3

The funnel and T-shaped pipe served as ducts for the air flow outlet in our design.In addition, the thermal and fluid modelling of the system was carried out using SOLIDWORKS CAD software, a parametric 3D mechanical design application that allows designers to quickly sketch ideas, experiment with functions and dimensions, and produce accurate models and drawings. It is used to design and simulate models of the building and the clay device.Microsoft Excel, a spreadsheet application in the Microsoft Office suite, offers calculation, graphing, data analysis, and programming functions via VBA. Here, it enabled us to process monthly temperature and relative humidity data for the study area.

Methods adopted :-
To achieve our objectives, after calibrating the temperature and humidity sensors, we followed a methodical approachbased on modelling the air cooler in SolidWorksand the manufacturing of the prototypeobtained based on the specifications and then carried out a series of measurements.

Operating principle :-
The mobile solar air cooler with a clay water tank works on the simple and natural principle of evaporative cooling. The device consists mainly of a clay tank filled with water, a misting system, and a solar-powered fan. Through capillary action, the clay causes a thin layer of water to migrate to its surface, where it evaporates under the effect of ambient heat: this endothermic process draws heat from the reservoir and the adjacent air, causing them to cool. At the same time, the misting system disperses micro-droplets into the air flow; the rapid evaporation of these droplets enhances heat transfer and increases cooling efficiency. The fan draws in warm outside air and sends it to the cooling zone (reservoir + misting system), so that the expelled air is cooler and slightly humidified. This synergy between natural evaporation, misting and solar ventilation lowers the indoor temperature by several degrees.

Specifications
Our project aims to create a mobile, energy-efficient air cooler that can cool the ambient air in areas without constant access to electricity, using local materials such as clay. The following considerations have been made:

- Type of room to be cooled: an office measuring L=3m; l= 3m and h =2.5 m
- Average outside temperature: 30°C.
- Outdoor relative humidity: 45%.
- Target indoor temperature: 24°C.
- Target relative humidity: 55%.
- System operating time: 8 hours per day.
- Air density: $\rho = 1.20$ kg/m^3
- Specific heat of air: 1.005 kJ/kg.K
- Water source: clay jugs with a capacity of 2 L.
- Latent heat of vaporisation□□ = 2500 kJ/kg
- Number of lamps used for lighting: 1 lamp
- Amount of heat emitted by the lamp: 16 W
- Amount of heat emitted by the computer: 250W

Description of thermal modelling:-
The fluid considered is air, modelled as a predefined gas with a molar mass of 0.0290 kg/mol and a specific heat ratio of 1.399. The dynamic viscosity, specific heat and thermal conductivity of air are considered to be temperature-dependent. The solid materials include PTFE, characterised by a density of 2200 kg/m³, a specific heat of 1300 J/(kg.K) and an isotropic thermal conductivity of 0.300 W/(m.K), as well as lightweight concrete with a density of 600 kg/m³, specific heat of 1000 J/(kg.K) and isotropic thermal conductivity of 0.190 W/(m.K). In terms of thermal properties, conduction in solids is activated while radiation is deactivated. Solids are assumed to be dielectric, without taking electrical conductivity into account.In addition, the mesh used for the simulation comprises a total of 3,946 cells, including 1,106 fluid cells and 2,840 solid cells.
Tables 2 and 3 provide information on the initial conditions, boundary conditions, and thermodynamic and turbulence models.

Table 2: Initial conditions and turbulence parameters

Thermodynamic parameters	• Static pressure: 101,325.00 Pa • Temperature: 32.00 °C
Velocity parameters	• Velocity vector • Velocity in the X direction: 0 m/s • Speed in the Y direction: 0 m/s • Speed in the Z direction: 0 m/s
Solid parameters	• Default material: Polytetrafluoroethylene (PTFE) • Initial solid temperature: 22.00 °C
Turbulence parameters	• Turbulence intensity and length • Intensity: 2.00% • Length: 0.002 m

Table 3: Boundary conditions and thermodynamic parameters

Ambient pressure	Type	Ambient pressure
	Faces	Face<1>@BOUCHON4<1>
	Coordinate system	Face coordinate system
	Reference axis	X
	Thermodynamic parameters	Ambient pressure: 101325.00 Pa
		Temperature type: Initial component temperature
		Temperature: 30.00 °C
	Turbulence parameters	Turbulence intensity and length
		Intensity: 2.00%
		Length: 0.002 m
	Boundary layer parameters	Boundary layer type: Turbulent
Outflow velocity	Type	Exit velocity
	Faces	Face<1>@BOUCHON3<1>
	Coordinate system	Face coordinate system
	Reference axis	X
	Flow parameters	Direction of flow vectors: Normal to the face
		Relative to rotating reference frame: Yes
		Normal velocity to the face: 3,000 m/s

Sizing :-
Cooling capacity :-
The assessment of this heat involves other loads that must be estimated beforehand. These include, for example:
- ✓ **Wall loads:**

$$Q_p=K\times S\times \Delta T (1)$$

Q_p : amount of heat lost through the walls (W).
S: total wall surface area (m²),
ΔT : temperature difference between the outside and inside of the room (K),
K : thermal transmission coefficient of the walls (W/m².K).
This coefficient is defined by the following formula:

$$K=\frac{1}{\frac{1}{h_i}+\sum_n^1 \frac{e_n}{\lambda_n}+\frac{1}{h_e}} (2)$$

$1/h_i$: Internal surface thermal resistance, in (m² K/W) .
$1/h_e$: External surface thermal resistance, in (m² K/W) .
$\sum_n^1 \frac{e_n}{\lambda_n}$: Sum of the thermal resistances of the different layers of material making up the wall (m²°C/W).

- ✓ **Solar radiation loads through walls**:

$$Q_{SRm}=\alpha\times F\times S\times R_m (3)$$

- ✓ **Loads due to air renewal and infiltration**
  Sensible gains due to air renewal:

$$Q_{Sr}=q_V(\theta_e-\theta_i)*0,33 (4)$$

- ✓ **Latent gains through air renewal:**

$$Q_{Lr}=q_V(\omega_e-\omega_i)*0,84 (5)$$

q_V = outdoor air renewal flow rate [m²/h]
θ_e = basic external temperature
θ_i = basic indoor temperature
ω_e = water content of outdoor airg/kg_{airsec}
ω_i = indoor air water content g/kg_{airsec}
$\omega_e$etω_i values are determined using the psychrometric chart based on the air conditions outside and inside the room.

- ✓ **Occupant loads**

$$Q_{oc}=n*(C_{Soc}+C_{Loc}) (6)$$

n = number of occupants;
C_{Soc}= sensible heat of occupants (W);
C_{Loc}= latent heat of occupants (W)

The cooling capacity of the system is calculated using the following equation :

$$Q_T=Q_p+Q_{SRm}+Q_{Sr}+Q_{Lr}+Q_L+Q_{OC}+Q_{OR} \quad (7)$$

Q_T : Amount of heat to be removed (W)
- Q_L : Amount of heat emitted by the lamp (W)
- Q_{OC} : Amount of heat emitted by the occupant (W)
- Q_{OR} : Amount of heat emitted by the computer (W)

We used the guide "Energy efficiency of air conditioning in buildings in tropical regions" published by the Institut de l'énergie et de l'environnement de la Francophonie (IEPF) for certain formulas and to determine other parameters.

Sizing the power supply system:-
The sizing of a photovoltaic system begins with an assessment of solar energy requirements.

- **Electrical energy requirements**

This requirement can be determined using the following formula:

$$E_c = \sum_{i=1}^{n} P_i * t_i \quad (8)$$

- E_c : Electrical energy consumed (Wh)
- P_i : Power of equipment i (W)
- t_i: Operating time of equipment i (seconds)
- n: Number of pieces of equipment in the building

- **Choice of panels:-**
  - ✓ **Peak power**

The peak power of the installation to be used is given by the following expression:

$$P_c = \frac{E_b}{I_r \times k} \quad (9)$$

- P_c : Peak power of the field in Wc;
- k : Cumulative coefficient of losses due to voltage and conversion , k= 0.65;
- I_r : Solar radiation received on 1 m^2in Wh/m²/day,I_r =5 kWh/m^2/dayin southern Benin.
-

✓ **Number of panels to be installed**
The number of panelsN_p is given by the following formula:

$$N_p = \frac{P_c}{P_{cu}} \quad (10)$$

P_{cu} : Peak power of a panel in (Wp)

✓ **Number of panels in series**
The number ofN_{ps} panels to be connected in series is given by the formula:

$$N_{ps} = \frac{\text{systemvoltage}}{\text{Ratedpanelvoltage}} \quad (11)$$

The voltage of the photovoltaic system is chosen according to the power of the PV field.

✓ **Number of strings**
The number of panels to be connected in parallelN_{pp} is given by the following formula:

$$N_{pp} = \frac{\text{number of panels}}{\text{Number of panels in series}} \quad (12)$$

- **Choice of batteries**

The capacity of the battery bankC_b is calculated using the formula below:

$$C_b = \frac{E_c \times N_j}{U_s \times DOD \times \eta_b} \quad (13)$$

- E_c : energy requirement consumed in kWh;
- N_j : desired number of days of autonomy in days;
- U_s : system voltage in V;
- DOD : deep discharge rate of the battery.
- η_b : battery efficiency. Either 0.7 or 0.9 is used as the efficiency, depending on the battery used.

- **Choice of charge controller**

The sizing carried out here concerns a PWM (Pulse Width Modulation) regulator due to its low cost. To size a charge regulator, it is essential to know two main parameters: the system voltage and the total short-circuit current of the PV solar field.

$$I_{cct}=1,25\times I_{cc}\times N_{pp} \quad (14)$$

- I_{cct} : total short-circuit current of the PV solar field;
- I_{cc} : short-circuit current of a PV solar module;
- N_{pp} : number of panels in parallel
-

Choosing an inverter:-
The power of the inverter is given by the following formula:

$$P_o=\frac{k\times P_t}{\eta_o} \quad (15)$$

- P_o : Power of the inverter in (W);
- P_t : Total load power in (W);
- η_o : Inverter efficiency;
- k : Reserve coefficient.
-

- **System wiring diagram**

Figure 1: Photovoltaic system wiring

Results and Discussion:-

Modelling and numerical simulation of the mobile solar air cooler with a clay cool water reservoir were carried out using SolidWorks in order to analyse the thermo-fluidic behaviour of the device. The results obtained mainly concern the distribution of air temperature and current lines within the system. Table 4 presents the results of the dimensioning.

Table 4: Design results

Parameters	Data
Thermal transmission coefficient of the walls (W/m².K)	0.922
Loads (in W) per	
Walls	285.020
Solar radiation through walls	158,930
Air renewal and infiltration	59,076
Occupants	10
Lighting	16
Machinery and equipment	250
Refrigeration capacity	869,026
Energy requirement (Wh)	6,952
Peak power (Wc)	1854
Number of panels	4 panels of 500 Wp
Battery bank capacity (Ah)	181
Number of batteries	4 x 12 V – 200 Ah batteries in series
Short-circuit current (A)	52
Converter power	1500 W

Based on the estimated cooling capacity, the system's energy requirement is estimated at approximately 7 kWh/day. With a 2 kVA / 1.6 kW – 48 V inverter, the photovoltaic field has been sized at 2 kWp, taking into account the sunlight conditions in Benin and system losses. Energy storage is provided by a 48 V – 200 Ah battery bank, guaranteeing one day's autonomy.

3D models of the building and the cooling device:-
Figures 2 and 3 show 3D models of the building and the designed device.

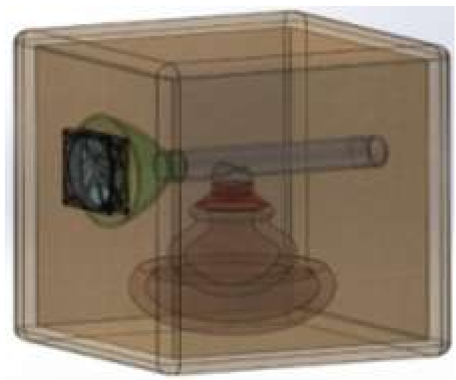

Figure 2: 3D model of the building

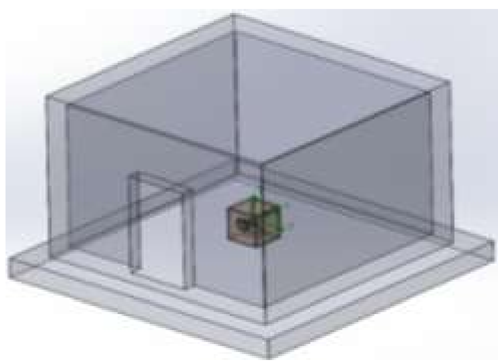

Figure 3: 3D model of the device: front view

Simulation results:-
The result obtained from the simulation of the device is shown in Figures4, 5 and 6.

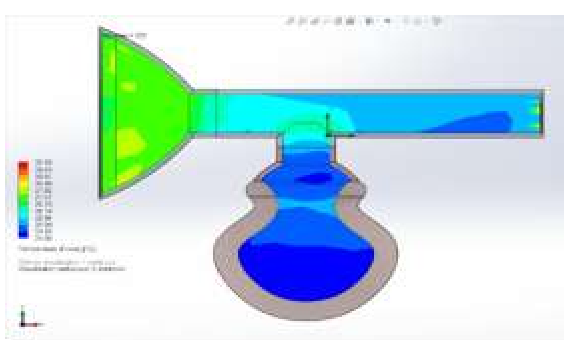

Figure 4: Thermal simulation of the device

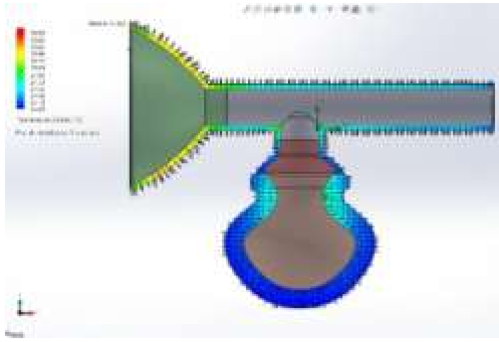

Figure 5: Contour simulation of the device

The results show that the temperature inside the clay canary is mainly between 24 and 25 °C, particularly in the lower and central areas of the tank. This high prevalence of low temperatures, shown in dark blue, indicates effective and stable cooling of the air in contact with the tank.On the other hand, the upper part of the canary and the transition zone to the T-shaped duct have slightly higher temperatures, reaching 28 to 29 °C. Similarly, the air circulating in the horizontal duct initially maintains a higher temperature, close to 29 °C, corresponding to the air entering the device.This thermal distribution reveals the existence of a significant temperature gradient between the air duct and the clay reservoir, reflecting a gradual heat transfer from the warm air to the cooling wall of the canary. Similar results were reported by Wang et al(2017), who showed that air circulating near water-saturated porous clay tubes undergoes a significant decrease in temperature due to heat transfer and evaporation through the porous walls.

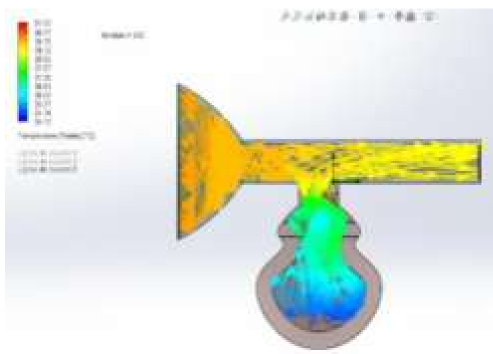

Figure 6: Thermal simulation of current lines at the device's

The simulation results show that the device is capable of producing cooled air at a temperature of around 24°C, which is particularly interesting for areas with a hot climate. The temperature difference observed between the incoming air and the cooled air highlights the real potential ofthe system for passive cooling of buildings.However, the persistence of higher temperature zones in the T-shaped section suggests that cooling is limited by the air-clay contact time, an aspect also highlighted in the literature as a key parameter influencing the thermal performance of passive coolers (J.S. Reed, 1995). These results indicate that geometric optimisation of the device could lead to further performance improvements.

Experimentation :-

Prototype of the device:-

Figure 7 shows a physical prototype of the system which would be subjected to experiments.

Figure 7: Physical prototype of the device

Testing under real conditions:-

After the air cooler was built, a commissioning and testing phase was carried out. It was observed that the device gradually lowered the temperature of the room shortly after being switched on. The temperature dropped from 29 °C to around 25 °C. However, the desired temperature of 24 °C could not be reached. The temperature stagnated at 25°C.Figure 8 below shows the prototype under experimental conditons.

Figure 8 : Test under real conditions on the device

To ensure the reliability of the values, we took several measurements. Table 5 below shows the estimated uncertainties associated with the various measurements taken

Table 5: Estimation of uncertainties

Measurements	Temperature (°C)	Relative humidity (%)
1	25.42	55
2	25.50	54
3	25.41	56
4	25.12	55
5	25.32	59
6	24.94	53

7	25.09	58
8	24.92	54
9	24.98	54
10	25.30	55
Average	25.2	55.3
Standard deviation	0.216	1.888
Measurement uncertainty	0.072	0.629
Standard uncertainty	0.123	0.629

We note that temperature (T) and humidity (HR) can be expressed as$T=25.2\pm0.123$ °C and$HR=55.3\pm0.629$ %, respectively. The relative uncertainties for temperature and relative humidity are 0.48% and 1.14% , respectively. This complies with ISO/IEC 17025: 2017, which specifies a value of less than 5%.

Evaluation of the cost of the control module:-

The Table 6 below summarises these cost estimates.

Table 6: Estimated cost of producing the module.

Description	Quantity	Total cost (FCFA)
Box	1	20,000
Canaries	2	500
Fan	1	5,000
Mist sprayer	1	12,000
Photovoltaic panel	4	25,000
Battery	4	15,000
Labour	-	20,000
Other	-	3,200
Total		221,500

The cost of construction is estimated based on the cost of components, materials and labour.The prices shown in Table 6 are based on local market rates. It is important to note that these rates may be subject to fluctuations depending on the supplier or subject to VAT.The total estimated cost of producing the control module is 221,500 CFA francs. The results of our experiments indicate that the device shows promise in terms of efficiency and quality. However, further investigation is needed to explore other avenues such as automatic cooling control and geometric optimisation of the T-shaped part of the device. Studies to determine water flow and consumption must also be carried out to complete this work.

Conclusion:-

This study has experimentallyvalidated a mobile solar air cooler that provides a mobile economical and environmentally friendly cooling solution suitable for areas with high temperatures and low access to electricity. The choice of local materials such as clay, combined with a low-voltage ventilation system and a misting device, has made it possible to achieve satisfactory thermal performance, with an air outlet temperature of around 24°C in ambient conditions of 30 to 35°C. The results obtained indicate that the device used is promising in terms of efficiency and quality. Furthermore, the study will need to be continued in order to propose an optimal model for the geometry ofthe device, especially with regard to the T-shaped section.

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Declaration of competing interests :-

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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