Development of a mobile solar air coolerwith a clay-based cool water reservoir

Abstract - This study presents the design, simulation in SolidWorks and experimental validation of a mobile solar air cooler using clay as the base material. Faced with the challenges of climate change and limited access to conventional air conditioning in developing countries, this system offers an energy-autonomous and economically viable alternative. The methodology includes a literature review, multi-physics thermal modelling coupling heat transfer in porous media and fluid dynamics, the optimal choice of components (clay, 145.39 Wp photovoltaic panel, 50 Ah battery, fan) and the experimental characterisation of the prototype. Simulations were used to optimise the geometry and predict thermal distributions. The experimental results show a temperature reduction of 5°C (indoor temperature of 25°C for 30°C outdoors) with a relative humidity of 55%, an autonomy of two (02) days and a daily consumption of 537.6 Wh.

Keywords: *Evaporative cooling; Clay; Simulation; Thermal comfort*.

1. Introduction

The steady rise in global temperatures, exacerbated by climate change, has increased demand for air conditioning systems, particularly in tropical and subtropical regions (T.F. Ishugah et al, 2024). This growing demand poses major challenges, especially in developing countries where access to electricity remains limited and energy costs represent a significant economic constraint. In sub-Saharan Africa, where temperatures can exceed 40°C for long periods, conventional cooling solutions remain largely inaccessible to a large part of the population (R. Lufu et al, 2025). In response to these challenges, evaporative cooling technologies using local materials and renewable energy are emerging as 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 (T.S. Workneh, 2010). Recent research has demonstrated the effectiveness of these technologies in various applications, ranging from food preservation to building air conditioning (L. Xu et al, 2022). 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 (D.P. 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 (G.A. Mustafa et al, 2025). The integration of solar energy into evaporative cooling systems represents an innovative approach that combines environmental sustainability and energy efficiency. Research conducted by S. Singhal (2021) has demonstrated the technical feasibility of solar-powered evaporative cooling systems, paving the way for autonomous solutions suitable for regions with high levels of sunshine (S. Singhal, 2021). This approach is particularly relevant for Africa, where solar radiation is abundant throughout the year. Experiments conducted in different African regions have confirmed the potential of cooling technologies using local materials. Studies conducted in the Sahel have highlighted the promising performance of photovoltaic systems coupled with evaporative cooling using local plant materials (E.M.S. El-Said et al, 2024). However, a critical analysis of the literature reveals certain gaps in existing research. Although many studies have explored the use of clay in static cooling applications, few have focused on the development of mobile systems incorporating a fresh water reservoir. Yet this mobility is a considerable advantage for small-scale residential and commercial applications, allowing flexible adaptation to specific user needs. Furthermore, most existing studies focus on specific applications such as food preservation (pot-in-pot systems) or photovoltaic panel cooling, without fully exploring the potential of clay systems for air conditioning living spaces. Recent work by S.O. Oyedepo et al(2021) on the experimental analysis of evaporative cooling of water in porous clay containers provides a solid foundation, but needs to be extended to air conditioning applications (S.O. Oyedepo et al, 2021).This study aims to fill these gaps by proposing the design and construction of a mobile solar air cooler with a clay-based cool water reservoir, specifically adapted to the climatic conditions and socio-economic constraints of developing countries such as Benin. The 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.

2. 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.

2.1. Presentation of the study area

Located in the centre of Benin, the commune of Abomey is the capital of the department of Zou. It has seven (07) districts, including the district of Djegbe. Within the latter, there are several villages/city districts, notably the Sogbo-Aliho district, where the Abomey University Centre (the subject of our study) of the National University of Science, Technology, Engineering and Mathematics (UNSTIM) is located, not far from the Sogbo-Aliho crossroads opposite the Sino-Beninese secondary school.

Figure 1: Map showing the location of the municipality of Abomey

2.2. *Equipment/materials used*

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

Table 2: List of equipment/materials

Equipment/Materials	Technical specifications
Clay canaries	○ Apparent density: 1800-2200 kg/m³ ○ Porosity: 25-45% (microporous structure) ○ Water permeability: 1×10^{-12} to 1×10^{-10} m² ○ 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 ○ Maximum air pressure: 1 mmH2O ○ 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, 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 features 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.

2.3. Heat balance in the cooking stove

To achieve our objectives, we followed a methodical approach based on modelling the cooling system in SolidWorks with a case study to experimentally validate the results.

2.3.1. 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.

2.3.2. 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: ρ = 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
- Amount of heat emitted by the occupant (sensible gains): 67W

2.4. Sizing

2.4.1. Amount of heat to be removed

The amount of heat that the cooling system must overcome can be estimated using the formula:

$$Q_T = Q_L + Q_{OC} + Q_{OR} \quad (1)$$

- 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)

2.4.2. Volume of the room to be cooled

The volume of the room to be cooled is calculated using the following formula:

$$V_{ch} = L * l * H \quad (2)$$

- L : Length of the room in metres (m)
- l :Width of the room in metres (m)
- H : Height of the room in metres (m)

2.4.3. *Mass flow rate of evaporated water*

The formula opposite allows us to find the mass flow rate:

$$q_m = \rho_e * q_v \quad (3)$$

- q_m: Mass flow rate of evaporated water (kg·s^{-1})
- q_v : Volumetric flow rate of water (m^3 ·s^{-1})
- ρ_e : Density of water (kg.m^{-3})

2.4.4. *Cooling capacity*

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

$$P_f = q_m * L_v + q_{ma} * C_P * \Delta T \quad (4)$$

- P_f : Cooling capacity (W)
- q_m : mass flow rate of evaporated water (kg·s^{-1})
- L_v : latent heat of vaporisation of water (kJ·kg^{-1})
- q_{ma} : air mass flow rate (kg·s^{-1})

- C_P : specific heat of air (kJ/kg.K)
- ΔT : Temperature difference (K)

2.4.5. *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:

$$E_c = \sum_{i=1}^{n} P_i * t_i \quad (5)$$

- 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:

$$P_c = \frac{E_b}{I_r \times k} \quad (6)$$

- 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 $1\ m^2$ in Wh/m²/day, $I_r = 5$ Wh$/m^2$/jour in southern Benin.

  - ✓ ***Number of panels to be installed***

The number of panels N_p is given by the following formula:

$$N_p = \frac{P_c}{P_{cu}} \quad (7)$$

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

  - ✓ ***Number of panels in series***

The number of N_{ps} panels to be connected in series is given by the formula:

$$N_{ps} = \frac{system\,\text{voltage}}{Rated\ panel\ voltage} \quad (8)$$

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 parallel N_{pp} is given by the following formula:

$$N_{pp} = \frac{\text{numberofpanels}}{\text{Numberofpanelsinseries}} \quad (9)$$

- ***Choice of batteries***

The capacity of the battery bank C_b is calculated using the formula below:

$$C_b = \frac{E_c \times N_j}{U_s \times DOD \times \eta_b} \quad (10)$$

- 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.

$$I_{cct} = 1{,}25 \times I_{cc} \times N_{pp} \quad (11)$$

- 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:

$$P_o = \frac{k \times P_t}{\eta_o} \quad (12)$$

- 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 2: Photovoltaic system wiring

3. 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.

3.1. Study area conditions

Figures 1 and 2 show the evolution of temperature and relative humidity over time, respectively.

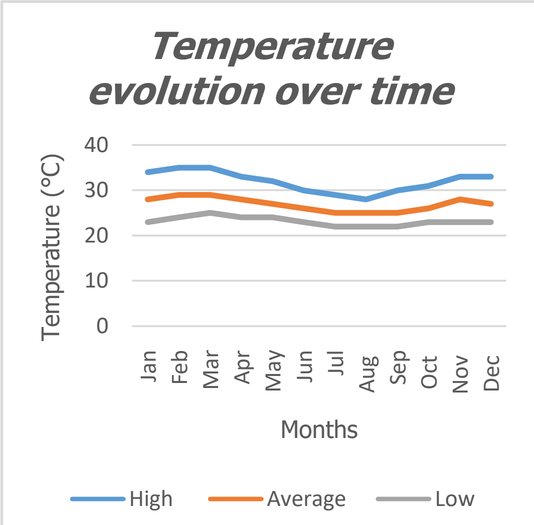

Figure 3: Temperature change over time.

The shape of the temperature curves shows the following trends:

- The high temperature varies between 28°C and 35°C, with a peak around February and March.
- The average temperature varies between 25°C and 29°C, with a relative low in July and August.
- The low temperature is fairly stable at around 22°C to 25°C throughout the year.

We note that the cooler must be able to effectively manage temperatures around 30 to 35°C during the dry season while remaining efficient and stable for lower and average temperatures throughout the year.

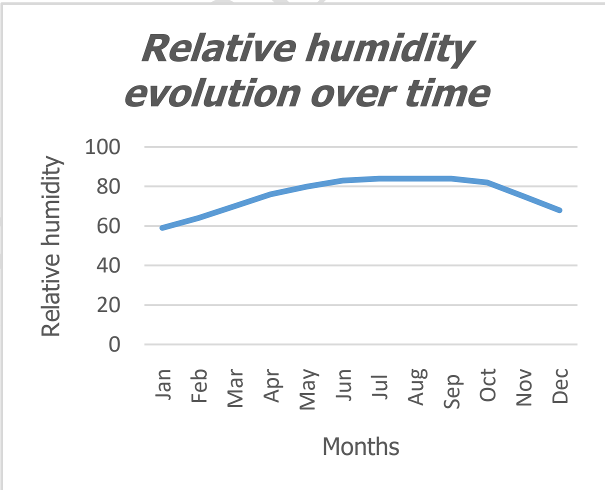

Figure 4: Change in relative humidity over time

From the figure 4, it can be noticed that:

- Relative humidity is 60% at the beginning of the year (November–February: dry season). This creates favourable conditions for evaporation.
- Relative humidity increases to ~82–85% in the middle of the year (June–August: peak of the wet season). This creates conditions that are not conducive to direct evaporation.
- Relative humidity then decreases (September–October: return to the dry season).

The performance of the device must therefore be highly seasonal: effective in the dry season and limited in the rainy season.

3.2. *3D models of the building and the cooling device*

Figures 5, 6 and 7 show 3D models of the building and the designed device.

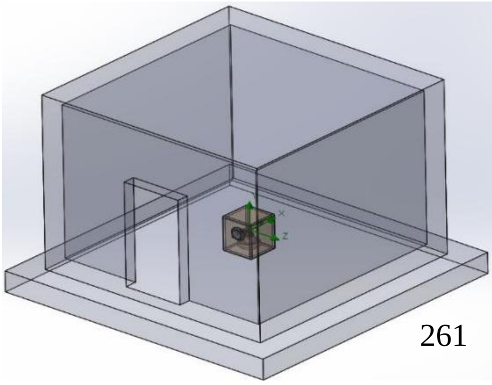

Figure 5: 3D model of the building

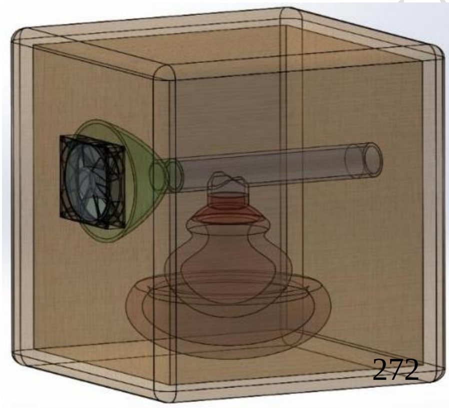

Figure 6: 3D model of the device: front view

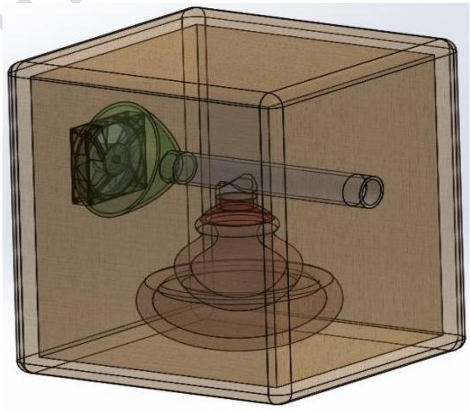

Figure 7: 3D model of the device: rear view

3.3. *Simulation results*

In Figure 8 shows the result obtained from the simulation of the device.

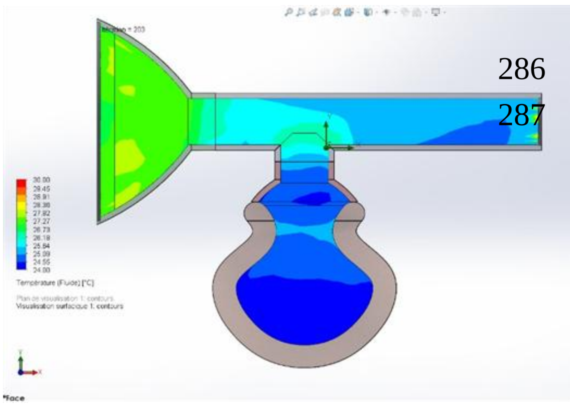

Figure 8: Thermal simulation of the device

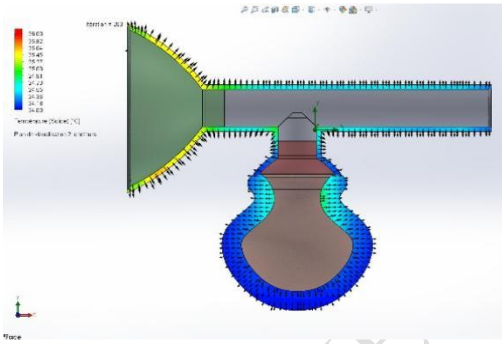

Figure 9: Contour simulation of the device

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 F. 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.

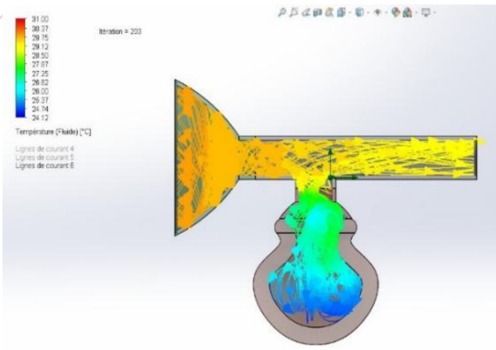

Figure 10: Thermal simulation of current lines at the device's

Analysis of the streamlines reveals a steady flow of air from the inlet duct to the reservoir. Warm air from the room first enters the T-shaped section and is then gradually cooled as it passes into contact with the internal walls of the canary.

The thermal stratification observed, with colder air concentrated in the lower part of the tank, can be explained by the higher density of the cooled air and the low level of turbulence inside the canary. This behaviour is characteristic of a passive thermal tank, promoting cooling stability over time. This is precisely what Figure 11 shows when the device is simulated inside a building.

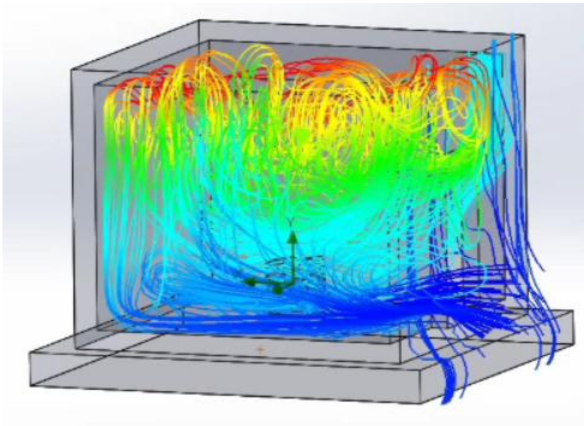

Figure 11: Thermal simulation of current lines at building level

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 of the 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.

3.4. Experimentation

3.4.1. Prototype of the device

A physical prototype of the system was built, as shown in Figure 12, and was subjected to experiments.

Figure 12: Physical prototype of the device

3.4.2. *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. This seems to be mainly related to the geometry of the T-shaped part of the device.

Figure 13: Test under real conditions on the device

3.5. Influence of thickness

TheTable 2 below summarises these cost estimates.

Table 2: 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	1	25,000
Battery		12,000
Labour	1	20,000
	-	
Other	-	3,200
Total		98,500

The cost of construction is estimated based on the cost of components, materials and labour.The prices shown in Table 2 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 98,000 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 .

4. Conclusion

This article proposed a mobile, economical and environmentally friendly cooling solution suitable for areas withhigh temperatures and low access to electricity. The cooler developed is based on the principle of direct adiabatic evaporation, where water absorbed into the clay wall evaporates on contact with hot air, causing a significant drop in temperature (30 to 24 °C). 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 airflow temperature close to 24°C in ambient conditions of 30 to 35°C, as confirmed by numerical simulations.

Overall, the device effectively meets expectations; however, future improvements could make it even more efficient. Indeed, the geometric optimisation of the T-shaped part of the device and the addition of a regulation system to better control ambient conditions are all prospects that will make the device more efficient and attractive.

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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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