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New Theoretical And Experimental Approach On The Establishment Of Thermal Comfort In A Monozone Building Using Hybrid Solar Panels

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Abstract – This article presents a new approach to improve thermal comfort in a single-zone building using an air conditioner based on Peltier effect modules and a hybrid solar panel (photovoltaic and thermal). The thermal comfort is a key factor to ensure the well-being of the occupants of a building, and the use of innovative technologies is essential to achieve this objective. The theoretical approach proposes the use of heat transfer models and fluid dynamics to evaluate the thermal behavior of a monozone building equipped with an air conditioner based on Peltier effect modules. The thermodynamic equations are used to describe the heat exchange inside the building, as well as the operation and performance of the Peltier effect modules. In parallel, an experimental approach is implemented to validate the theoretical results. Precise measurements of temperature and humidity are carried out in different areas of the building in order to evaluate the effectiveness of the Peltier effect air conditioner to establish optimal thermal comfort conditions. The results obtained from this theoretical and experimental approach are analyzed and compared to evaluate the effectiveness of the Peltier effect module air conditioner in establishing thermal comfort. Parameters such as cooling capacity, energy consumption and temperature uniformity are taken into account to evaluate the performance of the system. The use of an air conditioner based on Peltier effect modules offers several potential advantages, such as reduced energy consumption, compact size and precise temperature regulation. This new approach allows exploring the possibilities offered by this technology to improve thermal comfort in monozone buildings. The conclusions of this study provide valuable information for building designers and air conditioning engineers to optimize the use of Peltier effect modules in order to establish optimal thermal comfort conditions in monozone buildings.

Keywords – Thermal Comfort, Peltier Effect, Heat Transfer, Energy Efficiency, Hybrid Solar Panels.

I. Introduction

Au fil des décennies, depuis les temps primitifs jusqu'à nos jours, l'instinct de survie inné pousse les êtres humaans à recherche et à amelioré leurs conditions de vie. Having a refuge has always been the first sign of security against various dangers such as ferocious animals, enemy invaders or bad weather. Cependant, avec l'évolution du temps, il est devenu evident que se mettre à l'abri ne suffit pas à assurer le bienêtre. En effet, even though the hoped-for refuge offers protection against the external elements, it does not protect against temperature variations, be it glacial cold or intense heat.

These days, comfort has become one of the main topics discussed during the qualification and normalization of a habitat.

Several methods are used in parallel to maintain the ambient temperature, generally around **20 to 25°C** , during the summer and winter periods corresponding respectively to an increase and a decrease in temperature. Among these methods, the use of

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polyurethane-based coatings or foams, as well as electric heating and cooling systems, are the most commonly used. However, maintaining the thermal comfort in a habitat in this way requires an important amount of additional energy and financial investment.

To remedy these problems, researchers have conducted different studies focused on the use of solar energy. Two categories of air conditioning technologies have thus emerged: passive air conditioning and active air conditioning. The so-called passive technology implies the orientation of the buildings towards the sun, the selection of specific construction materials with a high thermal capacity, as well as the direct use of solar light without resorting to an external sensor. En revanche, the active technology converts solar energy directly into electrical energy, which is then used to produce thermal energy.

We present an innovative approach for the management of the air conditioning of a single-zone dwelling thanks to the use of a mixed active system that takes advantage of a thermal sensor and exploits the phenomena of the thermocouple. This approach allows to effectively maintain the temperature and to manage the variations more quickly

1. Statement of the proposal

Let's take the case of a building located in Tananarive, Madagascar, to examine its thermal behavior. Tananarive is located in a region of tropical climate with moderate temperatures. Temperatures can vary throughout the year, with average daytime temperatures ranging from **20°C** to **27°C** and nighttime temperatures ranging from **10°C** to **16°C** **[1-2]** .

However, the buildings built in Madagascar do not take these thermal and climatic aspects into account. The majority is constructed in a banal way. We can examine some general aspects. The houses are often built with brick and clay walls covered with cement inside and outside.

Here is a comparative table of thermal conductivity of commonly used construction materials **[2].**

Table 1 : Thermal conductivity

Material	Thermal conductivity W/(m·K)
Clay bricks	0.6 - 1.2
Cement bricks	0.7 - 1.5
Concrete	1.0 – 2.5
Cement	0.8 - 1.2
Mortar	0.5 - 1.5
Sable	0.25 - 0.35

Taking these values into account, it is possible to estimate the thermal conductivity of the walls using thermal calculations. Let's take the case of a 22cm wall relative to 1cm of cement thickness for each side of the wall and 20cm of brick. The thermal conductivity of clay brick (k_{brick}) is generally between **0.6** and **1, 2** W/(m·K), and cement cell (k_{cement}) is about **0.8** to **1.2** W/(m·K). The surface resistance of the wall is equal to **0.17 K·m²/W [3]** .

Let's calculate the thermal resistance (R) for each material:

The formula for calculating the thermal resistance is given by par

$$R_{Thermal} = \frac{\text{épaisseur\_brique}}{k(\text{brique})} \quad (1)$$

So

- $R_{brick} = \frac{\text{épaisseur\_brique}}{k(\text{brique})} = \frac{0{,}10m}{(0{,}8W/(m\cdot K))} = 0.125$ K·m²/W

- $R_{cement} = \frac{\text{épaisseur\_brique}}{k(\text{ciment})} = \frac{0{,}01m}{(1.5W/(m\cdot K))} \approx 0.007$ K·m²/W

- $R_{sup} = 0.17$ K·m²/W

Let's now move on to the calculation of the total thermal resistance (R_{total}), which corresponds to la

Sum of the individual thermal resistances:

$R_{total} = R_{ciment} + R_{brique} + R_{brique} + R_{ciment}$

$+R_{sup}$

$R_{total} = 0.434$ K·m²/W

Finally, the thermal conductivity of the wall is given by the following relation:

$k_{total} = \frac{\text{épaisseur\_totale}}{R_{total}} = = \frac{0{,}22}{0{,}434} 0.506$ W/(m·K) (2)

The calculations made clearly reveal that the thermal resistance of buildings built in Madagascar is significantly lower than the recommended norm of 1 K•m²/W, both in Africa and in the Mediterranean area **[4]** . This disparity underlines the urgency of adopting a new active air conditioning system, capable of dealing with temperature variations, whether they are high or low.

The figure below shows the Ensemble system proposed

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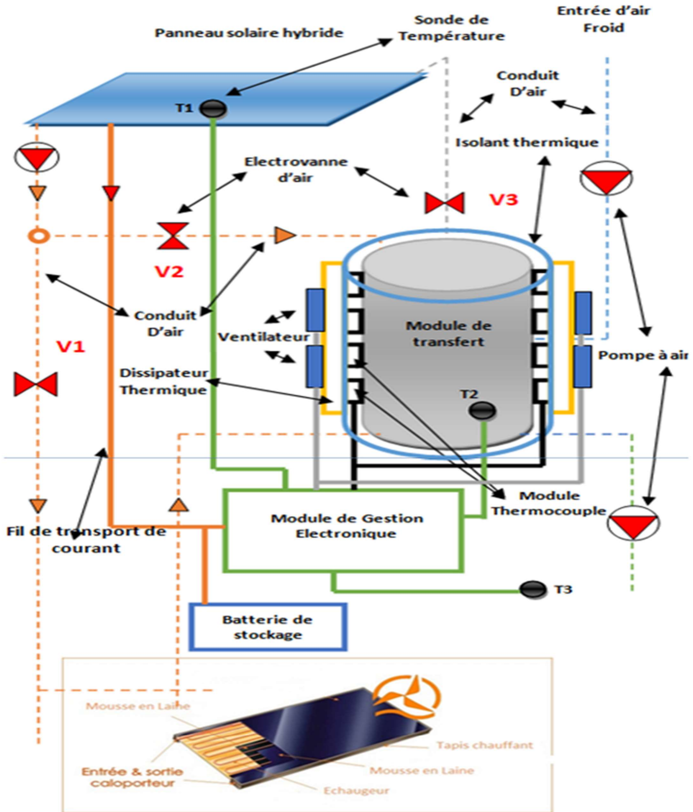

Figure 1: Diagram of the proposed air conditioning system

The system comprises several elements:

- Hybrid solar panel
- Transfer module or air balloon
- 8 thermocouple modules
- An electronic management module
- Three temperature probes
- 3 air valves
- Two electric air pumps

2. **Theoretical study of sensors**

The solar collector used in the system is a 100Wc full-black monocrystalline solar panel that works in a hybrid manner. Full Black monocrystalline solar panels can achieve an absorption coefficient of more than 95% over a wide range of wavelengths. This system has been adapted to include an insulated air chamber underneath, allowing electricity to be produced and the air trapped under the panel to be heated. A pump is used to ensure efficient air circulation under the panel.[5]

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Table 2 : Percentage of absorption according to light

Rayon type	Wave length	Absorption percentage
Blue light	450 nm	98%
Green light	550 nm	97%
Red light	650 nm	96%
Infrared light	800 nm	95%

What interests us here is the heating time of the stationary air in the chamber below the sensor.

At constant pressure, the heat capacity of air is 1006 J/kg·K [6]. The volume of air in the room is 0.016575 m^3. Our objective is to increase the temperature of the air in the room from 20°C to 40°C before sending it to the upper floor of the air conditioning system.

The mass of air can be calculated using the density of air, which is approximately 1.2 kg/m^3 at ambient temperature (20°C) [7].

Mass = Volume × Density (3)

Mass = 0.016575 m^3 × 1.2 kg/m^3

Mass ≈ 0.02 kg

The energy required in J to raise a mass of air of 0.02 kg at a temperature of 40°C is given by the following relation:

$$E = m.c.\Delta T (4)$$

$$E = 0{,}02 \,.\, 1006.\ 20 \approx 402{,}4\, J$$

A Monocrystalline Full black solar panel is capable of absorbing 98% of the sun's radiation [8],

Let's now see the thermal power that a 100Wc full black solar panel can absorb

To adapt the calculation to the specific conditions of the capital of Madagascar, Antananarivo, we must use more precise sunshine data for this region [9]. In Antananarivo, the average sunshine is generally around 5.5 to 6 hours of full sun per day, with an average intensity of solar radiation of approximately 200 to 250 W/m^2.

Take the minimum interval of 200 W/m^2

The thermal power available on the hybrid solar collector of 100Wc is defined by :

$$P_{th} = I . S_p (5)$$

P_{th}: Represents thermal power

I : Solar irradiation

S_p : Surface of the solar panel or the flat sensor

The thermal power absorbed by the 100Wc full black solar panel is then:

$$P_{th} = 200\ \mathrm{W/m^2}\ .\ 0{,}5\ m^2 = 100W$$

Knowing the thermal power available at a given instant, the time required for the sensor to heat the air of 0.016575 m³ is given by the following relation:

$$t = \frac{E}{P} (6)$$

By substituting the two values we have:

$$t = 4.024\ s$$

According to this value, following an exposure of about 4s, the air under the solar panel reaches a temperature of 40°C. A forced circulation pump will move the air in two distinct places according to the conditions of the demand for comfort

Sot

Directly in the house through a heat exchange mat

Sot

In the temperature stabilizer balloon (cf figure 1)

II Approach to optimized management of the temperature in the house

The temperature stabilizer balloon allows air to be stored playing the role of thermal capacity otherwise it homogenizes the temperature of the air before sending it to the thermal exchanger in the house. It consists of an aluminum thermos covered with wool allowing a quasi-adiabatic function. A part 8 thermocouple modules are placed by 4 on two sides of the balloon (cf Figure 1)

Our bus is to stabilize the temperature in the building in the thermal comfort zone, i.e. around 25°

3.1 Temperature optimization approach

Note $\theta_c$the thermal comfort temperature. Definitions of the thermal comfort zone $20°C \leq \theta_c \leq 27°C$and $T_b$the temperature inside the monozone building.

T_{air}: being the temperature of the air in the balloon

- We adopt the new approach to manage the negative temperature.

If $T_b \leq 20°C$, the air in the Stabilizer balloon is rapidly passed through the thermal sensor by a forced circulation pump and kept in a closed circuit until the temperature T_{air}reaches 40°C, then released in the thermal exchanger in the building

We have 6 variables to manage: $T_{air}, T_b, \theta_c, V_1,\ V_2,\ V_3$, P 1

Where $V_1,\ V_2,\ V_3$, represents the solenoid valve that plays the role of blocking and unblocking the air circulation in the ducts (Cf la figure 1)

The objective is to keep the temperature $T_b$in

The comfort interval is defined by:

$$\theta_{Cmin} \leq T_b \leq \theta_{Cmax}$$

In other words:$T_b \geq 20°C$

Below is the Algorithm of operation:

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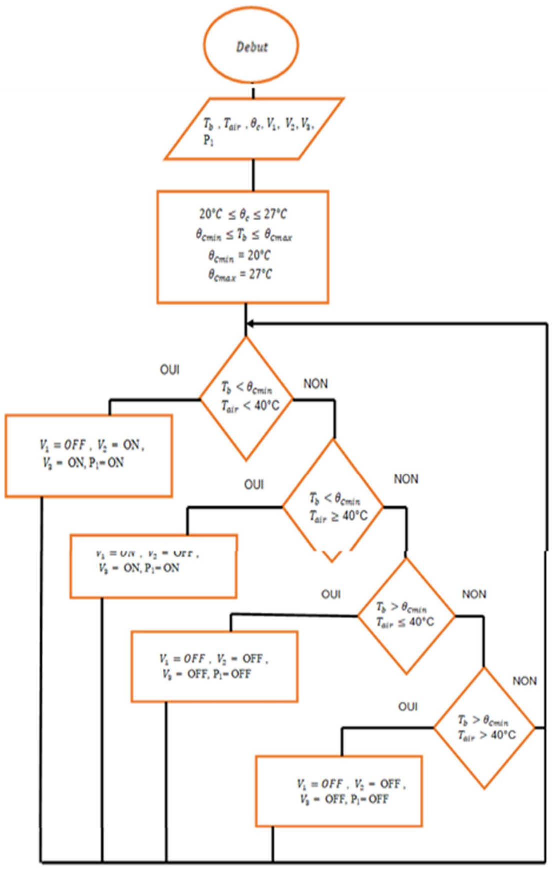

Figure 2: Low Temperature Management Algorithm

The new algorithm approach below allows to manage the negative temperature variation in a monozone building.

During the day the electricity generated by the solar panel is stored in a battery. L'Electricité Stocké will primarily serve as a power supply for all the electrical and electronic parts of the system.

The electronic part permanently measures the variable temperatures T_{air}, T_b and makes decisions based on the measured values then sends the activation or deactivation commands to the forced circulation pump and the opening and closing of the three electrovalves.

- Heat exchanger side

Even if the algorithm is effective for managing the low temperature in the building, part of the installation of the comfort temperature depends mainly on the heat exchanger.

The principle of operation rests on the transfer of heat between the warm air that circulates in the pipes of the serpentine and the ambient air plus cold around the serpentine. En circulant, the hot air gives off part of its thermal energy to the ambient air via the walls of the serpentine, increasing the temperature of the room.

Let's take the case of a single-zone building of 2 m^3 , we define the minimum temperature inside T_{in} to be 5°C. A copper pipe heat exchanger in the form of a serpentine is placed under a carpet in the building so that the heat from the hot air in the balloon can be transferred to the cold ambient air. Let's see the time interval necessary to restore thermal comfort:

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The heat flux emitted by the serpentine is defined by the following relation [10] :

$$Q = U \,.A.\, \Delta T$$

Q: Heat flux

A : Serpentine surface

ΔT: Temperature difference between the air in the coil and the ambient air (in °C or K).

The global thermal transfer coefficient U depends on the materials, but for a standard air-air exchanger, a typical value of around U = 20 W/m².K can be taken [11]

$$Q = 20\,.\,1{,}5\,.\,35\text{K}$$

$$Q \approx 1050\ \text{J s}^{-1}$$

If the temperature of the air that circulates in the serpentine is constantly maintained at 40°C, the serpentine is capable of providing a heat flux of around 1050 J s^{-1} . This value is typically possible considering the thermal inertia of the air in the balloon of 22.71J/°C. Autrement l'air Stocké dans le balloon circulates permanently in the solar collector Hybrid before d'acheminer dans le serpentine.

Before calculating the time needed to bring the temperature T_b down to 22°C, let's define the following relationships:

Knowing the power available from the sensor, we must calculate the air mass in the single-zone building as well as the energy needed to bring it to 22°C:

The density of air is equal to 0.83 kg / m ^{3} at 5°C, in this case, the mass of air in the building is then:

$$m_{air} = \frac{2\ m^3}{0{,}83\ kg/m^3} = 2.41\ \text{kg}$$

Starting from T_{in}= 5°C to 22°C the temperature difference $\Delta\, T = 17$°C

The energy required to heat this mass of air is given by relation (4):

$$E = 2.41.\ 1006.\ 17\text{K}$$

$$E \approx 41\ 234,62\ J$$

In effect, if the heat exchanger is capable of exchanging a heat flux of 1050 Js $^{-1,}$ the time necessary to raise the temperature T_{in} to 22°C is given by the relation

$$t = \frac{E}{Q}$$

$$t = \frac{41\ 234{,}62}{1050} \approx 39{,}27s$$

First observation:

The time needed to heat the air in the building is more or less rapid, this proves that the proposed solar thermal system is practically effective in managing the negative temperature.

To maintain thermal comfort in the building, we need to initiate another additional system to manage bad weather. In other words, an algorithm called ETMS (Energy Thermic Management System) or Thermal Energy Management System.

As our Solar Sensor is Hybrid, it generates both heat and electricity. In the diurnal cycle, the EMS algorithm calculates and then acts as follows: When thermal energy is sufficient to maintain thermal comfort in the building, part of the electrical energy provided by the solar panel is stored in chemical form in a high-performance lithium battery, plus a system called Electro Thermique (ET) composed of several thermocouple modules, 8 TEC 12706, generates electricity from the temperature difference between the thermal stabilizer balloon and the medium environment thanks to the Seebeck effect [12]. The energy from the ET will contribute to the recharge of the batteries as well as the energy needs of the electronic management system. In effect, in difficult conditions or in deficit of thermal energy, the energy stored in the batteries is therefore restored in the ET contributing in turn to heating the air and vice versa in the Balloon thanks to the Peltier effect [13].

Below is the additional system management algorithm

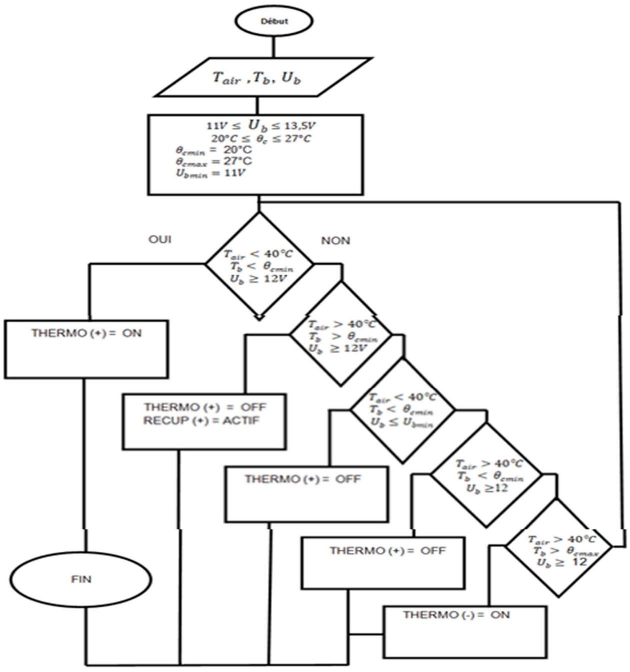

Figure 3: additional system management algorithm

U_b: represents the voltage value at the battery terminal

THERMO (+) : represents the heating function of the Thermocouple module

THERMO (-) : represents the Cold function of the Thermocouple module

When the temperature T_{air} is lower than 40°C in a long time lapse during the diurnal cycle, it effectively shows that the heat collected by the sensor is not sufficient to drive and maintain T_{air} at 40°C, in this case the algorithm restores the electrical energy stored in the battery, the cell that is directly produced from the sensor, as well as that from the recovery of the ET to activate the THERMO function (+), to boost the production of heat so that it T_{air} reaches 40° C.

In the opposite case, that is, the temperature in the building exceeds the maximum comfort temperature limit: $T_b > \theta_{Cmax}$ the first algorithm stops pumping air into the balloon while the second supplementary management algorithm collects the same l'énergie disponible dans le système à l'instant, pour activater la fonction THERMO (-) qui genere du froid pour rapide abaisser la temperature T_{air} jusqu'à trisctement inferior à θ_{Cmax} puis acheminer dans le serpentin ramenant ainsi T_b dans l'interval de confort.

One of the mentioned functions, when the temperature T_b is in the comfort interval and $T_{air} \geq 40$°C, the ET converts a part of the air heat in the balloon into electricity. This new function allows optimal management of thermal energy minimizing losses

III - Conclusion:

In conclusion, this study illustrates in detail the potential of air conditioners based on Peltier effect modules, in addition to a solar sensor, to significantly improve thermal comfort in monozone buildings. The integration of a solar panel adapted to contain the air below, allows the exploitation of solar energy not only to power the electrical system, but also to improve heat exchange. The theoretical analysis, supported by a rigorous experiment, allowed us to confirm the effectiveness of this solution, especially for confined spaces where conventional air conditioning options can be limited.

The results show that Peltier modules offer notable advantages: reduced energy consumption, compact size and precise temperature regulation, while maintaining uniform thermal comfort conditions. In addition, the combined use of renewable energy sources, such as solar energy, allows to strengthen the global efficiency of the system and to encourage a sustainable approach in the management of energy resources of buildings.

This approach proposes a robust and adaptable technical solution to the current needs of designing buildings with low environmental impact. Thus, air conditioning designers and engineers have a solid base to optimize the integration of Peltier modules in air conditioning systems, favoring optimal comfort conditions while respecting energy and ecological constraints. These conclusions open up new perspectives for the use of innovative technologies in thermal management of monozone buildings.

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