Original Research Article

Experimental study and determination of the energy performance of an air conditioning system using the Peltier method

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ABSTRACT

Thermal comfort is one of man's natural needs. In order to ensure this comfort while being respectful towards the environment, we proceeded to an experimental study of an air conditioning system with Peltier modules. For this purpose, we considered a test room with a base temperature of 29 °C in which we installed a Peltier effect air conditioning system to lower its temperature to 25 °C, a useful threshold to ensure thermal comfort in a tropical zone. Through the two different tests carried out, we were able to approach 25 °C by making an improvement to the cooling circuit of the Peltier effect air conditioning system. Thus, we concluded from this study that this alternative air-conditioning system would be more interesting for demanding enclosures with small and medium cold powers for thermal comfort and that further research should allow to improve the system.

Keywords: Thermal comfort; Air conditioning; Peltier module

1. INTRODUCTION

As fossil fuel sources worldwide become increasingly depleted, the shift to alternative energy sources is becoming more and more inevitable. Thus, the international community has set itself the challenge of meeting the world's growing energy demand while promoting new, non-polluting energy sources to limit the emission of greenhouse gases, the main cause of climate change.

Today, almost 20% of the total electricity used in buildings is related to indoor air conditioning. The search for thermal comfort is one of the human needs that involves the production of cold, which is a major energy consumer [1]. The International Energy Agency warns that if no action is taken to increase the energy efficiency of the cooling process, energy consumption will triple by the middle of the 21st century [IEA 2018]. Generally, this production is accompanied by the use of refrigerants that are harmful to the environment. Thermoelectric conversion offers an alternative to cold production without the use of refrigerants. It has already proved its worth, in particular as a means of producing electrical energy for distant space probes (Seebeck effect) [2]. In addition to this aspect of electricity, thermoelectric cooling, commonly referred to as cooling technology using thermoelectric coolers (TECs), has advantages of high reliability, no mechanical moving parts, compact in size and light in weight, and no working fluid. In addition, it possesses advantage that it can be powered by direct current (DC) electric sources, such as photovoltaic (PV) cells, fuel cells and car DC electric sources [3].

Conventional refrigeration systems are based mainly on compression cycles and consume a lot of electrical energy worldwide. In the case of thermal comfort, air-conditioning systems are not only electricity intensive but also contain environmentally hazardous refrigerants. They lead to increased energy consumption and contribute to climate change. The problem that arises is the following: How can air-conditioning be technically and reliably provided to achieve thermal comfort in an environmentally friendly manner?

The present study is a technological innovation, the result of which could serve as a benchmark for future design or improvement. The impacts of this cold production from Peltier modules are ecological and economical.

From an ecological point of view, the use of Peltier modules for cold production makes it possible to considerably reduce the production of greenhouse gases and especially to eliminate the use of refrigerants, which are far from being good friends of the environment.
Economically, our system will reduce energy consumption through its simple DC power supply available with the use of solar modules.

The majority of the works and innovations carried out on the Peltier modules relate to their use for refrigeration. It is the example of Akacha which made the study and the realization of a cooler of drink by the thermoelectric effect. He designed and built a mini refrigerator by TEC with interesting energy performances for the cooling of drinks [4].

In the same way, Amin and Rabah have proceeded to the improvement of the performances of a cooling system with Peltier effect. Through this study, they were able to reveal the potential of the Peltier modules while obtaining results well above other thermoelectric cooling systems from the improvement of the components of the Peltier effect cooling systems [5].

The use of Peltier modules for air conditioning is not widespread, however, the company Melcor has developed a thermoelectric system for air conditioning of electrical cabinets. The cooling of a 2.5 m room simultaneously with hot water production is also reported. This is for small space applications, but for large spaces we note the air conditioning of train carriages in the 1980s. In the 1990s, the air conditioning of high-speed trains was based on Peltier modules. This system can produce 700 to 900 W of cooling power with 48 Peltier modules and a COP of less than 0.4 for an airflow of 150 ~~m^2/h~~ m^3/h. A heat pump based on 24 Peltier modules has also been designed which can provide up to 300 W of cooling power and 2.4 kW of heating power [6]. Yu et al. conducted research on the performance analysis of thermoelectric cooling systems for electric vehicles [7]. Similarly, Vishwanath et *al.* published an article on the Thermoelectric Multi-Utility Water Heater cum [8].

The present study aims to determine the energy performance of an air conditioning system using the Peltier method. It studies an alternative and economical cold production system with Peltier modules.

2. MATERIAL AND METHODS

2.1 Material

The materials used for the realization of the whole system can be divided into four parts according to four well defined functions:

Cold production : To ensure the production of cold, we mainly used Peltier modules, the main component of the system. This is the Peltier module TEC-12706.

Heat dissipation : To get a useful amount of cooling from the Peltier modules, it is imperative to keep the hot side of the modules at the lowest possible temperature and to properly share the cold produced in the room to be cooled[9]. For this reason, cooling blocks and a radiator were connected in series to ensure this heat dissipation. The cooling circuit thus formed is supplied with water in a closed circuit by a tank equipped with a submerged pump. In addition, the heat sinks are used to increase the exchange surface of the cold side of the Peltier modules and the room to be air-conditioned in order to favor the convection of the cold side of the Peltier module with the air of the room to be air-conditioned.

The power supply : The whole system must be supplied with a voltage of 12V and the Peltier modules, which represent the heart of our system, require a current of between 4.3 A and 4.6 A at this voltage in order to be able to operate at full power as we wish. The assembly of the Peltier modules becomes a large current consumer. We therefore need a power source capable of supplying at least a voltage of 3*12 V = 36 V and a current of at least 4.5*4 A =18 A to supply the 12 Peltier modules of our system, which are associated in series with three modules, and the other components of the system (fans, Arduino board, water pump, relay, etc.). In view of all these requirements, we have chosen to use a power supply that takes a voltage of between 110V and 220V as input and provides a power output of 1000W at 12V, 24V, 36V and 48V.

Data acquisition : We used the Arduino Uno programmable electronic board for data acquisition and system regulation. To this board has been connected two different sensors: temperature sensor and water level sensor. The temperature sensors will allow to take data on the output temperature of the cold produced and on the temperature of the heat to be evacuated. The water level sensor is used to take data on the water level in the tank. An SD module is also used to digitally take temperature data during the experiment. The SD module used with the Arduino board is a quick and easy way to store a lot of information. It will allow us to store data on the different temperature and humidity of the system.

Other system components : In addition to these four main materials, we also have other system components such as :

- The study room

The premises allocated to our work is an administrative office located in the south of Benin in Lokossa in the Mono department. It is located on the ground floor of a paved building in contact with the outside and has dimensions of 3m*3m*3m, i.e. an area of 9m². Its north and west sides are in contact with unconditioned premises and the south and east sides are in contact with the outside. On the south side, there is a natural wood door measuring 1.8m*1m and a window measuring 1.2m*1m [10].

- The housing.

The housing is mainly made of wood and the whole system is housed in it. Indeed, it is composed of an upper part with a dimension of 450*450 mm in which all the Peltier modules and the heat dissipation system (coil, fan) as well as the other electronic components are housed. The lower part is subdivided into two parts: a 550*100 mm part that supports the converter and a second 550*350 mm part that houses the water tray. Apart from the front and rear sides of the box, all other sides are hermetically sealed. On the front side there is a fresh air opening on the top and on the rear side there is a square hole to house an electrical socket.

- Polystyrene.

In order to avoid heat loss, polystyrene is used to insulate the housing. The different methods used are as follows:

2.2 Method of heat load assessment.

To evaluate the thermal load of the room to be air-conditioned, we will proceed to the determination of the internal and external load contributions by the following different formulas taken from the reference [11].

External expenses

- Load contribution by transmission through external walls (walls, roof, ceiling and floor)

$$Q_{Str} = k * S * \Delta T \text{ (W)} \tag{1.1}$$

k is the overall thermal transmittance of the wall or glazing in W/m^{2}K.
S is the area of the wall considered in m^2.
ΔT temperature difference between the two sides of the wall considered in K

- Heat input from solar radiation through the walls.

$$Q_{Srm} = \alpha * F * S * R_m \text{ (W)} \tag{1.2}$$

α is the absorption coefficient of the wall receiving the radiation depending on the color and nature of the wall.
S is the area of the wall considered in m^2.
F is the solar radiation factor indicating the proportion of heat absorbed by the surface and transmitted through the room wall.
R_m is the solar radiation absorbed on the wall surface in ~~W/m2~~ W/m^2 and depends on the latitude of the room, the orientation of the wall and the time of day at which the calculation is made.

- Heat input from solar radiation on glazing.

$$Q_{Srv} = \alpha * g * S * R_v \text{ (W)} \tag{1.3}$$

α is the absorption coefficient of the glazing.
g is the reduction factor depending on how the window is protected against solar radiation.
S is the glazed area in m^2.
$R_v$is the solar radiation intensity on the glazing W/m^2 ; it is defined in the same way as R_m.

- Heat input through air exchange and infiltration.

Air exchange in an air-conditioned room is necessary for hygienic reasons. As a general rule, it is done by ventilation (natural or mechanical) of the premises as well as by infiltration, introducing outside air into the air-conditioned premises. It is a source of sensible and latent heat input in the room to be conditioned.

Sensitive gains by air renewal:

$$Q_{Srv} = q_v * (\theta_e - \theta_i) * 0.34 \text{ (W)} \tag{1.4}$$

Latent gains through air change:

$$Q_{Lr} = q_v * (\omega_e - \omega_i) * 0.84 \quad \text{(W)} \tag{1.5}$$

q_v is the outdoor air renewal rate in m^3/h.

θ_e is the basic outdoor temperature.
θ_i is the basic indoor temperature.
ω_e is the water content of the outside air g/kg dry air.
ω_i is the water content of the indoor air g/kg dry air.
0.34 is the volumetric heat capacity of air in Wh/m^{2}K.
0.84 is the specific volume of air (25 °C, 50% relative humidity), in m^3/h.

Internal expenses

- Heat input by occupants.

It is given as a function of the indoor temperature and the degree of activity. There are two kinds of gains generated by the occupants:

Occupant-sensitive gains:

$$Q_{Soc} = n * C_{sco} \quad \text{(W)} \tag{1.6}$$

Occupant-latent gains:

$$Q_{Loc} = n * C_{Loc} \quad \text{(W)} \tag{1.7}$$

C_{sco} is the sensible heat of the occupants (W).
C_{Loc} is the latent heat of the occupants (W).
n is the number of occupants.

- Heat input from lighting.

It is a sensitive heat source and depends on the type of lamp.

Fluorescent lamp:

$$Q_{Secl} = 1.25 * P \quad \text{(W)} \tag{1.8}$$

Incandescent lamp:

$$Q_{Secl} = P \quad \text{(W)} \tag{1.9}$$

P is the power of the lamp in W.

- Heat input from machines and appliances.

Most appliances are both a sensible and latent heat source. The heat inputs of machines and appliances are determined according to the specifications of various manufacturers. They are reduced by a weighting coefficient according to their operating times. For example, an appliance that operates for only half an hour per hour is considered to release half of its nominal electrical power as heat input.

$$Q_{max} = coefficient\ d'utilisation * P \quad \textbf{(W)} \tag{1.10}$$

With P the rated power of the machine.

2.3 Method of sizing the air conditioning system.

The sizing of the air conditioning system takes into account the sizing of the Peltier modules and the determination of the exchange surface.

- Peltier module sizing method.

To dimension the Peltier modules, we used the following equations 2.1, 2.2 and 2.3 as well as the information in the Peltier module data sheet provided by the manufacturer and available in the appendix of the document to determine the number of modules needed to ensure the thermal comfort of the study room.

$$Q_c = \alpha I T_c + \frac{1}{2} R I^2 - k(T_c - T_f) \tag{2.1}$$

$$P_e = Q_c - Q_f = \alpha I\left(T_c - T_f\right) + R I^2 \tag{2.2}$$

- Method of determining the exchange area.

The heat exchange between the air in the room to be cooled and the cold side of the Peltier module will take place through the surface of the fins. It is therefore imperative to dimension this fin surface to have an optimal exchange. To achieve this, we will study the heat transfer by conversion between the surface of the fins and the air forced into motion by the ventilation of the room.

$$Q = h.S.(T_{air} - T_{ail}) \tag{2.3}$$

With

Q the heat load of the room to be cooled
h: The exchange ratio by conversion in W/m^2K
S : The surface of the fins inm^2
T_{air} and T_{ail} : Respectively the air temperatures of the room and the fin in K

From this equation (3.1) the exchange surface S gives:

$$S = \frac{Q}{h.(T_{air} - T_{ail})} \tag{2.4}$$

The determination of the exchange coefficient by conversion h depends on several parameters such as: the characteristics of the fluid, the nature of the flow, the temperature, the shape of the exchange surface.

To estimate the value of the exchange coefficient, either the expression of h is calculated or known (analytically or by a numerical method) in cases where it is possible. The range of values for h is given in the table 1.

Table 1. **Orders of the convective coefficient h (W/m^2 K).[12]**

convective coefficient	Value
Free ~~conversion~~ convection (air)	5-25
Free ~~conversion~~ convection (water)	100-900
Free ~~conversion~~ convection (air)	10-500
Free ~~conversion~~ convection (water)	100-15000
Free ~~conversion~~ convection (oil)	50-2000
Forced ~~conversion~~ convection (molten metals)	6000-120000

Boiling water	2500-25000
Condensing water vapour	50000-100000

In our case where the ~~conversion~~ convection is forced by fans, the order of the convective coefficient is between 10 and 500W/m^2K.

- Expérimental method.

Experimentation consists in testing the system and taking temperature and humidity data in order to evaluate its performance.

The first step of the experimentation consisted in programming the Arduino UNO board to acquire signals from the different temperature sensors connected to the board. This programming was carried out on the Arduino software and flashed on the microcontroller of the Arduino board and the temperature data obtained will be directly recovered in the form of a CSV file via an SD module connected to the Arduino board that we can import into an Excel spreadsheet to generate graphs. The computer program of the board is available in the appendix of the document.

The second step of the experiment consists in ensuring the correct arrangement of the DHT22 temperature and humidity sensors. In addition to being connected to the Arduino board, the sensors are also powered by it. We used two temperature sensors: one to take data from the room and a second to take data from the air released by the radiator.

The third step was to make sure that all the components of the system, from the Peltier modules to the fans and the pump, were properly connected and working. This involves checking that the components are powered by the power supply and connected as they should be.

Finally, we will record the different temperatures T_f, and T_c, corresponding respectively to the room temperature and the radiator temperature, as well as the humidities h_f and h_c corresponding respectively to the room humidity and the radiator humidity.

Each sequence of the experiment is carried out over a period of one hour and the temperature and humidity data are recorded in a time unit of one minute.

Experimental assumptions.

To carry out the experiment, we made two different assumptions.

First assumption: The data from the different temperature and humidity sensors are reliable.

Second assumption: The different temperature sensors are placed at any location of the heat sources. We therefore assume that the temperature and humidity data obtained at these locations are uniform across the heat source.

Test conditions.

The tests are carried out in the test room with a base temperature of 29 °C and a relative humidity of 72%. During the first test, the system is placed next to an opening to the outside (the windows) to facilitate the release of heat from the hot side of the modules. In addition, the water in the cooling circuit is at a temperature of 25°C. In the second test, we added ice to the water in the cooling circuit to bring its temperature to 18°C.

3. RESULTS AND DISCUSSION

3.1 Determining the heat load of the room to be cooled

In order to air-condition the room, it is first necessary to determine the heat balance of the room. Based on the dimensions of the room to be air-conditioned and using the different heat transfer formulas, the different heat inputs have been expressed and recorded in the tables 2 to 12. The transmission contributions through the various walls of the room are shown in Table 2.

Table 2. Transmission contributions through the various walls of the room

Opaque walls	S (m^2)	hi (W/m^2.°C)	He (W/m^2.°C)	ei (m)	λi (W/m^2.°C)	ei/λi (m^2.°C/W)	K (W/m^2.°C)	Te (°C)	T (°C)	∆T (°C)	Φtr (W)
South wall	6	9	16.7	0.15	0.4	0.375	1.832	32	25	7	53.84
North wall	9	9	9	0.15	0.4	0.375	1.674	28	25	3	39.18
West wall	9	9	9	0.15	0.4	0.375	1.674	28	25	3	45.21
East wall	9	9	16.7	0.15	0.4	0.375	1.832	32	25	7	115.39
Concrete ceiling	9	20	20	0.2	0.14	1.429	0.654	32	28	4	23.55
Doors in Wooden	1.8	9	16.7	0.035	0.044	0.795	1.035	32	25	7	13.04
Window made of glass	1.2	9	16.7	0.005	1	0.005	5.682	32	25	7	47.73
				Total							**337.94**

The estimated heat input through the different walls is therefore equal to 337.94 W. The radiant heat input of the walls exposed to external solar radiation is presented in the table 3. The radiant heat gains from walls exposed to external solar radiation are shown in the table 3.

Table 3. **Heat input by radiation through the walls**

Walls	**α**	**H (m)**	**l (m)**	**S (m^2)**	**F**	**Rm (W/m^2)**	**Φrp (W)**
South wall	0.4	3	3	9	0.127	315	143.451
East wall	0.4	3	3	9	0.156	250	140.4
Wooden door	0.4	2	0,9	1,8	0,179	315	40.484
			Total				**324.335**

The total heat gain through radiation from the walls in contact with the solar radiation is therefore estimated to be 324.335W. The heat gain through solar radiation on the window glazing is presented in the table 4.

Table 4. **Radiant heat input through the glass**

Walls	**L (m)**	**l (m)**	**S (m^2)**	**α**	**g**	**Rv (W/m^2)**	**Φrv (W)**
Window made of glass	1.2	1	1.2	1	0.28	200	67.2
			Total				**67.2**

The radiant heat input to the room's window pane is therefore estimated at 67.2W. The sensible heat supplied to the room through air exchange is shown in Table 5.

Table 5. **Sensitive heat input through air exchange*.***

qv (m3/h)	**θe (C)**	**θi (C)**	**θe-θi (C)**	**volumetric heat capacity of air (Wh/m^2K)**	**Φras (W)**
27	32	25	7	0.34	56.7
		Total			56.7

The sensible heat gain from air change in the room is therefore estimated at 56.7W. The latent heat gain per air change is presented in the table 6.

Table 6. **Latent heat input through air exchange**

qv (m3/h)	**ωe (C)**	**Ωi (C)**	**ωe-ωi (C)**	**Specific volume of air** (m^3/h)	**Φral (W)**
27	0.0255	0.0108	0.0147	0.84	333.39
		Total			333.39

The latent heat contributed by the air change in the room is therefore equal to 333.396W. The sensible heat input of the room occupants is presented in the table 7.

Table 7. **Sensitive heat input by occupants**

Number of occupants	Sensitive Heat (W)	Φsensitive (W)
01	67	67

The sensible contribution of the room's occupants is therefore 67W. Table 8 shows the latent contribution of the room's occupants.

Table 8. **Latent heat input by occupant**

Number of occupants	Latent heat (W)	Φlatent (W)
01	49	49

The latent heat of occupants in the room is estimated at 49W. Table 9 shows the heat input by occupant.

Table 9. Heat input by occupant

Φsensitive (W)	**Φlatent (W)**	**Φ occ (W)**
67	49	116

The total input from the room occupants is therefore estimated at 116W. The heat input through the lighting of the room is presented in the table 10.

Table 10. **Heat input through lighting**

Number of lamps	**Power (W)**	**Φécl (W)**
01	18	22.5

The heat gain through the lighting in the room is therefore estimated at 22.5W. Table 11 shows the heat input from the various electrical and electronic devices in the room.

Table 11. Heat input from devices in the room

Device	**Quantity**	**Power (W)**	**Coefficient of use**	**Φmac (W)**
Computer	01	45	100%	45
Printer	01	200	15 %	30
		Total		**75**

The total heat input through the units is therefore equal to 75W. Table 12 shows the balance of the different heat inputs in the room and the total air conditioning load.

Table 12. Total heat input

Φtr (W)	**Φrp (W)**	**Φrv (W)**	**Φras (W)**	**Φral (W)**	**Φocc (W)**	**Φécl (W)**	**Φmac (W)**	**Φtot (W)**
337.943	324.335	67.2	56.7	333.396	116	22.5	75	1333.073

Thus, the air conditioning load for the room is 1333.073 W. The next step in our technical study will therefore be to size the air conditioning system. Note that 1333.073 W of power is quite high for the air conditioning of a 9 m^2 room. This result is therefore purely theoretical, as generally with conventional air conditioning systems this power corresponds to the power required to ensure thermal comfort in a $20m^2$ room.

As a comparison, the work carried out by Mohamed and Oussama on the production of cold by the Peltier effect in a computer room made it possible to obtain a thermal load of 11287.84 W for a room of 95 m^2 generally occupied by 17 people who can use 17 computers and whose lighting is provided by 46 fluorescent lamps [2].

3.2 Sizing of air conditioning systems

The sizing of the air conditioning system includes the sizing of the Peltier modules and the sizing of the heat exchange surface.

3.2.1 Sizing of Peltier modules.

To size the Peltier modules, we chose to use the TEC1-12706 Peltier modules whose performance specification table provided by the manufacturer is available at reference [9].

In order to determine the number of Peltier modules needed to ensure the air-conditioning of our room, we first determined the cooling capacity of a TEC1-12706 module under our real operating conditions. We used the curve provided by the manufacturer of the TEC1-12706 Peltier modules who represents the cooling capacity Q_C of the Peltier modules as a function of the temperature difference DT according to the supply current when the temperature T_C=50°C. [13]

By setting a desired temperature T_F= 20°C on the cold side of the Peltier module, we obtained a temperature difference DT= 50-20 = 30°C. Using the Q_C(DT) curve, it is easy to see that the best cooling capacity that can be obtained on the cold side of the module for a temperature difference DT=30°C when a current I_{max}= 6.1A is passed through it is Q_C=42W.

By using the curve provided by the manufacturer of the TEC1-12706 Peltier modules, we noted that for a temperature difference DT =30°C and a current I_max= 6.1A, the module must be supplied with a voltage U=14V [13].

In summary, for a temperature difference DT =30°C, the Peltier module TEC1-12706 provides a cold power of 42W on its cold side when supplied with a voltage of 14V and a current of 6.1A. The thermal load of the room is estimated at 1333,073W, so to maintain the temperature of the room between 20°C and 25°C it will be necessary to use 32 modules TEC1-12706.

The result of the field sizing of the Peltier modules is presented in table 13.

Table 13. **Peltier module sizing report.**

Peltier module type	Supply voltage	Supply current	Cooling capacity on the cold side of the module	Heat load of the room	Number of modules to be used	Unit power supply	Total power supply
TEC1-12706	14V	6.1A	42W	1333.073W	32	127.4W	4076.8W

To ensure the thermal load of the room, a total of 32 TEC1-12706 Peltier modules will be used, which will be supplied with a current of 6.1A and a voltage of 14V. The power supply required to power this field of Peltier modules is 4076.8W.

3.2.2 Determination of the heat exchange surface.

The required exchange surface S is between: $\frac{1333.073}{500*(25-20)} \leq S \leq \frac{1333.073}{10*(25-20)}$. That means $0.533\ m^2 \leq S \leq 26.66\ m^2$. With this result, the minimum estimate that can be made of the exchange surface necessary for the objective is 0.533 m^2. Comparing with the results of T. Mohamed and M. Oussama who stipulate that a surface of 28.2196 m^2 is needed to overcome the 11287.84 W of thermal load [2].

3.2.3 The operating principle of the system.

The operating principle of this new system can be described according to the four functions it performs: the distribution of the cold from the modules, the dissipation of the heat from the hot surfaces of the Peltier modules, the supply of power to the system and the regulation of the system. The cold produced by the Peltier modules in the system is distributed throughout the room to be cooled by means of fins and fans mounted on the hot surfaces of the modules. To maintain the temperature difference between the two sides of the modules, a heat dissipation system is mounted on the hot sides of the modules. This system consists of cooling blocks connected in series to a radiator by a pipe in which the cooling liquid (water) circulates. A tank equipped with a pump is used as a source of cooling water for the pipework.

In order to collect temperature and humidity data at different levels of the system, an Arduino UNO board connected to temperature sensors is used. This board is also used to regulate the whole system. All the electrical and electronic components of the system (Arduino board, pump, fans, modules, sensors) are powered through a power supply box which takes its source from the wall socket.

Evolution of the temperature and humidity of the room over one hour is presented in the figure 1.

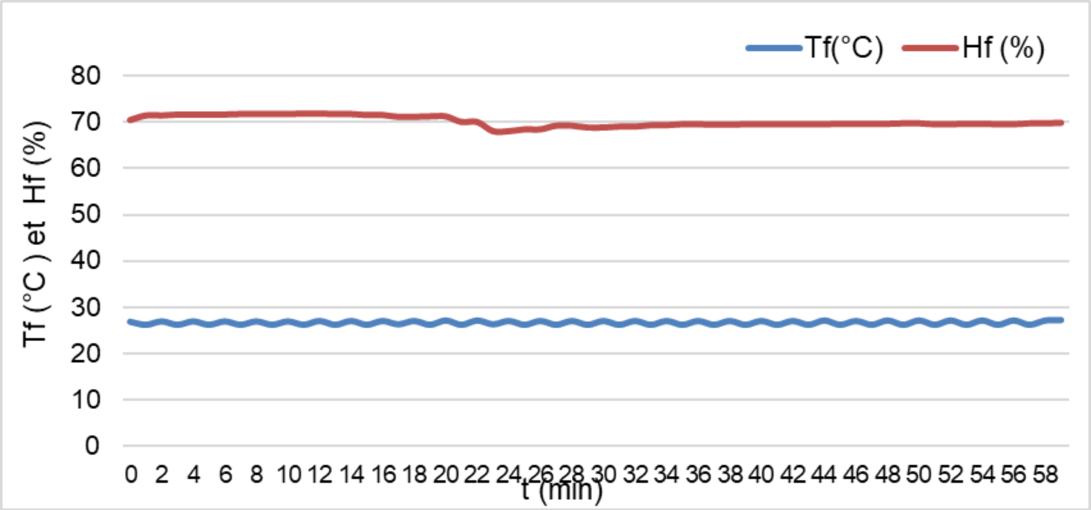

Fig.1. **Evolution of the temperature and humidity of the room over one hour (First experiment).**

Evolution of the temperature and humidity of the air released by the radiator as a function of time is presented in figure 2.

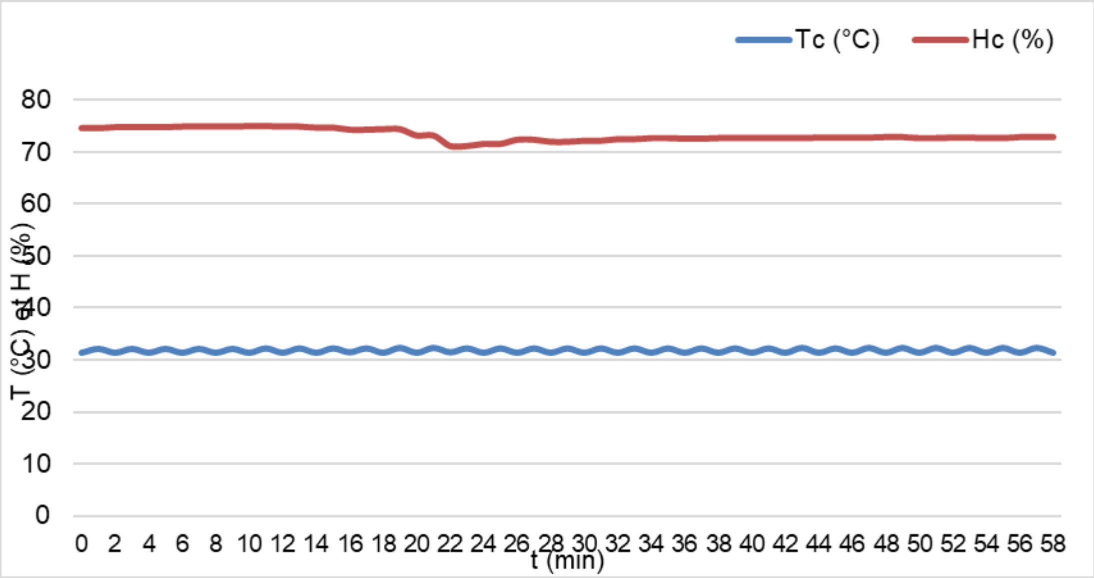

Fig. 2. Evolution of the temperature and humidity of the air released by the radiator as a function of time (First experiment).

The figures 1 and 2 show respectively the variations of the temperature and humidity of the room and of the air released by the radiator during the first test. The graph in figure 4 shows the evolution of the temperature and humidity of the room, and it can be seen that the temperature T_f of the room is maintained between 26 °C and 27 °C by the system. Knowing that the room temperature was initially 29°C and that the design temperature to ensure thermal comfort is 25 °C, it should be noted that for this first test the system did not ensure the desired thermal comfort. Furthermore, if we refer to the graph in figure 5 concerning the evolution of the temperature and humidity of the air released by the radiator, we can see that the temperature Tc of the air released at the radiator varies between 31°C and 32 °C. Thus, these radiator temperatures are quite high for a room that is basically 29 °C. It is therefore imperative to reduce the temperature of the air generated at the radiator by improving the cooling circuit of the hot face of the modules in order to take better advantage of the cold generated by the system.

To improve the cooling circuit of the hot faces of the modules of the system, we used ice to lower the cooling water of this circuit to 18°C and carried out a second series of tests of the system over a period of one hour.

The results of the second test, are presented below.

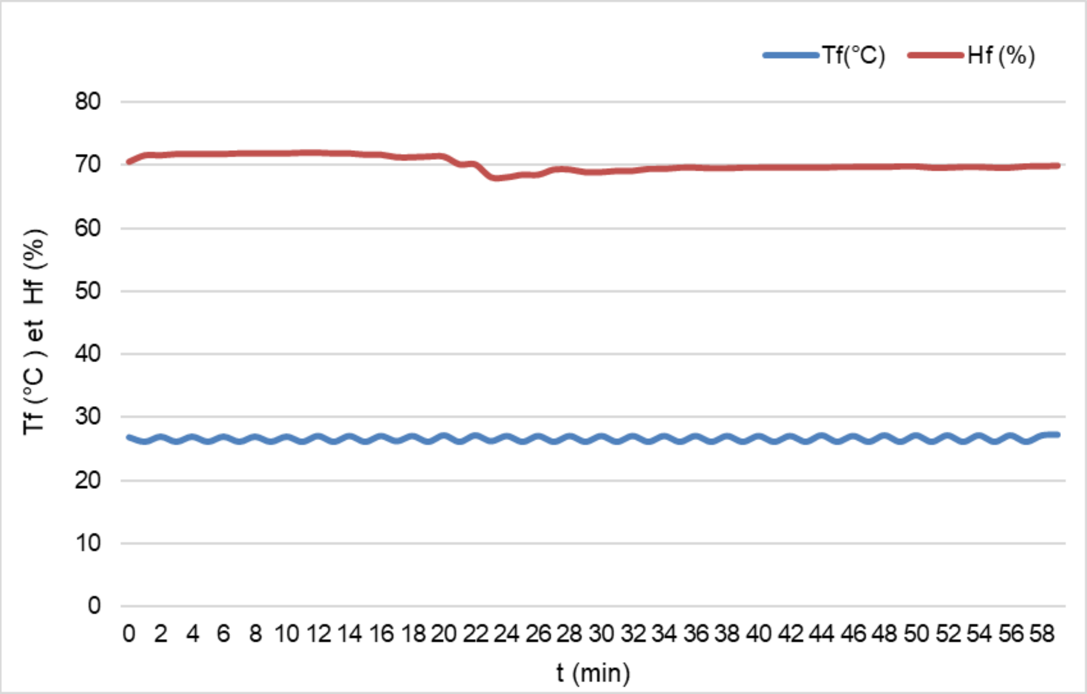

Fig. 3. **Evolution of the temperature and humidity of the room over one hour (Second experiment).**

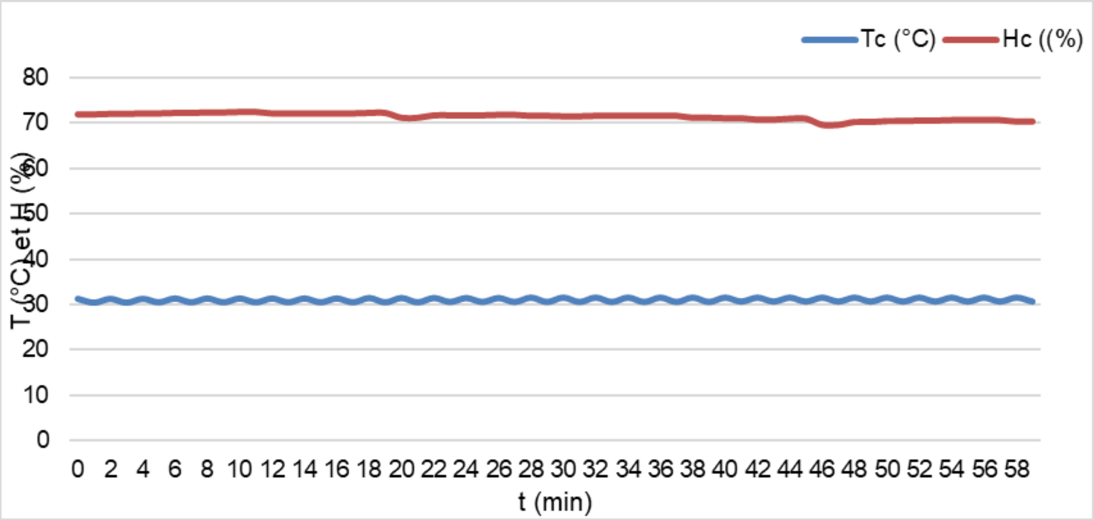

Fig. 4. **Evolution of the temperature and humidity of the air released by the radiator in one hour (Second experiment).**

The figures 3 and 4 show the variations of the temperature and humidity of the room and of the air released by the radiator during the second test respectively. From the figure 6 concerning the evolution of the temperature and humidity of the room, we can see that the temperature Tf of the room is maintained between 25°C and 27°C thanks to the system. Knowing that during the first test this temperature was between 26°C and 27°C, it can already be noted that lowering the temperature of the water in the cooling circuit of the hot faces of the modules by introducing pieces of ice had a positive impact on the performance of the system. However, the system is still not reliable enough to provide thermal comfort.

Also, based on the Figure 7 concerning the evolution of the temperature and humidity of the air generated at the radiator, it can be seen that the value of the temperature Tc remained between 30°C and 31°C during the whole experiment. This is already a clear improvement compared to the first test and it validates the positive effect that the lowering of the cooling water temperature has had on the system performance.

For comparison, the work of Gołębiowska and Justyna in their research on experimental investigation of thermoelectric cooling system with heat recovery allowed to cool an experimental room from a temperature of about 21°C at the base to a temperature of about 8°C after 40 minutes of experimentation. In addition, the water in the cooling circuit went from a temperature of 10.5°C at the beginning to a temperature of 50.5°C at the end of the experiment [14].

3.3 The economic balance of the system.

For the implementation of this test scheme, some financial efforts have been made. The table 14 shows the total financial expenditure for the implementation of the test project.

Table 14: Financial statement.

Designation		Quantity	Unit price (FCFA)	Total price (FCFA)
Peltier modules TEC1-12706		12	2000	24000
Arduino board		01	9900	9900
DHT22 sensor		01	4500	4500
ST045 Sensor		01	960	960
LCD display		01	1750	1750
Power supply unit		01	52000	52000
LED		03	18	54
Fan	12*12cm	02	5500	11000
	05*05cm	06	4500	27000
Electric pump		01	25000	25000
Cooling block		03	10000	30000
Radiator		01	25000	25000
Wing		03	13400	40200
Switch		01	200	200
Electrical socket		01	2000	2000
Thermal paste		01	2500	2500
Aluminium sheet		01	3000	3000
Cords (telephone wires)		10m	100	1000
Cords (jumper)		29	40	1160
Battery connector for Arduino		01	300	300
Tank		01	500	500
Paint			8000	8000
Welding		-	10000	10000
Electronic brochure		01	1500	1500
Wooden box		01	25000	25000
Armaflex		01	750	750
Roulette wheel		04	625	625
Various				15000
			Total	3178999

This financial statement includes both the expenditure on the old and the new system. As the majority of the parts were ordered from outside the country, particularly from China, the delivery costs for receiving the parcels on time were quite high and made the bill larger. Similarly, the unit purchase price of the materials is also high and a bulk order of materials would be more affordable.

4. CONCLUSION

The general objective of this research has been to study an alternative and economical cold production system with Peltier modules. We can say that the most common means of air conditioning is the mechanical compression system, which has a relatively high efficiency and cooling capacity despite the use of refrigerants. However, the use of Peltier modules for cold production is an interesting alternative solution for small enclosures and cold power while being environmentally friendly. Further studies could further improve this new air conditioning system. Thus, an integration of power supply by photovoltaic panels could make the system energy self-sufficient, and a complementary study on the distribution of cold could increase the system's efficiency.

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