*International Journal of Engineering & Technology*, 12 (2) (2023) 48-57

International Journal of Engineering & Technology

*Website: www.sciencepubco.com/index.php/IJET*

***Research paper***

# Performance of a cold room powered about energy solar photovoltaic for the preservation of mangoes

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**Abstract**

This article focuses on the study of the performance of a cold room powered by photovoltaic solar energy for the preservation of agri-food products, more particularly mangoes. The objective of this work is the analysis of the thermal profiles of the cold room and the evaluation of the capacity of the latter to keep the products in good conditions. A study was carried out on the components of the cold unit as well as its operating principle. In addition, the evolution of the temperature of the cold room, depending on external conditions, was studied. Thus for an average internal temperature of the room which varies in the interval [14°C, 15°C], the Amelie mango variety is the one which loses the most mass during storage; it loses 10% of its initial mass after two weeks of storage and 15% in three weeks. The mass loss of Kent and Lippens mango varieties is approximately 4-5% in two weeks and 11-12% in three weeks. The average cooling power of approximately 3 kW and an average COP of 1.9 were established. The photovoltaic generator proved sufficient to power the cold unit.

***Keywords***: *Cold Room; Solar Photovoltaic; Mangoes.*

## 1. Introduction

In Burkina Faso, the seasonal nature of food production requires their conservation in order to make them available throughout the year. Preserving certain fruits at low temperatures is essential in order to meet demand during periods of scarcity [1]. Also, the cold necessary for this conservation must be produced in such a way as to avoid breaking the chain cold production. However, most developing countries experience difficulties related to energy supply, especially during hot periods of the year [2]. It is in this context that solar cold production appears as a possible solution for our country because it adapts very well to rural living conditions. The system necessary for solar conservation must be able to produce cold during periods of no sunlight to ensure uninterrupted operation. A study carried out among market gardeners allowed us to discover the major problems they face in their daily activities. These problems are essentially linked to the lack of means of preserving their productions. In view of these difficulties, cold preservation appears to be a reliable option. In recent years, several models of solar cold rooms have been designed and built for the preservation of fresh products. However, these designed rooms must be efficient in order to ensure the preservation of the fruits. To address this concern, we undertook the study of the performance of a cold room powered by photovoltaic solar energy. Note that mango constitutes a challenge to the economic, social and very important climate. Indeed, the mango sector generates more than 15 billion turn over per year. She counts 33701 ha distributed in 8 provinces for a production of 300,000 tons per year including 15,000 producers, 14 international exporters, and 76 drying units [3]. The west of the country constitutes the main mango production area. The high basins and waterfalls regions alone concentrate 75% of national production [4]. In addition, this sector contributes to food security in producing areas and plant cover which limits the effects of climate change. However, this sector has confronted these enormous difficulties in recent years such as parasitic pressure, drying out of mango trees due to climate change, poor road conditions for transport from production areas to consumption areas [5]. We also have mango tree diseases as well as the disorderly start of mango exports. This work presents the results of an experimental study of a solar cold room for the conservation of agri-food products, particularly the conservation of mangoes. The choice of mangoes is justified by their rarity in certain periods of the year, but also by their importance on an economic, health and social level.

# 2. Method of preserving agricultural products

These preservation processes aim to slow down or in the best case block the activity of the micro-organisms responsible for the rotting of products [6]. Fungi such as Penicillium, bacteria and ethylene produced by fruits have a notable effect on the expiration date of fruits and vegetables but also of flowers and plants in general. Healthy, clean air, free of these contaminants, allows for a significant extension of shelf life. Fruits and vegetables are natural carriers of fungal spores (Penicillium, Botrytis, etc.), which contaminate the air and spread to all stored foodstuffs [7]. The destruction of these contaminants significantly slows the rotting process. Active oxygen (O-, $O^{2-}$…) generated by bioclimatic air purifiers destroys airborne mold and spores in cold rooms and storage areas in general, by oxidizing their membrane phospholipids [8]. This disintegrates, causing the death of the microorganism. The production of cold makes it possible to reduce ethylene emissions and when the conservation device is well ventilated, the ethylene is extracted from the conservation enclosure as it is produced. Ethylene with the chemical formula $C_2H_4$ is a molecule produced naturally by climacteric fruits, and triggers the ripening of fruits and vegetables [9-10]. In storage areas for these perishable foods, maturation is synonymous with loss of product through rotting. To avoid significant financial losses, it is necessary to ventilate the enclosures, manage the concentrations of oxygen, carbon dioxide and the relative humidity of the air [11-12]. This process dehydrates and wilts the fruit. Man has always looked for ways to preserve food to ensure his survival in times of scarcity. Drying is one of the first and simple methods of preservation drying. Other techniques such as salting, preservation with sugar (jams) and fermentation (wine, cheese, sauerkraut, etc.) came later. More recently, preservation by heat and cold has developed with refrigeration installations [13]. These different processes each have their advantages in terms of practicality and nutritional quality.

## 2.1. Conservation by drying

Drying is a process which consists of reducing the humidity level of a product below a threshold value which does not allow the development of micro-organisms. Several techniques can be used to dry products. Since ancient times, grains, fruits, meats and fish have been dried in the sun. More late, drying was carried out in ovens [14]. Today, foodstuffs are dehydrated by techniques more advanced: hot air dryers, infrared ramps, heating cylinders, fluidization (passage of hot gases through a grid plate). In Burkina Faso, the drying of agri-food products, particularly mangoes, is a widely practiced activity for processing and preservation from a commercial perspective [15]

## 2.2. Preservation by heat and by adding chemicals

This method of preservation consists of destroying microorganisms contained in foodstuffs using heat, and packaging them in airtight packaging to avoid subsequent microbial re-contamination. The technique most used for this purpose is pasteurization [16].
Preservation by adding chemicals to contain the development of micro-organisms denatures the product and affects the flavor and composition of the product [17].

## 2.3. Preservation by processing and cold

This method consists of transforming the product and storing it in a suitable environment. These are generally candied products, jellies, syrups and fruit compotes. The technique does not adapt to all products [18]
Cold preservation of products consists of placing the products that we wish to preserve in a room where the temperature is low enough to slow down or even block the development of microorganisms [19]. This temperature must not be lower than the product-specific storage temperature as this risks denaturing the product.
There are several cooling techniques: refrigeration and freezing/freezing. Regarding refrigeration, it consists of slowing down the development of the main pathogenic bacteria by storing foodstuffs at +3°/+4°C [20]. Refrigeration delays the development of a perishable product by a few days and extends the distribution time of fresh products such as dairy products, meats, fish, fruits and vegetables. It is also used on a large scale to preserve fruits such as apples and pears for several months in fruit stations [21]. As for freezing, it is a technique for preserving organic products. It helps increase the shelf life of foods while maintaining color, flavor and texture. The nutritional value of foods is preserved by freezing. This is the least destructive technique of all, provided it is carried out properly: freezing must be rapid, and the storage temperature must be sufficiently low. After defrosting, the objective is to obtain a product of a quality as close as possible to that of the original product. The domestic freezing temperature, for food, is defined at -26°C while the freezing technique used by food manufacturers is based on exposure temperatures ranging from -35°C to -196°C [22]. Only products thus frozen or quick-frozen must be maintained at a storage temperature of -18°C. Freezing is a method which consists of very quickly lowering the temperature of a food below -18°C, to block microbial activity. But the rapid reduction to -40°C in cooling cells or freezers leads to the formation of very small ice crystals where the cellular structure of the products is preserved [23]. However, for certain foodstuffs of animal origin, the presence of residual enzyme activity can cause fats to go rancid during storage. This method of preservation is today very widespread in developed countries, for its practicality and the wide variety of products available (fruit, vegetables, meat, fish, ready meals, bakery-pastry, etc.) [24].

## 2.4. Conservation par ionization

Ionization is a physical process which is based on the exposure of foods to the direct action of certain electromagnetic radiation (X-rays) or electronic radiation (ß radiation) allowing them to be preserved by destroying insects and parasitic microorganisms, preserving as much as possible their organoleptic, health and nutritional qualities. This preservation process must often be associated with refrigeration or freezing. Currently, ionization is mainly used to treat spices, aromatic herbs, and to extend the life of certain fruits (strawberries, etc.) [25-26].

# 3. Materials and methods

## 3.1. Cold room

Our solar cold room is a negative cold room in the form of a container held by supports above which the photovoltaic solar modules are placed. It is a parallelepiped shaped device with dimensions (5.0m x 2.8m x 2.3m) or a useful volume of $32.2\mathrm{m}^3$. It is connected to two refrigeration units of 1.5 HP each which use R404A as refrigerant. The electrical energy supply to these groups is provided by a photovoltaic generator of 5 kWp Two 5 KVA hybrid inverters power the two chillers. A storage system made up of 24 2V-500Ah batteries arranged in the technical room ensures the energy supply during cloudy periods or at night. Figure-1 gives an overview of the room. The items are specified in the table below.

**Table 1:** Characteristic of the Photovoltaic Field

| Designation | Name |
|---|---|
| 250Wp solar module | 20 |
| Battery 500Ah-2V | 24 |
| 5KVA hybrid inverter | 2 |

**Fig. 1:** Cold Room.

### 3.2. Preparation of the product

Mangoes composed of three varieties such as: Amelie, Lippens and Kent are washed in order to disinfect them then they are placed in transport and storage crates. These crates are introduced into the cold room. The tests were carried out with 400 kg of mangoes distributed in 24 crates of 17 kg each. The products were placed on shelves. Apart from washing with soapy water, no prior treatment was carried out on the mangoes. Our experiments stopped from ripening mangoes.

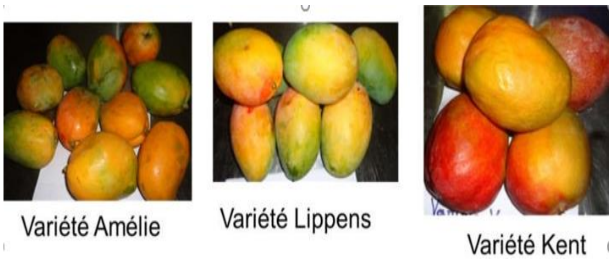


**Fig. 2:** Varieties of Mangoes.

### 3.3. Measuring equipment

To be able to follow the evolution of the mass during storage, we weighed the mangoes every week during the 21 days of storage using a Severing brand digital scale. The daily radiation is monitored using a solar meter placed on a horizontal plane on the experimental site during the days of the experiment. The relative humidity of the ambient air is measured using a hygrometer every 10 minutes. An AIR-MATE CF402RI brand humidifier made it possible to maintain the humidity of the air in the room at a sufficient level to prevent the fruits from drying out. A cup anemometer is an instrument for measuring wind speed. It allowed us to determine the maximum, instantaneous and average values (important for evaporation phenomena and energy potential) of the wind speed at the entrance and exit of the evaporator.


**Fig. 3:** Digital Scale.

**Fig. 4:** Data Logger.

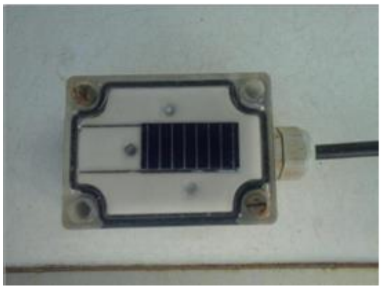

**Fig. 5:** Solarimeter.

**Fig. 6:** Humidifier.

## 4. Results and discussions

Figure 7 above represents the variation of ambient temperature and that of solar irradiation as a function of time on June 14, 2018. In fact, the lowest ambient temperature is in the morning at around 6:30 a.m. This relatively low value is due to the absence of the first rays of the sun. By against, from around 12:30 p.m., we notice a high value ambient temperature which is around 34°C. These relatively high values are due to the fact that the sun is at the zenith. As for irradiation, it is low from 6:30 a.m. with a value of 105W/$m^2$ is due to low solar radiation. She grows and reaches its maximum value of 912W/$m^2$ in the afternoon around 1 p.m.

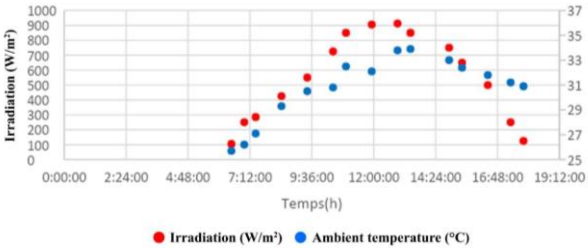


**Fig.7:** Variation in Ambient Temperature and Irradiation on June 14, 2018.

### 4.1. Evolution of temperature profiles

The measurements were taken to monitor the evolution of the internal and external temperatures of the cold room over days' conservation. The temperatures of the internal walls of the cold room measured on 06/20/2018 are presented in the Figure at the same time as the external ambient temperature profile. Temperature differences between the interior wall temperature and the exterior ambient temperature can reach up to around 25°C, especially when the exterior ambient temperature reaches its maximum around 2:30 p.m.
The average values of these temperatures are summarized in table 2:

**Table 2:** Average Temperatures of Internal Walls and Ambient Air (06/20/2018)

| | Day | | Sunny period 8 a.m. to 12:59 p.m. | | 1 p.m. to 5:59 p.m. | | Non-sunny period 18h to 7h59 | |
|---|---|---|---|---|---|---|---|---|
| North wall | 13,3 | ± 1,1 | 14,0 | ± 1,0 | 12,4 | ± 0,9 | 13,4 | ± 1,0 |
| South wall | 14,0 | ± 0,8 | 14,8 | ± 0,7 | 13,3 | ± 0,6 | 14,0 | ± 0,6 |
| East wall | 14,2 | ± 0,7 | 14,8 | ± 0,6 | 13,5 | ± 0,6 | 14,3 | ± 0,6 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| West wall | 13,4 | ± 0,8 | 14,0 | ± 0,7 | 12,6 | ± 0,6 | 13,5 | ± 0,7 |
| Ambient temperature | 30,5 | ± 2,4 | 31,1 | ± 1,8 | 33,9 | ± 0,6 | 29,0 | ± 1,6 |

The east wall turns out to be the warmest whatever the time of day considered. This is explained by the fact that the technical room which contains the compressors is located in the cold room. The operation of the compressor motors generates heat which contributes to the heating of the east wall even outside of sunny periods.
The south wall is the second warmest area due to its greater exposure to solar radiation due to its south orientation.

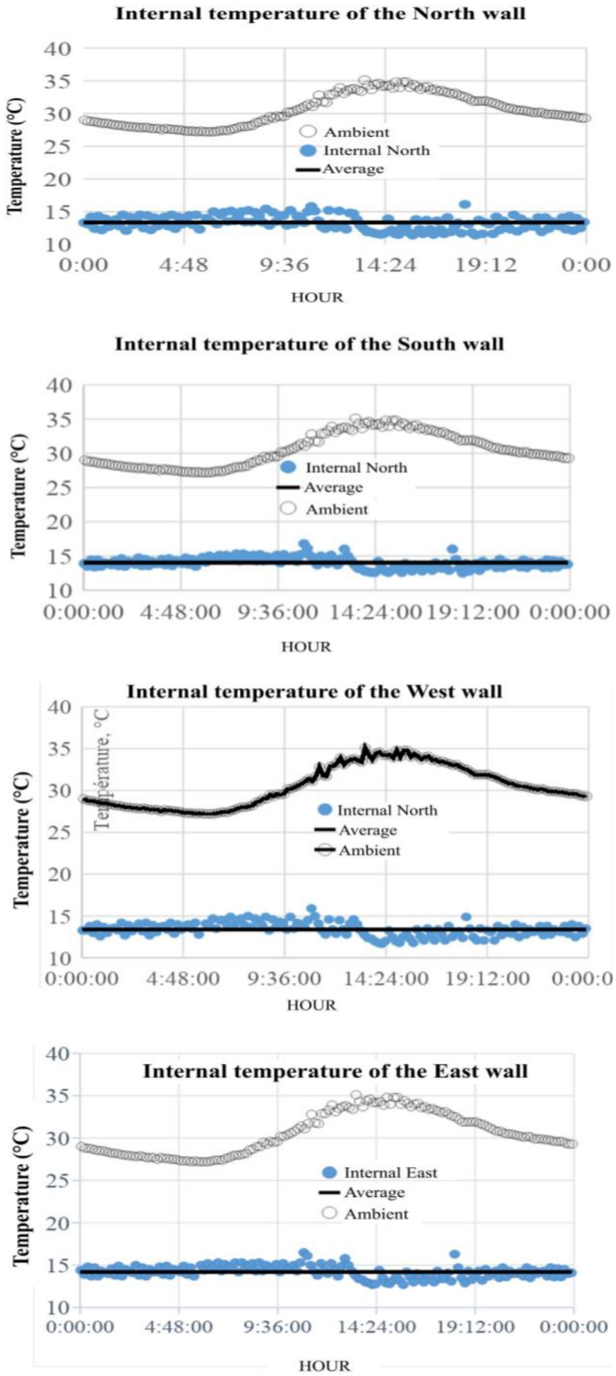


**Fig. 8:** Evolution of Internal Wall Temperatures and Ambient Temperature.

Measurements taken on the interior floor and ceiling indicate that these two walls have the same behavior with average internal temperatures of 13.6±0.7 and 13.2±1.1°C respectively.
The curve in Figure 8 represents the variations in the internal temperature of the cold room empty, that is to say without product inside on the date of 06/29/2018. The average value of the internal temperature is 13.8°C ± 2.0°C. For comparison, the ambient temperature and its average (27.9 ± 1.9 °C) are provided on the same curve. We note a difference between these two average values of 14.1°C. The maximum difference between the different external and internal temperatures is 18.7°C.

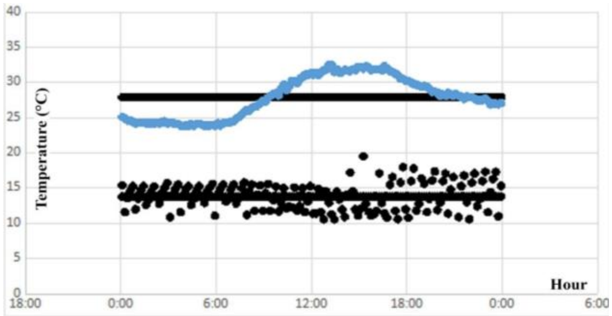


**Fig. 9:** Variation in Internal Temperature on June 29, 2018.

The temperatures of the internal and external walls of the cold room measured on 06/22/2018 are shown in Figure 9. They respectively represent the temperature variation of the West, Ceiling, South and North walls. The average values as well as the ambient temperature were determined. Temperature differences between the interior and exterior walls can reach up to around 30°C for walls exposed to solar radiation. The average values of these temperatures are summarized in Table 3.

**Table 3:** Average External and Internal Wall Temperatures and Their Deviations

| Walls | Day | Sunny period 8:00 a.m. to 12:59 p.m. | 1:00 p.m. to 5:59 p.m. | Non-sunny period 6:00 p.m. to 7:59 a.m. |
|---|---|---|---|---|
| Outer West | 32,51 | 35,59 | 44,13 | 27,35 |
| Inland West | 13,87 | 13,76 | 12,29 | 13,74 |
| Gap | 18,64 | 21,83 | 31,84 | 13,61 |
| Exterior ceiling | 30,24 | 33,47 | 35,48 | 27,31 |
| Interior ceiling | 13,59 | 13,58 | 13,88 | 13,45 |
| Gap | 16,66 | 19,87 | 21,56 | 13,87 |
| South exterior | 41,1 | 40,89 | 46,13 | 44,87 |
| Inner South | 14,54 | 14,56 | 15,12 | 14,29 |
| Gap | 29,56 | 26,4 | 31,10 | 30,7 |
| Outer North | 34,37 | 43,49 | 45,02 | 27,21 |
| Inner North | 13,74 | 13 ,72 | 14,14 | 13,57 |
| Gap | 20,63 | 29,77 | 30,5 | 13,66 |

The outer south wall is the warmest at certain times, according to the data in the table. Regardless of the time of day considered, this wall always had high temperatures. This is explained by the fact that it is oriented towards the south, therefore receiving maximum solar radiation. The outer west and outer north walls come in second place with average temperatures of 44°C in the afternoon. This is explained by the fact that these walls (especially the west wall) receive more sunlight when the sun is at its zenith. Finally, the exterior face of the ceiling Has temperatures close to ambient temperature because it is protected from direct irradiation by the solar modules.

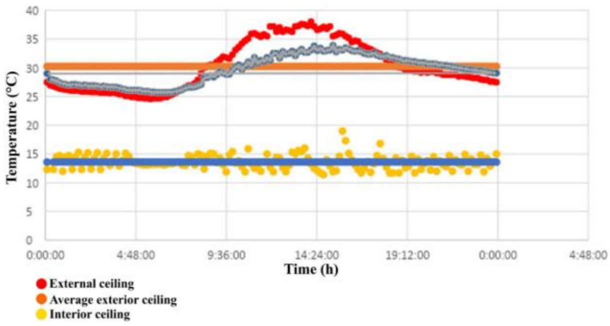


**Fig. 10:** Evolution of Internal and External Ceiling Temperatures and Ambient Temperature on June 22, 2018.

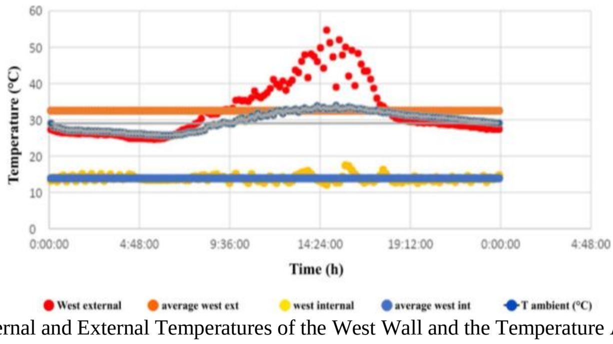


**Fig. 11:** Evolution of the Internal and External Temperatures of the West Wall and the Temperature Ambient From June 22, 2018.

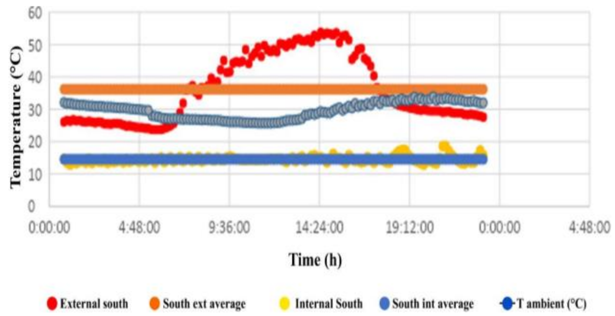


**Fig. 12:** Evolution of the External and Internal Temperatures of the South Wall and the Ambient Temperature on June 20, 2018.

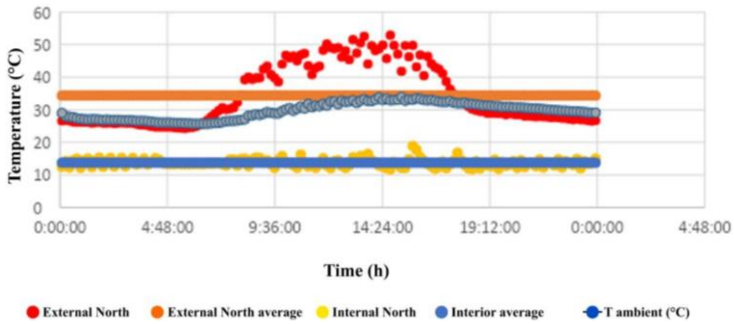


**Fig. 13:** Evolution of the Internal and External Temperatures of the North Wall and the Ambient Temperature of June 22, 2018.

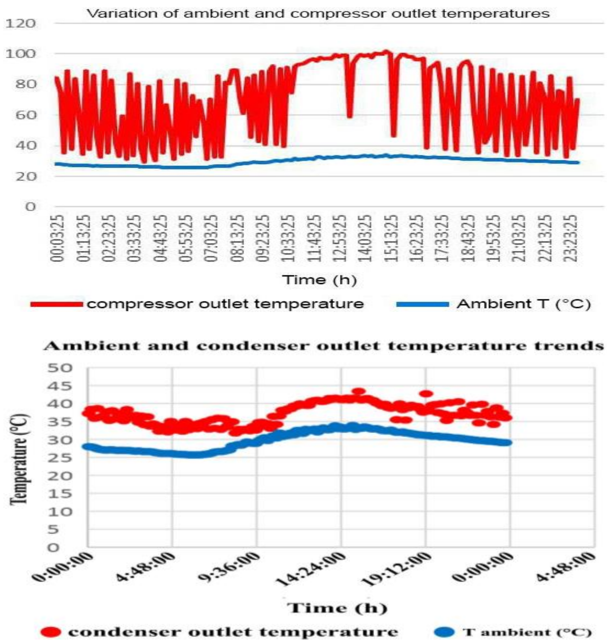


**Fig. 14:** The Temperature Evolution of the Different Elements of the Cold Group as of 06/22/2018.

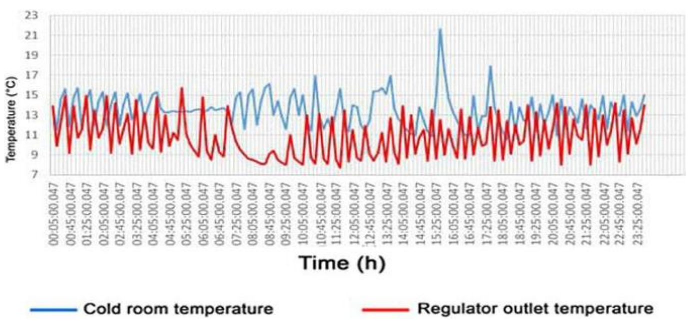


**Fig. 15:** Evolution of the Temperature at the Outlet of the Regulator Compared to the Cold Room Temperature.

## 4.2. Variation of ambient and compressor outlet temperatures

In the figure we notice high values, but also low values of the temperature at the compressor outlet. In fact, the compressor, by compressing the refrigerant, raises its temperature. Then, when the set temperature (set temperature for conservation) of the cold room is reached, the compressor stops and cools on contact with ambient air. However, the compressor temperature remains higher than that of the ambient environment, because it's stopping and restarting time is short. The number of cycles (operating time) reaches an average of 32 per day, i.e. 16 hours of effective operation and 8 hours of downtime (i.e. rest).

- The condenser

We see lower values of the condenser temperature compared to those of the compressor. This is due to the liquefaction of the refrigerant which cools on contact with the ambient air. However, the condenser temperature remains higher than the ambient temperature because of the stopping and restarting time of the cold unit which is very short. We have an average temperature difference of 7.43°C.

- The regulator

At the regulator we have a drop in temperature. At this level, the temperature of the refrigerant gradually decreases before it reaches the evaporator. We have fairly low temperatures at the regulator compared to the atmosphere. outside, with an average difference of 16.74°C.

### 4.3. Evaluation of cold room performance

The average power of the cold unites from 1663W. Thus, we calculated the cooling capacity at certain periods of the day of 06/14/2018 and we determined the average of the different performance coefficients (COP).

- Cooling capacity

According to the relationship$P_O = Q_{IN} * \rho * c * \Delta t$ we have

**Table 4:** Calculation Of Hourly Cooling Capacity

| Hours | Calculated cooling capacities |
|---|---|
| 07:04:58 | 2,445kW |
| 10:04:58 | 2,897kW |
| 13:04:58 | 2,968kW |
| 16:04:58 | 3,321kW |
| 19:04:58 | 3,321kW |

- Performance coefficient

**Table 5:** Calculation of Hourly Performance Coefficients

| Hours | Performance coefficients |
|---|---|
| 07:04:58 | 1,47 |
| 10:04:58 | 1,74 |
| 13:04:58 | 1,78 |
| 16:04:58 | 2 |
| 19:04:58 | 2 |

In summary, we obtain a COP average from the different coefficients calculated above:
$COP_{AVERAGE} = 1{,}9$
However, to be even more reassuring, we have determined theCOP using the COOLPACK software, which gave us a $COP = 2{,}42$ This gap of coefficient of Performance justified bydo that taking variations in the temperature values entering and leaving the evaporator was often complicated and we took average values.
The refrigeration yield is around $\eta = 56\%$ with an average cooling capacity of 2,98 kW

### 4.4. Change in the appearance of mangoes during storage

The conservation of the mangoes lasted 21 days (from June 7 to 28, 2018). The figures below give us the state of the mangoes during the storage period.

**Fig. 16:** Mangoes in the First Week.

**Fig. 17:** Mangoes in the Second Week.

**Fig. 18**: Mangoes in the Third Week.

### 4.5. Evolution of the mass of mangoes during storage

During the conservation period of the mangoes, the evolution of the mass of some samples of the varieties was followed.
The following figure shows the evolution of the mass of the different varieties during the 3 weeks of storage.

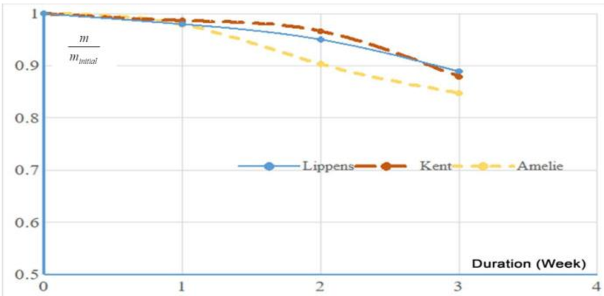


**Fig. 19:** Evolution of the Mass of Different Mango Varieties.

The Amelie variety is the one that loses the most mass during storage; it loses 10% of its initial mass after two weeks of storage and 15% in three weeks.
The Kent and Lippens varieties have similar development profiles. Their mass losses are approximately 4-5% in two weeks and 11-12% in three weeks.
In order to assess the delay of ripening due to cold storage, a sample of mangoes consisting of four triggers was placed in the open air. This sample reached ripening optimal in one week of storage.

## 5. Environmental impact of the cold room device

The cold room powered by the photovoltaic generator is of great importance from an environmental point of view. Unlike conventional thermal generators and generators which are very noisy and polluting, photovoltaic generators are soundless, non-polluting and avoid the emission of a large quantity of $CO_2$ which contributes to the greenhouse effect. Thus according to a study carried out by the West African Electric Energy Exchange System [27] on the Postman Resignation Networks Electric Nationally, the carbon emission factor of electricity produced by SONABEL in Burkina Faso is 0,57t eq $CO_2$/MWh. Photovoltaic solar modules also generate carbon emissions at the time of their manufacture, which is 0,15 t eq$CO_2$/MWh. Thus our generator makes it possible to spare the environment the rejection 102 t eq $CO_2$. These systems, if popularized, contribute to the effective fight against climate change.

## 6. Abbreviations

| | |
|---|---|
| Heat flux (W/$m^2$) | |
| K: Overall heat exchange coefficient (N /$m^2$).K | Δh: Enthalpy difference (Wh/kg). |
| S : Wall area($m^2$) | P : Power(kW) |
| ΔΘ: Temperature difference (K) | n : Number of lamps |
| $\theta_a$: ambient temperature of external air | $P_O$: Cooling power (W) |
| $\theta_f$: temperature in the cold room | Δv : Variation in air speed at the evaporator (m/s) |
| $h_i$: Coefficient interior convection (IN /$m^2$.K) | D : Diameter of the evaporator (m) |
| $h_O$: External convection coefficient (IN /$m^2$.K) | ρ:Air density (kg/$m^3$/) |
| It $is_j$ : Wall thickness j | C:Specific heat of air (J/kg.K) |
| Q: Quantity of heat (kWh). | Qv is the volume flow rate of the air ($m^3/s$), |
| V: volume of the cold room ($m^3$). | $T_{but}$ : Evaporator entering air temperature (°C) |
| $T_{as}$ : Evaporator outlet air temperature (°C) | |

## 7. Conclusion

This study on the performance of a cold room powered by a photovoltaic solar generator showed us that the photovoltaic generator is capable of providing the necessary energy, even during the least sunny periods thanks to the storage system for preserving fruit.

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