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Study and Design of a Mobile Solar Refrigerator Isolated by Ecological Materials

S. Sair*, A. Oushabi*, O. Tanane*, Y. Abboud*, L. Bih, M. Bouhamidi*** and A. El Bouari***

ABSTRACT

In this paper, we present a study of a new prototype solar mobile refrigeration for the preservation of food, the subject has a capacity of 1m3 and can carry 400 kg. Mounted on scooter, the fridge runs on solar energy through photovoltaic panels installed on its walls, and has a capacity of 16 hours autonomy. The insulation of the fridge is provided by renewable based materials, date palm waste of the region Errachidia in Morocco. The thickness of the insulating material is determined to reduce the losses by the different heat transfer modes. The simulation of refrigeration cycle and the calculation of heat balances of each element of the system, allows to estimate the consumption of our refrigerator and assess the capacity of the compressor motor to install, and therefore design the photovoltaic elements necessary for production of energy and the battery's capacity to install, taking account of the ability to 16hrs of autonomy.

Keywords: Solar cooling, photovoltaic systems, thermal insulation, wood date palm, etc.

1. INTRODUCTION

Preservation of perishable foods, especially meat and fish can't be insured without refrigeration. The fish life shelf depends on the degree of acidity and moisture content of the product. Some external influences such as oxygen (air), micro-organisms, storage temperature, light and water migration also play an important role. Cold temperatures slow the progress of the process (biochemical, physical and microbiological and prevent tampering). For a longer life shelf, the product temperature must quickly be lowered. Too slow freezing causes the formation of ice crystals which affect the structure of the product. The refrigeration of fish requires the use of a cold room. A good quality fish frozen at -30°C just after fishing keeps very long[1].

The shelf life depends on the quality of fish and storage conditions (e.g. temperature stability).In rural areas where it is difficult and expensive to feed them with the conventional power grid, the fish is sold by street vendors in carts with wooden frames this material is that it takes moisture or tends to rot quickly; the fish inside these trucks is exposed to room temperature which changes dramatically the quality and threatens public health. This model of truck archaic causes pollution because water flowing fish box sits directly on the floor.

A solar mobile refrigerator fig.1 solves these problems and performs other functions. The use of solar energy in sunny countries is an effective way to overcome the lack of energy among the methods of thermal transformations of solar energy, solar cooling application is most appropriate for the storage of food. Moreover, Morocco is a country where the solar potential is very important, annual sunshine is always greater than 20,000 kJ per m2 of collector area [2].

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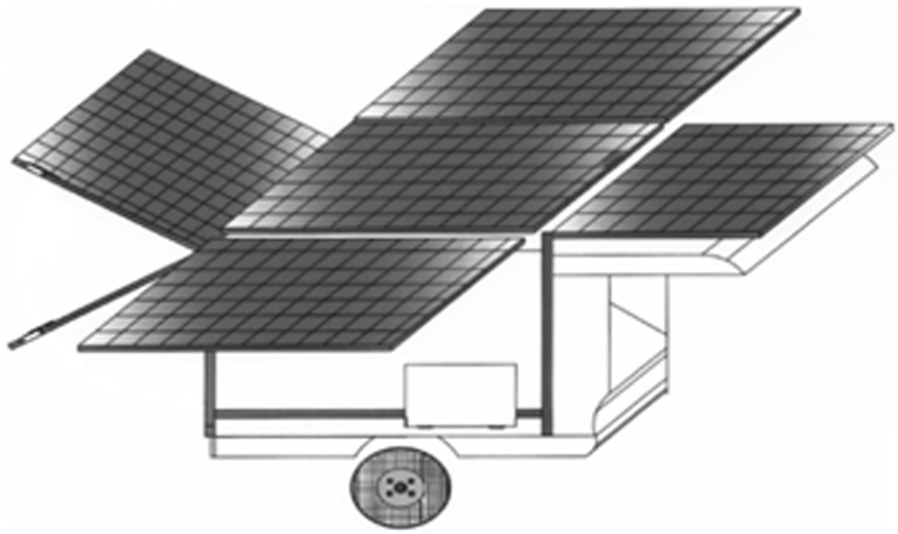


Figure 1: Solar mobile refrigerator

It is therefore important to use this natural resource especially in the field of production of cold. Several studies in the field of refrigeration have been successful [3, 4] and were carried [5, 6]. However, they are sometimes not suitable since there are few who have been tested under real weather conditions. Some recent control methods are discussed in [26-30].

2. EXPERIMENTAL DESIGN

2.1. Fabrication of the Solar Refrigerator

Following a very thorough literature review, and taking account into the recommendations of several authors [7, 8, 9], we proposed to our solar fridge, an article composed of a single compartment, as shown in Fig. 2.

2.1.1. Inside area

European regulations concerning the safety of the materials and articles in contact with food declares that stainless steels are among the most materials used in contact with food in the food industry. The choice of grade will depend mainly [17]:

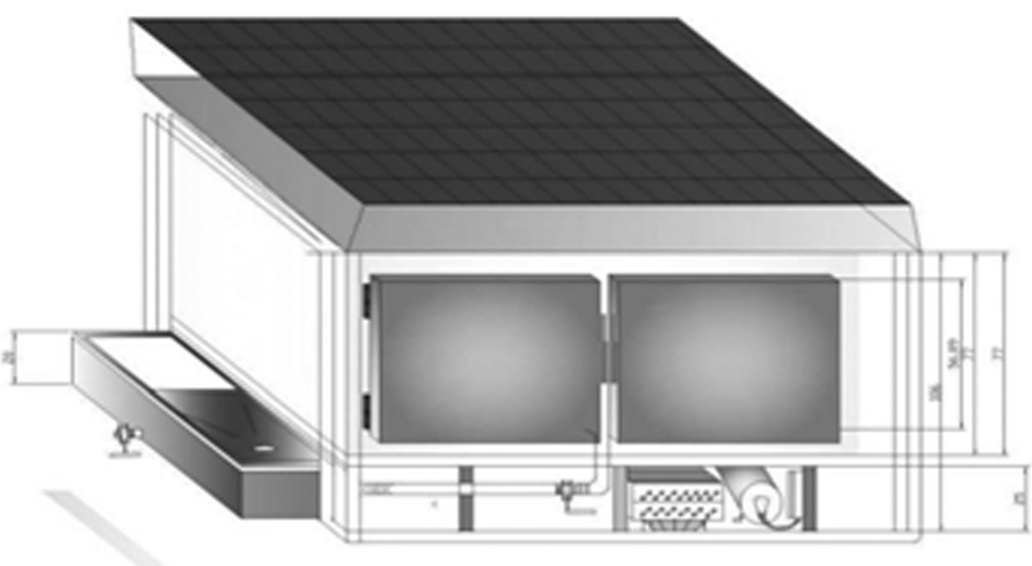


Figure 2: Drawing of the solar refrigerator

- Atmospheric and environmental conditions
- Architectural design
- The surface finish
- Frequency of meetings

NFA 36711 requires acceptance limits based on content stainless steel components:

- Minimum chrome content: 13%

It is possible to harden a few elements such as Ta, Nb, Zr, Mo, Ti, Al, and Cu with the following maximum levels:

- 1% Ta, Nb, Zr
- 4 % Mo, Ti, Al, Cu

The elements that are not mentioned in the decree can be used within the limits of chemical composition defined in the standard NF A 36711. In this work the inner surface of the refrigerator is made of stainless steel sheet of nuance316L, with the composition shown in (Table 1) and which respect the standard, Profiles of this material are given in (Table 2). Chrome provides the corrosion resistance. Nickel improves the ductility and the resistance to certain types of corrosion. The finishing process is very important for corrosion resistance qualities.

2.1.2. Exterior Area

The outer surface of the refrigerator is made of galvanized metal type AZ 150DX51D its composition is given in (Table 3) Other than his good corrosion protection in high temperature, good resistance to abrasion

Table 1
Stainless steel composition

Nuance	316L
Carbone	0.08 Max
Manganese	2.00
Silice	1.00
Chrome	18.00-20.00
Nickel	8.00-11.00

Table 2
Stainless steel 316L properties

Material	StainlessSteel 316L
Temperature (°C)	20
Density (kg/m^3)	7820
Specificheat (KJ/Kg.K)	0.460
Thermal Conductivity (w/m.K)	14

Table 3
Galvanized sheet metal properties

Mechanicalcharacteristics	
TensilestrengthR$_m$(N/mm^2)	270-500
Elongation at break A$_{80}$ % (min)	22

Table 4
Galvanized sheet metal composition

	Composition
C	0.18 Max
Si	0.5
Mn	1.20
P	0.12
S	0.045

due to its surface hardness, the choice of aluzinc sheet metal AZ 150DX51D has excellent reflection of light and heat.

2.1.3. The insulation material

The insulation material was prepared according to the procedure cited in Fig. 3, using waste date palm wood as the basic material for manufacturing of the insulation board, this waste was divided in different sizes, these latter were then mixed with other finer wood particles to ensure good homogenization.

The resin is applied in order to produce a high quality industrial particle board. Then a hot pressing is applied, where the material is compacted to a given level of density and thickness allows polymerizing the resin to agglomerate the particles and stabilize the panel, the prepared plate is then reinforced by two different type of plate using epoxy resin in order to increase the mechanical properties of the plate.

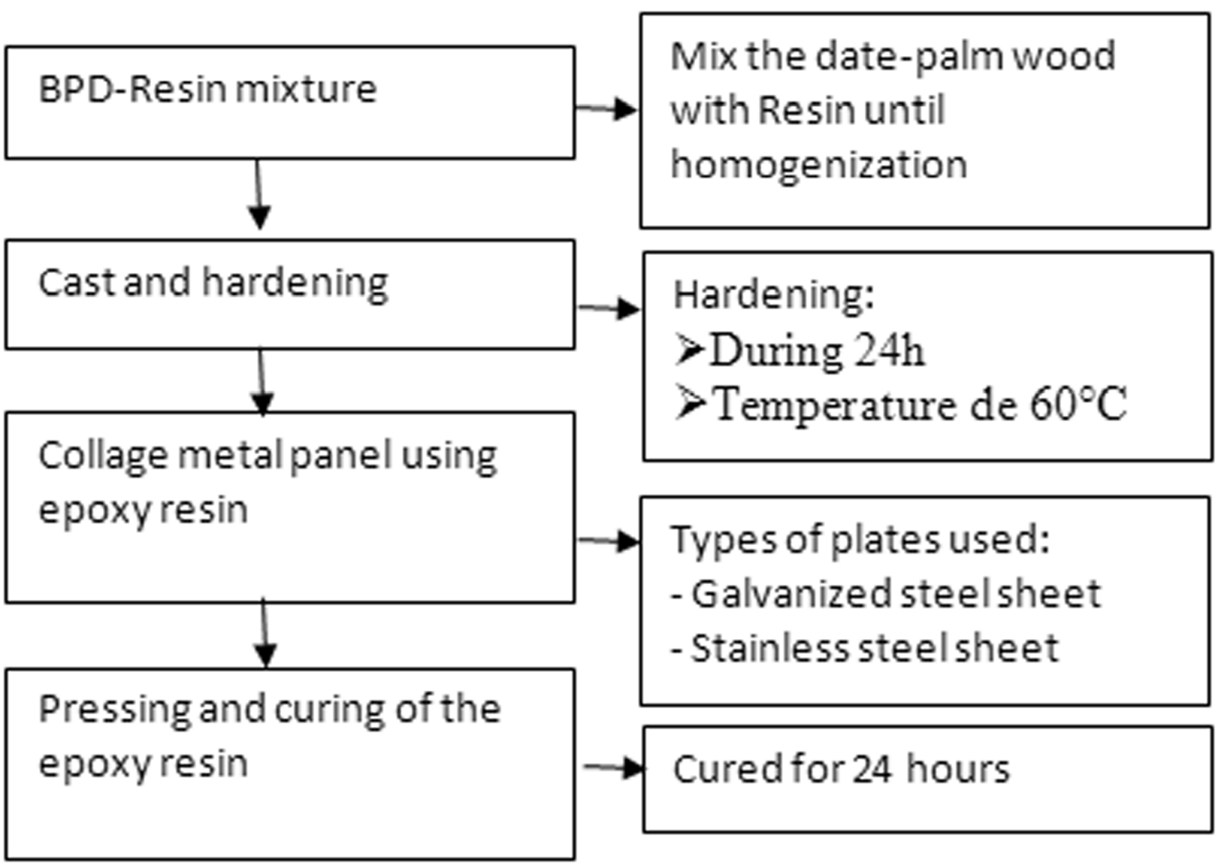


Figure 3: Preparation steps of insulating plates

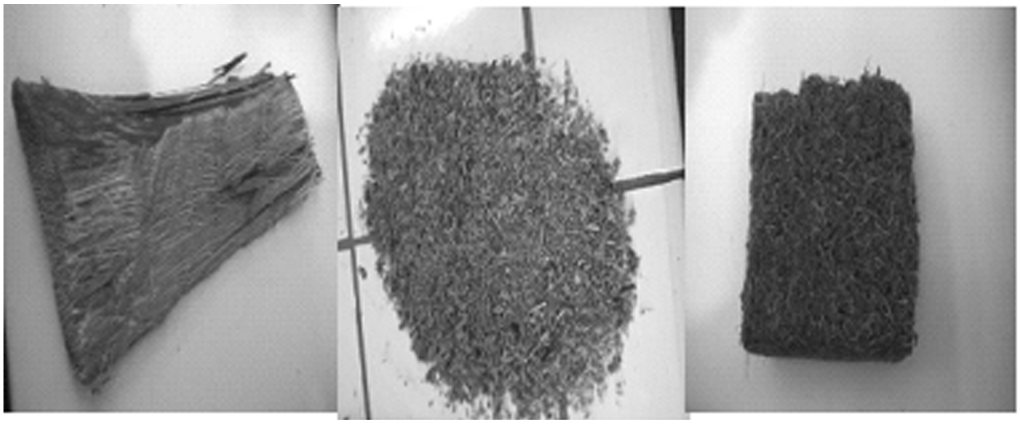


Figure 4: Wood date palm panel

3. CHARACTERISATION OF THE INSULATING MATERIAL

3.1. Thermal Conductivity

Determination of the thermal conductivity of waste date palm and insulating panel was performed using a Thermal Conductivity Analyzer (λ-Meter EP500e) (fig. 5), its measurement consists in applying variable heat flux in a block comprising a sample taken between two plates.

3.2. Scanning Electron Microscopy

To investigate the origin of the thermal resistivity of date palm wood, the sample of date palm wood and the polyurethane used in the insulation of refrigerators at industrial sector were analysed by scanning electron microscopy.

3.3. Flexion Test

The bending tests are an important part of the materials characterization process, the test results provide important information on how the material will behave under real operating conditions. For composite materials used in aerospace, automotive and energy, it is important to understand the level of bending the material and maintain its strength.

The mechanical bending tests were carried out on the Instron brand apparatus. Four rectangular samples of size 200 mm composite were tested at room temperature. The displacement speed used is of 1 mm/min.

Figure 5: λ-Meter EP500e

4. RESULTS AND DISCUSSION

4.1. Thermal Conductivity

The conductivity and the diffusivity value of date palm waste are respectively 0,041 K (W/mk) and 90.038 (W.s1/2/m^{2}K). These values are comparable to those found for other insulating materials in the market (Table 5).

The insulating panel showed an increase in the value of the thermal conductivity of about 0.058 W/mk According to Figure 6, this is due to the attachment of conductive metal sheets on its surface as well as the use of the resin epoxy for strengthening the panel.

4.2. Scanning electron microscopy

The images SEM in fig.7 of the samples (a) and (b) show that the materials are made up of closed cells having a roughly spherical shape each cell is completely enclosed by a membrane or thin walled plastic. For the polyurethane figure (7 a) demonstrates the existence of two types of open and closed cells [16].

In a closed cell, the polymeric membrane forming in the walls of the cells forms a barrier that prevents the passage of gases and liquids, although the gas can pass through the membrane by the slow diffusion process. Therefore, the closed-cell foams have a water absorption and water vapor permeability lower than

Table 5
Density and thermal conductivity of some materials

	Density (kg.m^{-3})	*Thermal conductivity (W/m.K)*
Extrudedpolystyrene	20-30	0,028 [10]
Polyurethane	30	0,030 [11]
Expandedpolystyrene	30-300	0,038 [12]
Date palm waste	200-800	0,041 thisstudy
insulating panel	–	0.058 thisstudy

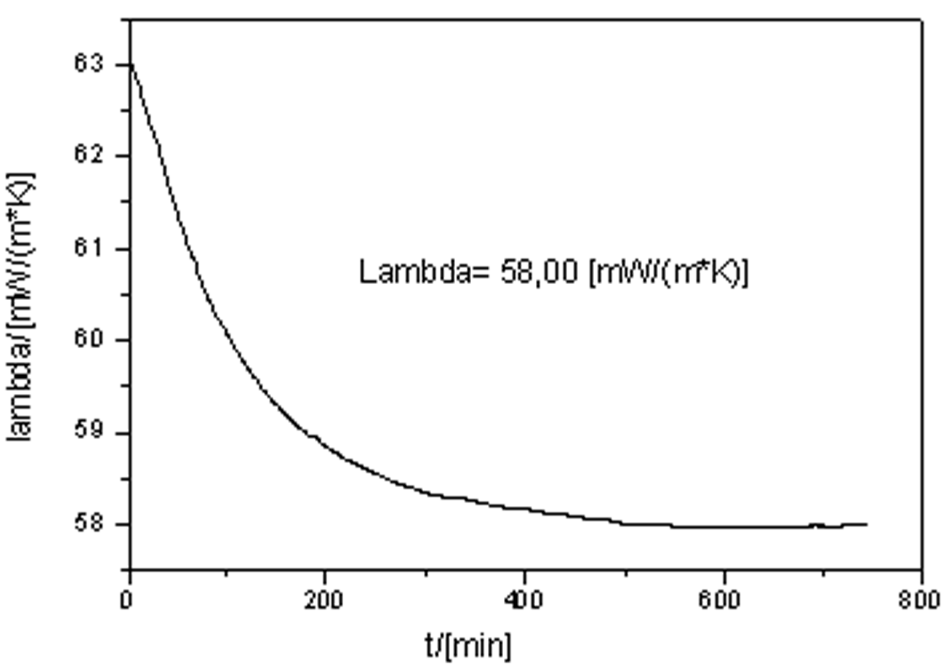
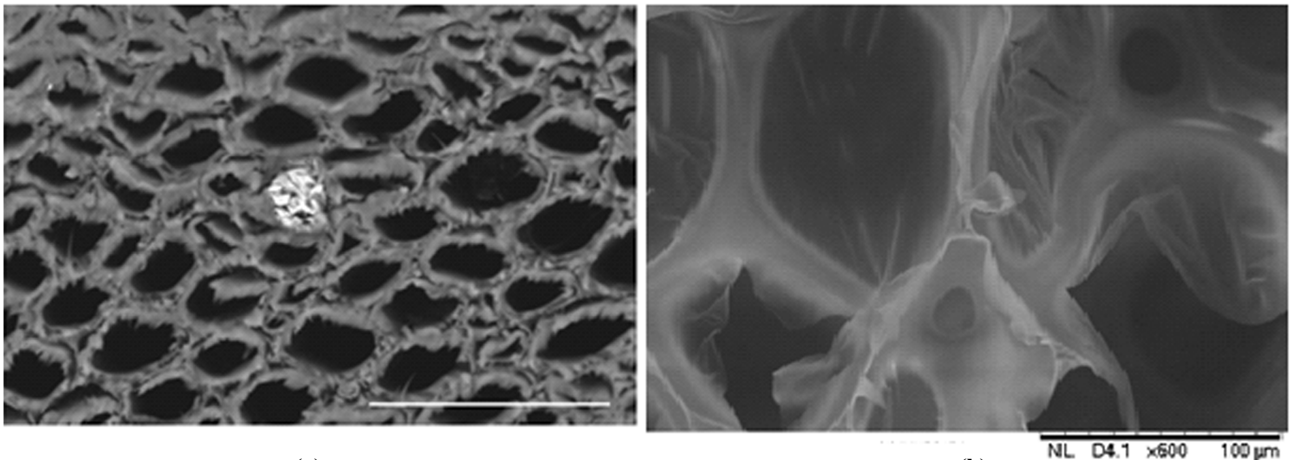


Figure 6: The thermal conductivity of insulation panel



(a) **(b)**

Figure 7: SEM photograph of sample (a) date-palm wood (b) polyurethane scale 100µm

those of open cell foams. If the gas has a low thermal conductivity, the closed cell foams generally have greater resistivity to heat transfer than those that open cells. The cell size also has an influence on the heat resistance. The internal structure of the date palm wood reveals the existence of two types of alveolar which explains the low value of thermal conductivity.

4.3. Flexion Test

According to the results obtained it is observed that the BPD-Epoxy composites exhibit very high flexural strength, it increases by increasing the fiber content .These results were reported in previous studies [13, 14, 15] using organic matrices and vegetable fibers.

The study of mechanical properties of BPD-epoxy composite asserts that the panel has a resistance to very large bending the order of 250 MPa.

4.4. Determination of the power refrigerator

4.4.1. Heat balance

Establish a cold balance is an inventory of the quantities of heat to be removed from the inside of a cold evaporator, to maintain a constant core temperature of products. The Heat contributions are made by: conduction through the walls (Q1), the introduction of external ambient products (Q2), Stokes respiration products (Q3), air exchange (Q4), the illumination system: (Q5) and mechanical ventilation (Q6). These heat quantities are calculated on 24 hrs. Another basic time corresponding to the working day can be considered. It was during this period that the machines are particularly stressed. To determine

Table 6
Data and basic conditions

	Dimensions of the bahut	
length (m)	*width (m)*	*height (m)*
1	1	1
	Basic conditions	
	inside	*exterior*
T (°C)	- 16,0	40,0
H.R. (%)	95	20

the thermal balance leading namely the power compressor installed, data and basic conditions have been specified, this information is given in (Table 6). Using this information and the equations of heat exchange [18, 19, 20], we calculated the different heat inputs by the wall, food, lighting and mechanical ventilation.

• Lossthrough the walls

The wall is generally constitutes of several layers of materials of different thermal conductivities, the thermal resistance was calculated using formula (1) shown below:

$$\frac{1}{K} = \sum \frac{e}{\lambda} + \left(\frac{1}{hi} + \frac{1}{he} \right) \tag{1}$$

K: heat transfer coefficient (W/m°C).

e/λ: Represents the sum of the ratios of the different layers.

e = thickness of the each material (m)

λ = thermal conductivities of each building material (W/m.°C).

1/hi, 1/he = thermal resistances of interior and exterior surface exchanges (m^2°C/W).

Table 7
Loss through the walls

Vertical walls	$Qw = K_w \times S_w \times \Delta T_w \times t = 751$ kJ
Roof	$Qp = K_r \times S_r \times \Delta T_r \times t = 916$ kJ
Floor	$Qp = K_f \times S_f \times \Delta T_f \times t = 938$ kJ $Qp = \sum Q = 5\ 605$ kJ = 0.1 KW

With:

K: coefficient of heat transfer through the walls (W / m^2K).

S: the surface of the walls in (m^2).

ΔT: the temperature difference between the external and internal environment (K).

t: time (s).

• Loss throughthe introduction of products with ambient temperature

The contribution of food depends mainly on their thermal properties the following tab.8 shows the thermal characteristics of some food products.

Table 8
Thermal characteristics of some food products.

1. Amountintroduced/time base (kg)	100
Amountstored (kg)	100
Temperature of introducing (°C)	12
Output temperature or storage (°C)	-16
Specificheatbeforefreezing C_1(kJ/Kg.K)	2,35
The latent heat of freezing (kJ/kg.K)	150,8
Specificheatafterfreezing C_2 (kJ/kg.K)	1,43

Table 9
Loss through the introduction of products with ambient temperature

Beforefreezing	QD1 = m × C1 × DT1	5170 kJ
Respiration	QD = m × R	- kJ
Duringfreezing	QD2 = m × L	15084 kJ
Afterfreezing	QD3 = m × C2 × DT2	858 kJ
	QD = ∑QDi	21 112 kJ = 0,4 kw

• Contribution by the air exchange

The heat gains (sensible and latent energy) from air infiltration due to the permeability of the openings and new air external supply for ventilation must be considered. These heats depend of the air inlets by infiltration and opening of the fridge door. To determine the contribution in this heat gains we have simulated the conditions of operation of opening and closing the door of the fridge solar these conditions are given in Table 10:

Table 10
Condition of using fridge during the day

	Opening the door
Opening time	10 s
Openinghours Frequency	10 times in hour
Daily use of the refrigerator	8 hours per day

$$Qr = \frac{\left(Vx\ \Delta hx\ jxn\right)}{1000} = 8913KJ = 0,\ 2\ KW \qquad (2)$$

Qr = amount of daily air exchange heat (kWh).

V = volume of the cold room (m^3).

Δh = enthalpy difference between the atmosphere in the cold room and the external environment (Wh/kg).

j = air density = 1.2 kg/m^3.

n = number of air changes in 8 h.

• Total daily balance Loss

QT = ∑Q = 40 262 kJ = 0, 70 kW

Based on the results of the thermal balance, the cooling capacity needed to cool the foodstuffs was determined, and the power of the associated motor-compressor, which is set at 700 W.

The photovoltaic simulation

The sizing of photovoltaic systems serves to identify two principal variables: the size of the field of photovoltaic modules generates energy and storage energy capacity (battery) for electric daily operation.

It is understood that the reliability and efficiency of the solar system, depend largely on the design. Many methods have been studied and used by various authors for proper sizing of photovoltaic systems. In our case, the choice fell on a method that combines between analytic and numerical methods. [21, 22] It consists in:

- The determination of the global radiation on a slope from the global radiation data on the horizontal plane and the ambient temperature at the site chosen for the installation of the refrigerator prototype.

- Secondly, determine the size of the field of photovoltaic modules (the surface of the field, the number of modules in series and in parallel) and the battery capacity to be installed.

The photovoltaic system simulation using numerical methods prove that using the photovoltaic panels monocrystalline, 45 Wp power and size 0.45 × 1, 00 m2 with a battery of 12V capacity, 172 × 227 × 306 (mm) in size and 30 Kg weight allows the proper functioning of solar fridge in weather conditions of the selected place.

Some losses are caused by an interaction between the environment, the inverter and modules [23, 24, 25]. Figure 8 show several types of losses are introduced in the form of a diagram the various losses are mentioned in %.

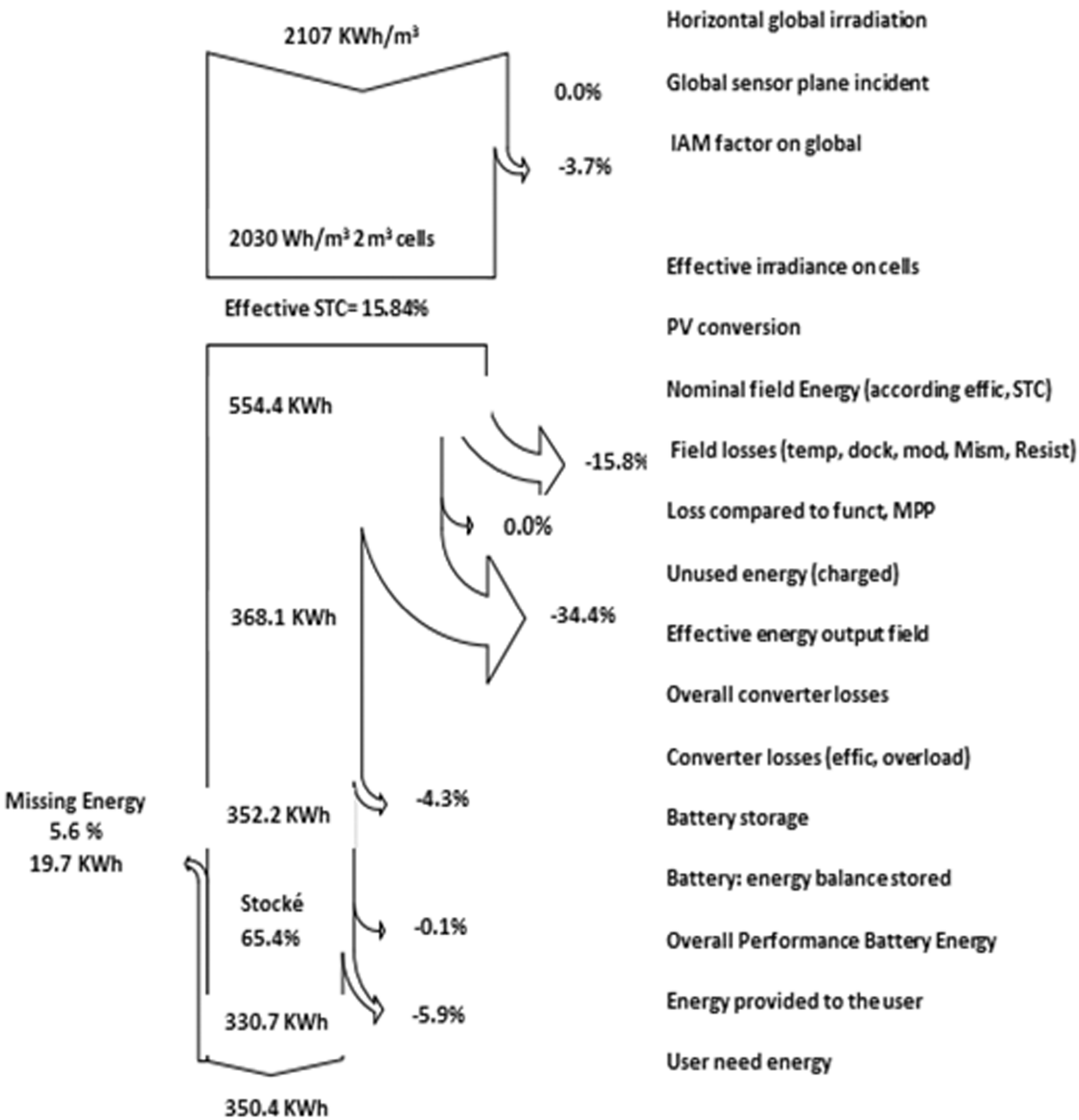


Figure 8: Diagram showing the various types of loss for the solar fridge in meteorological Conditions

5. CONCLUSIONS

In conclusion the use of compression machine for air conditioning, refrigeration or freezing is particularly interesting these machines can operate also with heat sources. Indeed in the context of sustainable development and the limitation of greenhouse gas emissions, it is a prerequisite for designing new processes to take into account at the same time the amount of implementation energy and also the quality of these energies. Thus we can adapt the energy resource used to produce desired useful energy. This report is a contribution to the solar refrigeration by mechanical compression. It presents the various stages of manufacture and testing of a solar cooling machine using photovoltaic panels in the site Errachidia to show that it is possible to build and operate this type of solar unit in developing countries, we have:

- Used the resources and local materials; simplified the manufacture of the machine elements while maintaining good performance.
- The simulation results obtained by this refrigerator, show that this type of refrigerator can contribute to environmental conservation and sustainable development in rural areas beyond the reach of the electricity grid.

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