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Conception of a Mobile Solar Photovoltaic Storage Cooler

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Abstract The current food industry is almost totally dependent on refrigeration in one form or another, to manufacture, store, store and bring the product to customers. The use of low temperatures for food preservation is known and practised for several thousand years, but it was not until the mid-19th century that Pasteur and others determined the bacteriological nature of food spoilage and the beneficial effect of cooling on food spoilage. And since then, man has constantly refined the various techniques allowing him to preserve food products. A cold room is generally used for the preservation of food products in their original freshness, in smaller quantities, for later consumption. It avoids loss of colour, taste qualities, values and weight of stored products by respecting health and safety rules for optimal operation.

In this study, we will see the different techniques of cold storage, the means of cold production. After having done the thermal balance of the cold room, we made the calculations of the various thermal loads to know the cooling capacity necessary for the cooling of some dairy products in our case. Finally, the design of the refrigeration system and the photovoltaic system was designed in order to choose the most suitable components for the proper operation of the cold room.

Keywords cold room, food, milk, refrigeration, photovoltaic, cooling capacity, Senegal

1. Introduction

In food, the atmosphere of housing and workplaces, travel, leisure, health, it is usually associated with cold. However, the new technologies used (freezers, air conditioners, ice water fountains, ...) must evolve to better meet the needs of the populations. Nowadays, the challenges faced by manufacturers are related to the consumption of appliances, and above all to ecology, as the appliance remains little respectful of nature. Refrigerants used in these refrigeration systems are highly volatile, as is the case for CFCs that are harmful to the ozone layer. They escape into the atmosphere through leaks during maintenance of the circuits but also at the end of life of the devices causing a decrease in performance and a considerable increase in their energy consumption (electric current). The manufacture of CFCs is now prohibited and alternative fluids such as HCFCs (hydro chlorofluorocarbons) are being introduced. And with the development of solar energy, it is now possible to power devices more easily.

Our study focuses on the design of a solar powered mobile cold room for the storage of dairy products, so we will focus on the use of cold in the food sector in particular food preservation.

In the review of the literature, we will come back to the means of production of the cold, the different techniques of preservation by the cold and the specificity of the cold chain according to the product and refrigerants. Then we will see the research methodology and the materials used. Then we will see the results obtained and make a discussion. And finally, we will conclude and identify some perspectives.

2. Literature review

The current food industry is almost totally dependent on refrigeration in one form or another, to manufacture, store, store and bring the product to customers. The use of low temperatures for food preservation is known and practised for several thousand years, but it was not until the mid-19th century that Pasteur and others determined the bacteriological nature of food spoilage and the beneficial effect of cooling on food spoilage. And since then, man has constantly refined the various techniques allowing him to preserve food products.

2.1. Means of production of cold

To produce cold is simply to absorb heat at a temperature below ambient temperature. Thus, the cooling of anybody below ambient temperature requires the use of an endothermic mechanism [1]. The heat then extracted from the body is then released into the ambient environment: air or water. Among the many endothermic mechanisms, various transformations can be cited:

- Thermodynamic processes such as the dissolution of solid bodies in a liquid (water, for example) or in a solid (ice, for example); the relaxation with constant enthalpy or constant entropy of a gas; the evaporation of a liquid phase, for example in an absorption or compression cycle; fusion or sublimation of a solid phase;
- Electrical or magnetic processes such as Peltier thermoelectric cooling or adiabatic desalination.

In thermodynamic cold production processes, we have the dissolution of a salt in water or ice, the relaxation of a compressed gas and evaporation fusion sublimation.

In the dissolution of a salt in water or ice, the salt, put in solution in water or in a liquid phase causes a strongly endothermic chemical reaction which induces a significant decrease in temperature. This is the case of the following bodies:

- Calcium chloride in solution (2.5 by 1 H2O) causes a 34°C reduction in temperature (in a medium without exchange with the atmosphere);
- Ammonium nitrate in solution (1 Nitrate for 1 H20) causes a temperature drop of 25°C;
- Sodium sulphate in solution in hydrochloric acid (1 Sulphate for 1 HCl) causes a drop of 28°C.

Lower temperatures can be reached when mixing salts with a solid phase such as ice: during this mixing, the melting temperature is strongly lowered and thus the melting heat of the ice serves to cool the mixture [2].

This principle of cold production remains very little used mainly because of its irreversibility. However, certain safety devices for cooling rooms or environments are based on this principle.

For the expansion of a compressed gas, we use the lowering of the temperature of a gas that we relax. Different types of detents must be distinguished for the analysis of this process:

- Detent with outdoor work production is used in gas compression refrigeration machines, which is the case for liquefaction of gases such as air, for low temperature refrigeration production following a JOULE / BRAYTON or STIRLING cycle;
- Relaxation by rolling (carried out in a regulator or an orifice or a capillary): known as relaxation Joule-Thomson, it is a transformation with constant enthalpy (no exchange of work or heat with the outside environment) At normal temperatures and for all gases (except hydrogen), gas expansion results in a drop in temperature;
- Detent in a centrifugal field: the device commonly referred to as a RANQUE tube (from the name of the French inventor who highlighted this effect) consists of a nozzle and a main tube.

These equipments are generally limited to very specific applications (localized cooling of mechanical parts) characterized by needs of low cooling capacities. The coefficient of performance (refrigeration production/ gas expansion energy) of this equipment is indeed very poor.

Finally for evaporation, fusion and sublimation, the change of state of a body can constitute a strongly endothermic transformation of evaporation (liquid to vapour), fusion (solid to liquid) or sublimation (solid to vapour). These transformations that implement latent heat transfers of vaporization, fusion and sublimation are the basis of the most common cold production processes.

The electrical and magnetic processes of cold production can be grouped into two groups: thermoelectric cooling by the Peltier effect and demagnetization.

In thermoelectric cooling by Peltier effect, if an electric current is circulated through a heterogeneous circuit consisting of a series of semiconductor bars placed between two conductive junctions, there is a cooling of one junction and a warming of the other. This effect is reversible according to the direction of the current. It therefore only works with direct current. If the hot surface is kept at a constant temperature by heat exchange with the ambient environment, refrigeration can be produced on the cold surface.

In demagnetization, some paramagnetic substances placed under a magnetic field and then subjected to adiabatic demagnetization cool down. This property is used at very low temperature (near absolute zero). Adiabatic desalination allows the temperature to be lowered further to lower values but the very notion of temperature becomes delicate because of the almost impossible to obtain a direct measurement but often an extrapolated value. These techniques are mainly reserved for the field of research in physics, but in recent years there has been a renewed interest in near-ambient temperatures thanks to the use of new materials. However, one of the most important elements in the production of cold is the refrigerant [3].

2.2. The different techniques of preservation by the cold

There are several cold storage techniques including refrigeration, freezing, freezing, and controlled atmosphere storage.

Refrigeration of a product is the act of artificially keeping it below room temperature, that is, at the optimum temperature for storage and above its freezing point. Refrigeration makes it possible to spread over time the marketing of fresh products and transport from the place of production to the place of consumption. It also allows the maturation of meats by increasing the tenderness of muscle fibres. It significantly slows down microbial evolution and its consequences (purification, toxins, etc.). However, it sometimes removes flavour from products. It causes the loss of oxidative vitamins, especially vitamin C. The two most common large-scale refrigeration technologies are compression and absorption systems.

- The compression systems: Steam-compression refrigeration is based on the condensation of steam from a refrigerant following compression and its evaporation following expansion;
- Systems with absorption: Gas-absorbing refrigeration uses a heat source to rotate the cycle to extract heat, instead of the compressor normally used.

Freezing is a food preservation technique. This technique involves lowering the temperature of the product and keeping it below the melting temperature of the ice (0°C) in order to suppress any biological activity (which depends on the presence of water in liquid form) see chemical and enzymatic (for very low temperatures). To obtain –18°C in the heart of the food within 24 hours. The different types of freezing are:

- Slow freezing at –25°C in 4-star domestic freezers (fresh produce or prepared meals);
- Rapid industrial, air-based freezing occurs through cold air tunnels or through indirect contact with a cooled plate (fruits, vegetables, fish, shellfish, prepared meals).

Freezing too slowly leads to the formation of ice crystals and thus a deterioration of the cells. When thawing, the product produces a lot of water. Food must be kept packed to avoid surface drying [4]. Thawed product should not be refrozen. Freezing is an industrial technique that consists of brutally cooling (minutes to an hour) food by exposing it intensely to temperatures ranging from 35°C to 196°C. Thanks to this process, the water in the cells crystallizes finely, thus limiting cell destruction. The treated products retain their texture, flavour and can be kept for longer. There are several freezing processes, mainly:

- The contact technique, reserved for thin foods, is performed by introducing a food between two plates in which a fluid circulates at -35°C;
- The convection technique is performed by exposing the product to cold air or gas at very low temperatures (up to -35°C for mechanical cold technology and -130°C for cryogenic technology);

- The immersion technique, suitable for products of irregular shapes, which involves immersing the food in a fluid at very low temperatures such as liquid nitrogen.

Controlled atmosphere storage is a storage method that prolongs the life of fruits and vegetables by controlling the concentration of gas that influences the ripening process of fruits and vegetables. The use of a controlled atmosphere brings many advantages, but mainly increases the lifespan of fruits and vegetables. Fruits and vegetables ripen by breathing in different gases. The controlled atmosphere controls this “breathing” to slow down the maturation process.

- Controlled fruit storage environment;
- A controlled vegetable storage environment;
- Controlled atmosphere in food preservation;
- Refrigerated cargo-controlled atmosphere;
- Controlled atmosphere in refrigerated transportation and food presentation.

However, depending on the nature of the commodity transported, there is a specific conservation feature.

2.3 The specificity of the cold chain according to the product and refrigerants

We call the cold chain or refrigeration chain all logistics and domestic operations (transport, handling, storage) to maintain food or pharmaceutical products at a given temperature in order to preserve their safety and taste qualities. With regard to food, cold acts essentially by delaying the appearance of weathering phenomena and by slowing down microbial multiplication, especially for pathogenic microorganisms. The use of the cold thus makes it possible to extend the life of foodstuffs and to increase health security. This corresponds to beneficial effects for all stakeholders, from the manufacturer to the final consumer, by allowing them, among other things, greater flexibility in product management.

Meat can be obtained from butchers (cow, sheep and horse), deli meat (pigs), poultry and game. These meats are made of muscle, fat and water. Degradation of the quality of the product begins at slaughter, the cold allows to delay the development of bacteria located mainly in the surface of the carcasses. Meat is stored at temperatures between +2°C and +4°C, with humidity between 75% and 85%. However, it may be necessary for certain substances to undergo a definite evolution in order to achieve the optimal state sought by consumers as such certain products such as mutton beef are hard if they are consumed immediately after the death of the animal [5]. The meat becomes tender after one week of preservation. But if the meat is not sufficiently cooled, it is the carrier of pathogenic germs. For this reason, maturation is done at a temperature not exceeding +4°C. If the shelf life of a meat should exceed 4 weeks, it will be frozen. Air freezing in a ventilated chamber is slow if the temperature is between + 18°C and - 22°C, or fast in a very ventilated tunnel if the temperature is between - 25°C and - 30°C. It is ultra-fast (frozen) in special tunnels if the temperature is between - 35°C and - 40°C.

In the conservation of fishery products, the degradation of the quality of the fish begins when it is caught. For newly caught fish, short-term storage is at -1°C in scaly or fragmented ice. Fresh product can be stored for a week at temperatures between 0°C and +3°C for a longer shelf life. Only freezing around -25°C is effective. Fish should not be frozen more than 24 hours after being caught or prepared as if to be cooked. The storage temperature of the frozen product is around -12°C. Live oysters, mussels and shellfish can be kept at a temperature between +6°C and +15°C. Shrimp, crabs and lobsters can be canned at +3°C. They must be cooked in boiling water before being frozen.

Cold weather allows the preservation of our plant-based foods:

- Fresh (refrigeration in the range of - 1°C to + 10°C);
- Dead, frozen (fast freezing around -30°C followed by storage a – 20°C)

Most fruits and vegetables contain a very high proportion of water and wilt quickly (they dry out). Storage conditions require a high humidity of 90-98% saturation and temperatures as close to their general freezing point of 0°C as possible. Some leafy vegetables are sprinkled with pieces of ice to keep it wet and cold. A few products, such as cucumbers and some potato crops, are kept at higher temperatures. These conditions vary depending on the variety, the state of maturity at harvest and the storage time required. Strawberries, other red fruits and pieces of cauliflower, are quickly frozen with liquid nitrogen. Frozen fruits and vegetables are sealed in plastic bags and stored at –18°C or lower because the humidity at this temperature is not important.

Milk is processed in the dairy and associated plants into whole or "market" milk, skim milk, creams, butters, cheeses, powdered milk, whey, yogurt, butter oil, condensed milk, powdered milk and ice. Across the dairy industry, the main mechanical cooling requirements are:

- Cool milk directly after it leaves the cow and before it is transported to a central dairy;
- Keep raw milk cool after entering the dairy;
- Chilled water for use in plate heat exchangers to cool milk and milk produced directly after pasteurization;
- Ice water to wash butter;
- Cold temperature stores for milk, butter, cheese, yogurt and other dairy liquids;
- Frozen storage for butter (and sometimes cheese);
- Continuous freezers, gridded and blown air for ice cream;
- Cold brine for ice freezing.

The milk comes from the cow at about 37°C and must be cooled for 2 hours to 4°C or less under hygienic conditions. At this temperature, all the microorganisms present do not multiply at a dangerous rate and milk can be transported.

Table 1: Storage conditions for some foods

Products	Storage temperature in (°C)	Humidity in (°%)	Lifetime
Apple	1 to 4	85 to 90	2 months
Banana	12 to 14	90	10 to 20 days
Beer	2 to 12	65	3 to 6 months
Cabbage	0 to 1	95	3 to 5 weeks
Carrot	0 to 1	95	1 to 2 months
Celery	0 to 1	95	5 to 8 months
Cucumber	10 to 12	90 to 95	10 to 14 days
Dairy products	0 to 1	-	2 to 4 months
Ice cream	-23 to -28	-	6 to 12 months

3. Research methodology and materials Used

A cold room is generally used for the preservation of food products in their original freshness, in smaller quantities, for later consumption. It avoids loss of colour, taste qualities, values and weight of stored products by respecting health and safety rules for optimal operation. This is why there are several types of cold rooms. Depending on the operating temperature there are two types of cold room: the positive cold room and the negative cold room.

In positive cold rooms the temperature is above 0°C. They are used to store food. However, an evaporation temperature of 5°C is observed. This temperature varies according to the food it contains. It is mainly used for fruits and vegetables that do not require refrigeration. Some types of refrigerants are recommended such as R134A.

In negative cold rooms the temperature is below 0°C. Generally, at 18°C, it can be configured for a lower temperature. They are used to freeze or freeze food. The evaporation temperature generally does not exceed 30°C. The products concerned by this type of chamber are foods that must be stored over a long period of time. For this cooler, the most common refrigerant used is R404A.

Whether it has a positive or negative operating temperature a cold room is usually built in two ways, hard or modular.\

3.1 The design of cold rooms

The hard cold room has a structure made up of traditional masonry, that is, cinder blocks, bricks, or simply reinforced concrete. The cold room is said to be modular if it consists of assemblable panels. They can be disassembled and moved to another location if necessary [7].

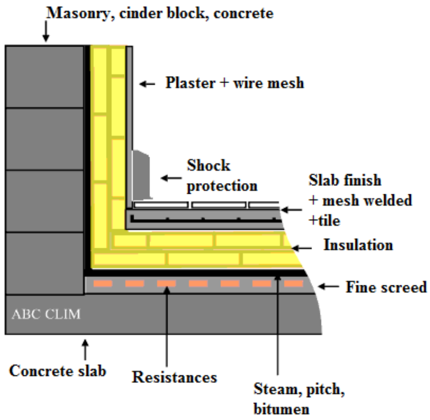

Figure 1: Diagram of a hard-built cold room [https://www.abcclim.net/chambre-froide-en-dur-isolation.html]

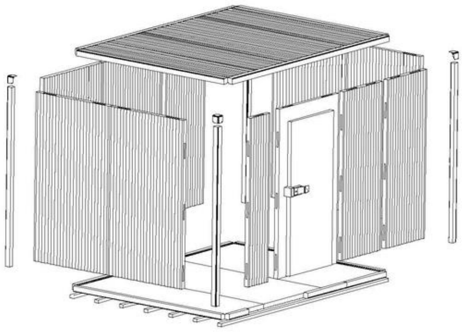

Figure 2: Example of a modular cold room [https://www.oceanis-frigo.com/fr/produits/chambre-froide-modulable.html]

Insulation plays an important role in the design of a cold room [8]. It allows to limit the exchange of heat between the internal and external environment of the cold room. Indeed, heat is transmitted between two environments of different temperatures in variable quantity. This transmission takes place in three ways: conduction, radiation and convection. This results in a heat flux (φ) between the two media. The overall influence of convection and radiation on an insulated wall is quite small compared to that of conduction. Thus, insulating a wall consists in reducing the transmission by conduction by interposing an insulating layer. And the quality of this insulation is measured using a physical quantity called thermal conductivity (λ).

Thermal conductivity is the quantity used to quantify a body's ability to transmit heat. It is also the amount of heat transferred per unit of time and per unit of surface under the action of a temperature gradient between the two sides of any wall. Thermal conductivity occurs in the statement of Fourier's law defining the transmission of heat through a wall. It applies, of course, to refrigeration insulation and reads as follows:

$$\varphi_x = -\lambda \frac{dT}{dx} A$$

A: exchange area in m²

λ: thermal conductivity of material W/m.K

φ_x: Unit Heat Flow in Watts

dT/dx: Temperature gradient across a wall

It should be noted that thermal conductivity determines the choice of insulation. Indeed, the lower the insulation the better.

Insulation in the walls reduces the exchange of heat energy between the inside and outside of the cold room. From an economic point of view, insulation is the best way to save energy. The choice of material to be used is therefore essential during construction. Therefore, good insulation must:

- Have very low thermal conductivity;

- Good resistance to water vapour diffusion;
- Be durable, lightweight and stable over time;
- Be flammable and reasonably priced;
- Be odorless and free from contact materials.

The most commonly used insulation materials are:

- Foam rubbers;
- Expanded cork;
- Fibreglass or Rock;
- Polyurethane foam;

Expanded or extruded polystyrene.

3.2. General functioning of a cold room

The operating principle of a cold room is based on the ability of refrigerants to evaporate or condense at various temperatures depending on the pressure. Changes in the state of the refrigerant allow to capture the heat present in the cold room. Initially, the fluid circulates in the evaporator where it is vaporized, thus becoming gaseous. This highly cooled gas seeks to rise in temperature and thus absorbs the heat of the food present in the cold room. It then passes through a compressor located outside the refrigerator. Then liquefies and passes through a coil called a condenser to release the heat into the ambient air. All the elements enabling this process to run smoothly are called the cold group.

A cold room is equipped with a refrigeration unit consisting of the condenser, dehydrator, evaporator, regulator and compressor. Each of these 5 elements plays an important role in the circulation of cold air in the aircraft.

The compressor is the element that sucks the low pressure and low temperature gas from the evaporator back to the condenser under high pressure and high temperature. Moreover, the compressors are composed of two parts: a motor part and a compression part, the compression part being the mechanical part driven by an electric motor (motor part).

The condenser is the element that allows the refrigerant to pass from the vapour state to the liquid state. This condensation phenomenon is achieved through cooling. It is possible to cool with a capacitor with fan, with a static capacitor or with a water capacitor. The capacitor transfers its energy to the medium considered to be air or water.

The dehydrator has 3 main functions it must maintain the refrigeration circuit as clean as possible by filtering the particles, it dehydrates the circuit and neutralizes the acids because the acid formation is harmful to the lubricating oil of the compressor and to the windings of the compressors

The holder is the organ that ensures the proper filling of the evaporator with refrigerant. It reduces the pressure at the evaporator inlet to reduce the temperature of the fluid. It's called a thermostatic regulator.

The evaporator is a heat exchanger that transforms the liquid into steam. To better diffuse the air in the cold room a ventilation system is often integrated. The evaporator is connected to a water drain for condensates. However, for negative cold rooms it is necessary to provide a warm wire that allows to avoid the formation of ice. The evaporator absorbs energy to the medium considered to be.

3.3. Measuring equipment

The purpose of the mobile cold room is to store dairy products (liquid whole cow milk). The product will be stored by refrigeration at a temperature of 4 for a shelf life of 7 hours with a humidity of 90%. The dairy product will be introduced with a temperature corresponding to the ambient temperature.

To ensure the mobility of the cold room it will be placed on a trolley. The use of this trolley requires constraints regarding the size of the cold room. So, a household refrigerator will be used to meet space constraints.

The trolley will be able to accommodate the entire refrigeration and photovoltaic system. As soon as the sun appears, the system produces cold. The only energy consumed is solar energy via a photovoltaic sensor. This energy to power a compressor directly, but with a storage consisting of batteries to offset a possible lack of energy in case of adverse weather.

The thermal balance will be done in order to find the necessary cooling capacity to choose the appropriate refrigerator.

The cooler will be a household refrigerator of length (L = 0.92 m), width (L = 0.37 m) and height (h = 1 m). It should be noted that these dimensions correspond to the outside dimensions of the cold room. Moreover, the high floor will serve as a door.

To know the internal dimensions of the cold room it will first be necessary to determine the thickness of the insulation to be put.

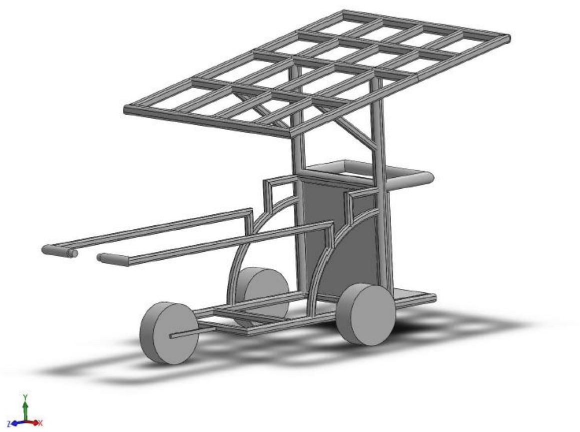

Figure 3: Modelling the Cold Room Support

Insulation in the walls reduces the exchange of heat energy between the inside and outside of the cold room. Our choice will be on insulation using insulating core sandwich panels made of polyurethane foam. The latter is injected between the two sides of the wall. Its properties are as follows:

- Density 30/40 kg/m^3
- Thermal conductivity: 0.027 W/m. K

After having made the choice of insulation several factors must be taken into account to determine the suitable thickness must be calculated for each wall so as to limit the overall exchange coefficient K = 0.36 W/m². C for positive cold rooms.

$$K = \frac{\lambda_{isol}}{e_{isol}} \quad ; \quad e_{isol} = \frac{\lambda_{isol}}{K}$$

$$e_{isol} = \frac{0.027}{0.36} = 71\ mm$$

Table 2: The dimensions of the cold room

External dimensions		Internal dimensions	
Length	0.920 m	Length	0.849 m
Width	0.370 m	Width	0.299 m
Height	1 m	Height	0.929 m
Volume	0.34 m^3	Volume	0.23 m^3

Since the internal dimensions are known, the total capacity of the refrigerator will be calculated according to formula which will give:

$$C = A \times h \times d_e \times \eta_0$$

With:

A= cold room area (low floor) in m²; A=0.92 0.37=0.3404 m²

h = maximum stacking height; h = 0.929 m taking into account insulation.

$d_e = 800\ kg/m^3$

$\eta_0 = 0.7$

$$C = (0.849 \times 0.299) \times 0.929 \times 800 \times 0.7$$

$$C=132.063 \text{ kg}$$

But the density of whole milk is about 1030 g/l, which is equivalent to about 128 l of whole milk, so in the cold room will be stored 128 l of whole milk.

4. Results and Discussions

4.1 Meteorological parameter

The variation in electrical characteristics over three months under actual natural climatic conditions is presented in Table 5:

Table 3: Monthly distribution of temperature and humidity in Dakar

Months	Max./Min. (°C)	Humidity. (%)
January	26/18	55
February	25/18	60
March	25/18	63
April	25/19	67
May	26/20	70
June	29/23	69
July	30/25	71
August	30/25	75
September	31/25	75
October	31/25	72
November	30/23	61
December	28/21	52
Average	**28/21.6**	**65.8**

The maximum annual average temperature of the Dakar region is 28 °C and the maximum humidity is 65.6%, for calculations we take 70%.

4.2 Calculation of thermal loads

Calculation of external thermal loads

- Thermal loads by transmission through the walls ($\dot{\mathbf{Q}}_{\mathbf{tr}}$)

This calculation is done wall by wall, that is, first the four vertical walls two by two, then the high floor (roof) and finally the low floor. Thermal loads by transmission through the walls are:

$$\dot{Q}_{tr} = \sum K \times A \times \Delta\theta$$

$$\dot{Q}_{tr1} = \frac{2 \times 0.36 \times (0.299 \times 0.929) \times (28-4)}{1000}$$

$$\dot{\mathbf{Q}}_{\mathbf{tr1}} = \mathbf{0.0048}\ \boldsymbol{kW}$$

$$\dot{Q}_{tr2} = \frac{2 \times 0.36 \times (0.849 \times 0.929) \times (28-4)}{1000}$$

$$\dot{\mathbf{Q}}_{\mathbf{tr2}} = \mathbf{0.0136\ kW}$$

$$\dot{Q}_{tr3} = \frac{2 \times 0.36 \times (0.299 \times 0.849) \times (28-4)}{1000}$$

$$\dot{\mathbf{Q}}_{\mathbf{tr3}} = \mathbf{0.00439\ kW}$$

$$\dot{\mathbf{Q}}_{\mathbf{tr}} = \mathbf{0.023\ kW}$$

- Thermal load by air renewal ($\dot{\mathbf{Q}}_{\mathbf{re}}$)

$$\dot{Q}_{re} = \frac{V_{cf} \times (h_e - h_i) \times \rho_{aa} \times n}{86400}$$

With:

V_{cf}: Cold Room Volume

ρ_{aa}: air density inside the cold room; $\rho_{aa} = \frac{\rho_0}{1+\frac{\theta}{273}}$

ρ_0 Being taken equal to 1.2745 kg/m 3

h_e = 87 kJ/kg (air enthalpy at 28°C with 70% humidity)
h_i = 21.07 kJ/kg (air enthalpy at 4°C with a humidity of 90%)
86400: number of seconds in a day
n = number of air changes in a day, $n = \frac{70}{\sqrt{V_{cf}}} = 145.96$

$$\dot{Q}_{re} = \frac{0.23 \times (87 - 21.07) \times 1.2745 \times 145.96}{86400}$$
$$\dot{Q}_{re} = 0.032\ kW$$

Table 4: Mass enthalpy in kJ/kg of some commodities

Foodstuffs	Temperature in °C										
	-8	-5	-3	-1	0	1	3	5	7	10	12
	Mass enthalpy										
Milk											
Condensed	4.2	10.9	15.1	19.7	21.8	23.9	28.5	32.7	36.8	43.5	47.7
Skimmed	12.6	37.7	57.4	157	291	294	303	310	318	330	338
Fermented					0	3.8	11.7	19.7	27.6	39.4	47.3
Cheese											
Pate	1.3	5.4	11.3	16.7	19.7	22.2	28.0	33.5	39.4	47.7	53.2
White	10.5	32.7	49.8	139	246	249	256	253	270	281	288

- Thermal load by opening doors

These charges are neglected in the case of small cold rooms with only one door because they are taken into account in the calculation of the charges due to air change. Therefore, since our cooler has only one door, these charges are negligible in our case ($\dot{Q}_{op} = 0$).

Calculation of internal thermal loads

- Calculation of the thermal load due to lighting

Since our cold room does not have any lighting so thermal loads are considered zero ($\dot{Q}_{ec} = 0$).

- Calculation of heat load due to persons

The room is not large enough for a person to enter the heat load due to people will be considered zero. ($\dot{Q}_{pe} = 0$).

- Calculation of the thermal load due to rolling stock

The cooler without rolling stock will be considered zero ($\dot{Q}_{mr} = 0$).

- Calculation of heat load due to various machines

The cold room does not have various machines so the heat load will be zero ($\dot{Q}_{md} = 0$).

- Calculation of the heat load due to incoming foodstuffs

The cold room ensures the refrigeration of dairy products therefore

$$\dot{Q}_{de} = \frac{m \times c_1(\theta_1 - \theta_2)}{86400}$$

With

- m = mass of food introduced per day, m = 132 kg/d
- c_1 = mass heat capacity before freezing, for whole milk 3.85 kJ /kg. K

$$\dot{\mathbf{Q}}_{\mathbf{de}} = \frac{\mathbf{132 \times 3.85(28 - 4)}}{\mathbf{86400}} = \mathbf{0.141\ kW}$$

- Heat load due to food respiration

The cold room being intended for the storage of dairy products the thermal load due to the respiration of the foodstuffs will be zero ($\dot{Q}_{resp} = 0$).

- Calculation of intermediate cooling capacity

$$\dot{Q}_{int} = \dot{Q}_{tr} + \dot{Q}_{re} + \dot{Q}_{op} + \dot{Q}_{ec} + \dot{Q}_{pe} + \dot{Q}_{mr} + \dot{Q}_{md} + \dot{Q}_{de} + \dot{Q}_{resp}$$

$$\dot{Q}_{int} = 0.023 + 0.032 + 0.141$$
$$\mathbf{\dot{Q}_{int} = 0.196\ kW}$$
$$\dot{Q}_{0,int} = \frac{\dot{Q}_{int} \times 24}{\tau_{inst}}$$
$$\dot{Q}_{0,int} = \frac{0.196 \times 24}{7}$$
$$\mathbf{\dot{Q}_{0,int} = 0.672\ kW}$$

- Calculation of effective power

$$\dot{Q}_0 = \dot{Q}_{0,eff} = \dot{Q}_{0,int} = 0.672\ kW$$
$$\mathbf{\dot{Q}_0 = 672\ W}$$

Simply choose a refrigerator with a compressor with a cooling capacity between 650 and 700 watts. But also, the choice of evaporator will be made taking into account the cooling capacity.

4.3. Components of the refrigeration system

Diagram of the refrigeration plant

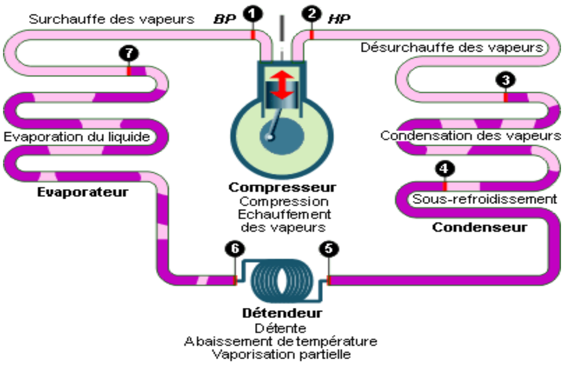

Figure 4: Diagram of the refrigeration cycle

The different points of the cycle:

1: compressor inlet under low pressure: the refrigerant (steam) is sucked under BP by the compressor.

2: High Pressure Compressor Outlet: Refrigerant (Steam) is pumped under high pressure to condenser

3: condenser inlet: refrigerant (steam) condenses

4: condenser outlet: the refrigerant (liquid) leaves the condenser to go to the holder

5: holder inlet: refrigerant (liquid) partially vaporized

6: holder outlet and evaporator inlet: refrigerant evaporates completely under HP

7: evaporator outlet: the fluid is again drawn by the compressor and the cycle starts again.

Choice of refrigerant

Refrigerant is a vital component of any refrigeration machine; it ensures heat transfers in the system. So, the choice of a suitable refrigerant greatly affects the performance of the refrigeration system. After a study of refrigerants, we chose R134a (1,1,1,2-tetrafluoroethane). R 134a is a very stable, non-toxic and flammable HFC. It does not affect the ozone layer (ODP=0) but has a measured effect on global warming (GWP=1430). It is the ideal fluid for small and medium power systems. And its properties are:

• Critical temperature:101 °C
• Critical pressure: 40.7 bar
• Atmospheric pressure boiling temperature: - 26.5 °C
• Water solubility in product: 0.097% by mass
• ODP = 0
• GWP_{100} = 1300
• Safety group A1 (A: low toxicity and 1: no flame spread a 18 °C and 101325 Pa)

Compressor Selection

According to the SECOP catalogue, the most suitable compressor will be the DANFOSS brand NL10MF compressor and its properties are:

• Type: Hermetic compressor
• Fluid used: R134a
• 230 V voltage
• Current type: single phase
• Frequency: 50/60 Hz
• Energy consumption at -5ºC: 360 W
• Energy consumption at 0ºC: 397 W
• Energy consumption at 5ºC: 435 W
• Energy consumption at -7.2ºC: 360 W
• Refrigeration capacity -5°C: 552 W
• Cooling capacity -0°C: 985 W
• 5°C cooling capacity: 841 W
• 7.2°C refrigeration capacity: 916 W

4.4. Design of the photovoltaic system

The design of photovoltaic systems and installations consists of the determination of the two main quantities, namely the size of the field of photovoltaic modules producing electrical energy for daily operation and energy storage for a use time of 1 hour per day and 1 day of autonomy in case of no presence of solar energy resource.

In general, to size this photovoltaic system, the respective sizes of the subsystems that compose it (field of modules) are given taking into account the existing solar energy resource on the site where the system is installed (solar radiation) and the load profile of the medical preservation system (i.e., average daily consumption). Of course, the reliability and efficiency of the solar system depends closely on the design.

Table 5: Table of electricity requirements

Equipment	Compressor
Current	DC
Rated power (W)	435
Hours of use	7
Daily consumption (Wh/d)	3045

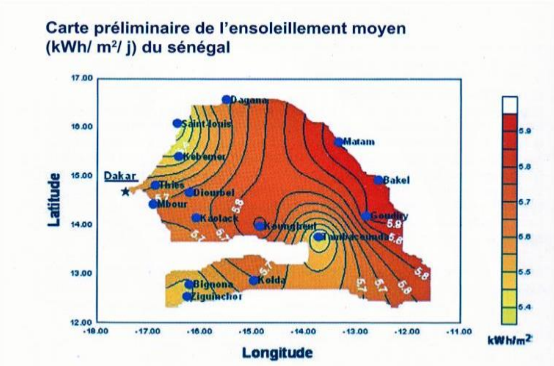

Figure 5: Average sunshine map of Senegal

The least sunny period of the year must be chosen in order to obtain the required electricity production during this period. Sunshine is generally expressed in kWh/m²/d [9].

Since our cold room works in the Dakar region we will have:

Average sunshine = 5.5 kWh/m².d.

Determination of peak power

$$\text{Pc (Wc)} = \frac{\text{Ej (Wh/j)}}{\text{Ens (kWh/m}^2\text{.j)} \times \text{K}} \times 1\text{kW/m}^2$$

With:

Pc: Peak power of equipment in Wc

Ens: Installation site sunshine in kWh/m²/d

K: conversion factor applied to account for various losses. Determined experimentally for value 0.6 in general

$$\text{Pc} = \frac{3045}{5.5 \times 0.6} \times 1$$

$$\mathbf{Pc = 923\ \mathit{Wc}}$$

It is possible to use 3 single crystal 300Wc panels with the following properties:

- Production 1800 Wh/d in case of favorable weather
- Manufacturer: VICTRON ENERGY
- Single crystal cells
- 24 V voltage

These panels will be used with the VICTRON ENERGY MPPT 75/10 regulator.

Estimated Storage Capacity

For a given load the storage capacity is obtained according to the following formula:

$$C_s = \frac{P \times t \times N}{U_{batt} \times b}$$

With:

P: Power of equipment in watts

t: usage time per day in hours

U_{batt} : Volt battery voltage

b: depth of discharge ~ 0.6 to 0.7

N: Autonomy desired during the day

$$\text{Cs} = \frac{3045 \times 1 \times 1}{24 \times 0.6}$$

$$\boldsymbol{Cs = 212\ Ah}$$

So only one ULTRACELL 24V/250 Ah solar battery will be used.

Selection of cable sections

In a photovoltaic system the cables must be carefully chosen to avoid excessive power losses [10].

The main wiring selection criteria are:

- Solar (UV) and weather resistance
- Cable section to avoid significant voltage drop (better system performance)
- The diameter of the cables for a DC photovoltaic system is larger than for an AC system.

The following formula is used to determine the appropriate cable section:

$$S_{min} = 2 \times L \times I_{max} / K \times \Delta U_{max}$$

With:

L: length of a single wire in m

K: copper conductivity = 58 Am/Vmm^2

ΔU_{max}: maximum voltage drop tolerated in volts

I_{max}: maximum ampere current

Each cable of the installation must be dimensioned to limit energy losses related to the transport of current [11]. For optimal operation, a maximum voltage drops of 3% from the nominal voltage is recommended. The voltage drop in the cables is calculated as follows:

$$\Delta U = 2\rho \frac{L}{S} I$$

ρ is resistivity (Ω.m). For copper ρ=17.10-9 Ω.m;

L and S are the lengths and sections of the cable.
The larger the cable section, the lower the cable resistance and the lower the voltage drop. Depending on the intensity that will circulate in the branch and the necessary length of connection, the appropriate section will be calculated.

5. Conclusion

Born of an awareness of the difficulty of access to electricity in the most remote areas of Senegal, this project allowed us to apply the knowledge acquired during our training. In fact, it constitutes an interaction between several domains: heat transmission, cold, air conditioning, renewable energy etc.
Regarding the utility of the cold room, it can be said that it solves many problems to have unemployment since it can be used to sell various products all remaining mobile and respecting the cold chain. It can be used for the conservation and transportation of vaccine in villages where access to electricity is very difficult.
Nevertheless, we can affirm the orientation towards renewable energies in particular photovoltaic energy is a respectful alternative to the problem of energy.

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