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Sizing of a Water Heating System in a Single-Family Residence through Solar Energy Capture: Case Study

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***Abstract*— *One of the major problems faced in the contemporary world is related to adopted energy matrices, since they result in a series of environmental impacts harmful to man. Therefore, it is necessary to develop new technologies for energy generation that can contribute to the preservation of natural resources and, consequently, reduce adverse impacts on the environment. the respective study presents itself as a tool of fundamental social, economic, ecological and environmental importance, since it is directed to the development of a project that aims to use a form of renewable energy to heat water in a single-family residence. The present study aimed to design a water heating system for a single family home, through the capture of solar energy. The methodological process used was the case study addressing the cost benefit of using photovoltaic energy technology to heat water in a single family home. For the dimensioning of the system, a survey of the number of people residing in the building was carried out, as well as the respective water consumption per capita. Based on the above, it is concluded that the project is economically viable since the results demonstrated a significant reduction in the cost of energy consumed at the residence. It presents itself as a tool of fundamental social, economic, ecological and environmental importance as it uses a renewable energy source.*

I. INTRODUCTION

The first stage of the entire process for energy to reach our homes and industries is the generation by which it can be produced through different energy sources, such as: solar, nuclear, wind, natural gas, coal, oil, hydraulic and thermoelectric, that is, by burning biomass (wood, sugarcane residues and rice husks).

The energy matrix existing on the planet is made up of a set of accessible sources for the generation of electricity, whether for the world, a country, state or municipality. In Brazil, a large part of the electricity generated comes from renewable sources such as hydroelectric plants, which makes the Brazilian electricity matrix mostly renewable.

One of the major problems faced in the contemporary world is related to adopted energy matrices, as they result in a series of harmful environmental impacts to man. Therefore, it is necessary to develop new technologies for energy generation that can contribute to the preservation of natural resources and consequently reduce adverse impacts on the environment.

To face these challenges, it is necessary to adopt energy sources that generate less negative environmental impacts, among the energy matrices, solar energy can be highlighted, as it is considered to be clean and renewable energy since it is produced by from natural resources that are always replenished by nature.

The renewable energy source is of fundamental importance for the environment, since there is a great global concern for the replacement of energy from non-renewable sources, such as oil, nuclear and coal. These types of power generation, once resources are exhausted, cannot be maintained.

Therefore, the Universities and Technological Research Institutions present themselves as the main sponsors of studies aimed at obtaining new technological alternatives with a view to generating energy for use in the civil construction industry, among which the use of solar energy can be highlighted, since it is a renewable energy source, obtained from the sun's rays.

In this sense, the respective study presents itself as a tool of fundamental social, economic, ecological and environmental importance, since it is aimed at the development of a project that aims to use a form of renewable energy for heating water in a single family home.

In this context, the research had as a general objective to dimension a water heating system of a single-family house, through the capture of solar energy and specific objectives to address concepts and standards related to the use of solar energy in civil construction works, dimension the system of capture of solar energy for the water heating of a single-family residence in the city of Manaus and analyze the cost-benefit of implementing the project object of this case study, in the residence in question.

II. LITERATURE REVIEW

One of the main factors contributing to world economic development and industrialization is energy. And among the various sources that energy can be obtained, solar can be highlighted, which has been presenting itself as of great importance to ensure the sustainability of production processes. The energy generated by the sun is an infinite and non-polluting resource (Bisht et al., 2018).

Brazil has a diversified energy matrix, having in its territory significant reserves of non-renewable sources (oil, natural gas, coal, uranium, etc.) and diversified sources of renewable energy, highlighting the vast hydroelectric, wind, and solar potential and biomass available in the country for electricity generation (Bandeira 2012 apud Kemerich et al., 2016).

For Cabral (2012), the energy crisis, an issue of not very recent origin, but still a much debated topic in society, constitutes one of the great challenges of today. Some factors related to it can be highlighted, such as: the reduction of world oil reserves, especially after the oil crisis in the 70s, environmental impacts caused by the use of polluting energy sources, the potential scarcity of natural resources and the increased demand for energy supply, due to the continuous growth of the population, which generates uncertainties about the world energy future and significant discussions at the global core.

Faced with this problem, an environmental concern has spread over the years that has consolidated and gained space in society, from which a process of searching for alternative sources of energy that promote the rational use of energy resources is observed, reduction of environmental impacts and expansion of energy in isolated areas (Cabral, 2012).

Cabral (2012) highlights that photovoltaic energy is an excellent alternative energy to non-renewable sources to meet the growing energy demand and expand access to energy in places where the implementation of the conventional electricity grid is technically and economically unfeasible, especially in rural areas.

It is important to highlight that Brazil is a country with a high potential for producing solar energy, as it benefits from the abundant solar radiation prevalent in almost every month of the year, despite the different climatic characteristics observed in our territory, it can be observed that the annual average of global irradiation shows good uniformity, with relatively high annual averages across the country (Kemerich et al., 2016).

According to Santana (2020), the term "photovoltaic" has etymological origins in the words phos, which means "light" in Greek and voltaic, in reference to the Italian physicist Alessandro Volta, a great scholar of electricity and inventor of the voltaic cell. Thus, solar photovoltaic energy is obtained through the direct conversion of light into electricity through the photovoltaic effect.

For Jannuzzi et al., (2009), the physical principle of operation of photovoltaic modules is called photovoltaic effect (photo = light; volt = electricity), which is the phenomenon presented by certain materials that, exposed to light, produce electricity.

For Bezerra (1982) highlights that the use of solar energy coming from the Sun is made through the capture of light and/or heat energy, which is transformed into something better usable by human beings, such as mechanical or electrical energy. Cometta (1985), on the other hand, says that solar energy is energy radiated by the sun, energy that is non-polluting and inexhaustible.

Water heating using solar collectors has been growing every decade. Domestic solar heaters are currently widely used to produce solar thermal energy at low temperatures and aim to reduce costs, use less natural resources and reduce pollution. For this reason, they have been the subject of several researches and studies since the 1950s (Marques et al., 2014).

The anthropic contribution to global warming through the burning of fossil fuels has become a consensus, putting on the agenda the need for mitigation measures, with emphasis on the use of a cleaner energy matrix. In this context, Brazil has a favorable structure. In 2014, renewable resources represented 50.8% of the country's energy matrix. In terms of the electrical matrix, in that same year, 74.6% of the domestic supply came from renewable sources, mostly hydraulic energy (Mme, 2015; Carvalho, 2017).

Jannuzzi et al., (2009) highlight that Brazil has a great challenge in the coming decades to seek solutions that will meet the growing requirements of energy services and, at the same time, meet criteria of economy, security of supply, public health, guarantee of universal access and environmental sustainability. The growing environmental pressures on the exploitation of the hydraulic potential located in the Amazon region and the energy resources that are increasingly distant from the load centers are some elements that are used to seek new solutions. In order to satisfy these criteria, significant public policy efforts for the insertion of new technologies must be started immediately with the objective of meeting the expected energy demand in 2030-2050.

1.1 Classification of Photovoltaic Systems

For Ribsol (2021), a photovoltaic solar energy system, also called a solar energy system, or even a photovoltaic system, is a system capable of generating electrical energy through solar radiation. There are two basic types of photovoltaic systems: Isolated Systems (Off-grid) and Grid Connected Systems (Grid-tie).

As they are electricity generators, photovoltaic systems are classified according to their topology in relation to the most common means of supplying electricity, the public electricity distribution network. They are classified as: isolated photovoltaic systems and photovoltaic systems connected to the grid (Santana, 2020), as described below:

1.1.1 Isolated photovoltaic systems

For Santana (2020), Isolated Systems are those that do not have any type of interconnection with the energy distribution network. They are used in remote locations or where the cost of connecting to the power grid is high. They are used in country houses, refuges, lighting, telecommunications, water pumping, etc. It is divided into: stand-alone without storage and Stand-alone with storage.

1.1.1.1 Standalone solar systems without storage

They are isolated photovoltaic systems formed by the set of photovoltaic modules, charge controller and inverter, Figure 1.

Fig.1: Standalone solar systems without storage

Source: Adapted from Santana (2020).

As an example of the use of autonomous systems without storage, we can mention the water pumps for dams and artesian wells, as illustrated in Figure 2.

Fig.2: Anauger solar pumping kit

Source: Adapted from Santana (2020).

1.1.1.2 Autonomous Solar Systems with Storage

According to Santana (2020), the autonomous photovoltaic system with storage, like the previous one, follows the same studied topology, consisting of a photovoltaic module, charge controller and inverter. However, the novelty comes through the connection of batteries to carry out the accumulation of energy, as illustrated in Figure 3.

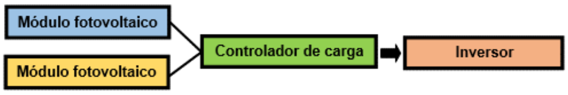

Fig.3: Autonomous solar system with storage

Source: Adapted from Santana (2020).

1.1.2 Grid connected photovoltaic systems

They are those that depend on the interconnection with the grid to carry out the transformation of solar radiation into electrical energy. For Ribsol (2021), the Solar System Connected to the grid, replaces or complements the conventional electric energy available in the electric grid.

Unlike isolated systems that serve a specific and local purpose, these systems are also capable of supplying the electricity grid with energy that can be used by any consumer on the grid. Connected systems have a great advantage over isolated systems in that they do not use batteries and charge controllers. This makes them about 30% more efficient and also ensures that all energy is used, either locally or elsewhere on the network. Grid connection systems can be used either to supply a home, or simply to produce and inject energy into the electricity grid, just like a hydroelectric or thermal plant.

One of the bets being made in several countries is the use of photovoltaic systems connected to the grid (SFCR). Although it is still an expensive solution today compared to other solutions, it is the technology that presents the highest growth rate and lower costs. In addition to the gains in scale and learning effects, technological advances and new discoveries are very promising to further lower costs. It is anticipated that energy generated through these systems will become competitive with electricity tariffs paid by European consumers between 2010 and 2020 and with average generation costs after 2030 (Jannuzzi et al., 2009).

Souza et al., (2018) mention that demand for energy has become increasingly higher, thus, research and searches for renewable energy sources are essential to ensure the sustainability of the energy sector. Among so many options, solar energy has stood out as an energy source with great availability.

Marques et al., (2014) highlight that domestic solar heaters, currently widely used for the production of solar thermal energy at low temperatures, have been the object of several researches and studies since the 1950s.

Siqueira (2009) mentions that the solar collector is the main component of a solar heating system. It promotes the conversion of solar radiation, transferring the energy flow from the incident radiation to the fluid that circulates inside it.

Flat collectors are used for temperatures below 93º C. It receives and uses solar radiation on the same surface. It consists of a black heat-absorbing plate, piping through which the fluid to be heated flows, thermal insulation, and generally with a transparent cover (Hudson et al., 1985 apud Sales, 2017).

In the solar water heating system there are two systems: active and passive. The active system needs a pump to support the circulation of water, requiring sensors and a system to control its operation. In the passive system or natural circulation, it does not need the use of a pump, the collector being installed at a level below the thermal reservoir (figure 1). The water naturally circulates inside the collector and goes up to the reservoir. This effect is called thermosyphon (Islam et al., 2013 apud Sales, 2017).

1.2 Legislation Applied to the Solar Energy Sector

According to Sales (2017), in Brazil there are technical standards that specify the products and equipment used in systems for the thermal use of solar energy, where they deal with specifications, materials, technical requirements, thermal performance and other associated topics, as described below:

- ✓ ABNT NBR 15747 - 1 (2009): Solar thermal systems and their components - Solar collectors - Part 1: General requirements.

The purpose of this part of the standard is to specify the requirements for durability (including mechanical strength), reliability, safety and thermal performance of liquid heating solar collectors. It also includes provisions for assessing compliance with those requirements.

- ✓ ABNT NBR 15747 - 2 (2009): Solar thermal systems and their components - Solar collectors - Part 1: Test methods.

This part of the standard aims to specify the test methods for validating the requirements of durability, reliability and safety and thermal performance of liquid heating solar collectors, which are specified in NBR15747-1. It includes three test methods for characterizing the thermal performance of collectors.

- ✓ ABNT NBR 15569 (2008): Direct circuit solar water heating system - Design and Installation.

This standard aims to establish the requirements for the solar heating system (SAS), considering the aspects of design, dimensioning, hydraulic arrangement, installation and maintenance, where the transport fluid is water, as it is applied to the SAS composed of flat solar collectors, with or without thermal reservoir, and an eventual auxiliary water heating system. It is also applicable to systems where the circulation of water in the solar collectors is done by thermosyphon or forced circulation. The same does not apply to the heating of water in a swimming pool or in the indirect circuit solar heating system.

- ✓ ABNT 10185 (2018): Thermosolar reservoirs for liquids for solar energy systems - Test method for thermal performance.

Its objective is to specify the test methods that allow the evaluation of the global heat flux coefficient for the environment, the loading and unloading capacities of thermosolar reservoirs used in systems of thermal utilization of solar energy.

1.3 Concepts

1.3.1 Photovoltaic system

In a basic definition, a photovoltaic system is an integrated set of photovoltaic modules and other components, designed to convert solar energy into electricity (Treble, 1991 apud Sales, 2017). For Santana (2020), it is a set of equipment that together form an energy generator through which it becomes possible to transform solar photovoltaic energy into electrical energy as we know it, as shown in Figure 4. The respective figure shows that there is an increase temperature and consequently the heating of the water as the solar rays affect the photovoltaic panels.

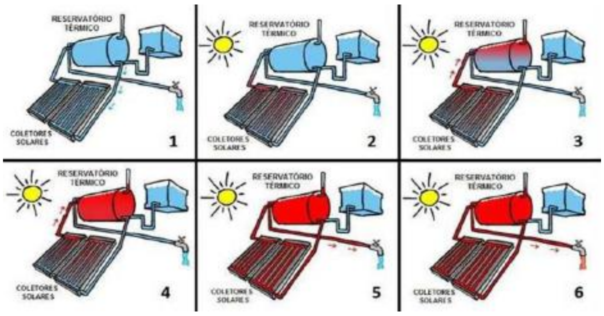

Fig.4: Photovoltaic System

Source: Cycle, 2020.

1.3.2 Photovoltaic Cell or Collector

According to Santana (2020), it is a device manufactured with semiconductor material, it is the main unit of this process of converting solar radiation into energy. As for ABNT NBR 15569 (2008), the solar collector is a device that absorbs incident solar radiation, transferring it to a working fluid, in the form of thermal energy, as shown in Figure 5.

Fig.5: Photovoltaic Cell

Source: Cycle, 2020.

1.3.2.1 Solar Thermal Energy

It is a form of alternative energy, and a technology, used to generate thermal energy or electrical energy, for use in homes or industries. These technologies allow us to convert solar energy into thermal with different developments depending on the range of temperatures required. As an example, there is the heating of swimming pools, water for bathing, space heating and heating for industrial processes (Agência Nacional de Energia Elétrica, 2008).

III. MATERIALS AND METHODS

The project on screen aims to analyze the cost-benefit of implementing the project of a solar energy capture system for the water heating of a single-family residence, located in the city of Manaus. The research was classified according to objectives and approach. As for the objectives, the research is presented as exploratory and descriptive.

It is classified as exploratory because it compiles information that will expand knowledge and familiarity with the subject outlined for the project, which will support the understanding of the concepts and applications of the studied object and is descriptive, as it aimed to describe, interpret and explain about the research topic. Regarding the approach, it is quantitative, as the results were quantified.

In order to enrich the research, a systematic survey of the literature related to the topic was carried out in electronic databases, including: Academic Google and Scielo, searching for studies published in the last 10 years.

The keywords used to survey the publications will be: solar energy, photovoltaic system, water heating. The project is a case study that addresses the cost-benefit of using photovoltaic energy technology to heat water in a single-family home. To design the system, a survey was carried out on the number of people residing in the building, as well as their per capita water consumption.

For the project, a single-family building consisting of 2 rooms, 5 bedrooms, kitchen, 5 bathrooms, pantry, service area and garage was used as the object of study, located in the Alphaville 2 condominium on H - 1 street, block K2, lot 42, neighborhood Tarumã in the city of Manaus, Figure 6.

Fig.6: Location of the building

Source: Google Maps.

1.4 SOLAR HEATING SYSTEM

According to ABNT NBR 15569 (2008), the solar heating system basically consists of three main elements: solar collector(s), thermal reservoir and auxiliary heating system. For its assembly, the materials and components described in Chart 1 are used.

Chart 1: Materials and components of the solar heating system - SAS

ITEM	COMPONENT	FUNCTION
1	Solar collector	Convert radiant energy to thermal energy
2	Thermal reservoir	Accumulate thermal energy in the form of heated water
3	Differential temperature controller	Control the operation of the solar heating system hydraulic motor pump and possibly have safety functions
4	Temperature sensor	Measure the water temperature at specific points on the solar heating system
5	Expansion reservoir	Protect the system against pressure variations and volumetric expansion during the operation of the SAS
6	Pressure relief valve	Automatically relieve SAS pressure if maximum pressure is reached
7	Retention valve	Do not allow reverse water movement
8	Air eliminator valve	Allow SAS air out
9	Vacuum break valve	Relieve negative pressures formed during the operation of the SAS, allowing the entry of air
10	Drain	Enable the drainage or drainage of water from the SAS
11	Motor pump	Promote the forced circulation of water through the SAS
12	Tubes and fittings	Interconnect components and transport heated water
13	Thermal insulation	Minimize thermal losses of SAS components and accessories
14	Auxiliary heating equipment	Supply the complementary thermal demand of SAS
15	Breather	Equalize SAS positive and negative pressures and allow air and steam to escape

Source: Google Maps.

1.4.1 Dimensioning of the solar heating system

ABNT NBR 15569 (2008) highlights that the purpose of the dimensioning is to determine the collecting area and the volume of the storage system necessary to meet the useful energy demand of a given consumption profile, which is carried out as determined by it and following the recommendations contained in manufacturers manuals. The respective dimensioning was carried out according to the steps of the items described below.

1.4.1.1 Calculation of the volume of hot water consumption in the home

The calculation was performed using the information and equation below, contained in ABNT NBR 15569 (2008) as follows.

Number of people residing in the building: 6 people;

Shower flow (shower): 6.6 l/min;

Average bath time: 10 min;

Bathing frequency: 2 baths per person

The calculation was performed using the equation (1).

Vconsumo = (Qch x Tu x Fu x Np) (1)

Vconsumo = (6,6 l/mim x 10mim x 2 x 6)

Vconsumo = 792 liters

In which:

- ✓ Vconsumo: total volume of hot water consumed daily (l);
- ✓ Qch: shower flow (l/mim);
- ✓ Fu: total number of shower usage per user per day;
- ✓ Np: number of people residing in the building.

1.4.1.2 Calculation of storage system volume

For this calculation, the parameters and equation contained in ABNT NBR 15569 (2008) were used, as follows:

Consumption temperature: 40ºC;

Annual average room temperature: 26ºC;

Water storage temperature: 50ºC.

For the calculation of this step, the equation (2)

$$\text{Varmaz} = \frac{\text{Vconsumo} \times (\text{Tconsumo} - \text{Tambiente})}{(\text{Tarmaz} - \text{Tambiente})}$$

$$\text{Varmaz} = \frac{792 \times (40 - 26)}{(50 - 26)}$$

Varmaz = 462 liters

In which:

- ✓ Varmaz: reservoir storage volume (l);
- ✓ Vconsumo: total volume of hot water consumption in the building (l);
- ✓ Tambiente: average ambient temperature in the locality (ºC);
- ✓ Tconsumo: hot water consumption temperature (ºC);
- ✓ Tarmaz: storage temperature (ºC).

For better security of the hot water supply in the storage system, a Boiler 500 liter hot water tank or 0.50 m^3 horizontal Rinnai high pressure (5 m.c.a) hot water tank was adopted, stainless steel 444R, double plate, Figure 7.

Fig.7: Rinnai high pressure 500 liters horizontal bolher

Source: Reservatório Solar (2021).

1.4.1.3 Calculation of useful energy demand and loss

For the respective calculations it was necessary to use the parameters and equations that are part of ABNT NBR 15569 (2008). The data used in this calculation step were:

- ✓ Specific mass of water (p): 1000, expressed in kilograms per cubic meter (kg/m3);
- ✓ Specific heat of water (Cp): 4.18, expressed in kilojoules per kilogram kelvin (kj/kg).

1.4.1.3.1 Calculation of useful energy demand and loss

For the calculation, on screen, the equation was used (3);

$$\text{Eútil} = \frac{\text{Varmaz x p x Cp x (Tarmaz – Tambiente)}}{3600}$$

$$\text{Eútil} = \frac{0{,}50 \text{ x } 1000 \text{ x } 4{,}18 \text{ x } (50 – 26)}{3600}$$

Eútil = 8,13 Kwh/day or 243,60 Kwh/month

In which:

- ✓ Eútil: Useful energy, expressed in kilowatt hours per day (Kwh/day);
- ✓ Varmaz: reservoir storage volume (m^3);
- ✓ p: Specific mass of water (kg/m^3);
- ✓ Cp: Specific heat of water, expressed in kilojoules per kilogram kelvin (kj/kg).
- ✓ Tarmaz: storage temperature (ºC).
- ✓ Tambiente: average ambient temperature in the locality (ºC).

1.4.1.3.2 Loss calculation

The energy from the losses was obtained using the percentage of 15% of the useful energy needed to heat the water, as recommended by NBR 15569 (2008).

For the respective calculation, the following equation was used (4);

Eperda = 0,15 x Eútil (4)

Eperda = 0,15 x 8,13

Eperda = 1,22 Kwh/day

In which:

- ✓ Eperda: Thermal losses of the primary and secondary circuits, expressed in kilowatt hours per day (Kwh/day);
- ✓ Eútil: Useful energy, expressed in kilowatt hours per day (Kwh/day).

1.4.1.4 Calculation of the solar energy collecting area

The sizing of the solar energy collecting area had as a starting point the value obtained in the calculation of useful energy demand. With the result achieved, it was possible to find the collecting area by consulting the table of Energy Consumption and Energy Efficiency of solar collectors from the National Institute of Metrology, Quality and Technology (2018).

In the aforementioned table you can find all manufacturers of collectors for solar water heating accredited in the Brazilian Labeling Program, showing the average monthly energy production of the equipment per square meter and per type of collector.

Therefore, to meet the demand for useful energy, equipment was chosen supplied by the company Rinnai Brasil, Tecnologia de heating LTDA, Rinnai brand, model RSC 1002V, bath application, operating pressure 40 mca, external collector area 1.01 m2, production monthly average of energy per collector 70.60 kWh/month.

With the information from the equipment, to meet the useful energy demand, which is 243.60 kWh/month, it is necessary to have a solar energy collecting area of 4.04 m^2, which could be supplied by 4 plates of 1.01 m^2 each . However, for safety reasons, 5 boards of 1.01m^2 each were adopted, totaling 5.05m^2.

1.4.2 Installation of solar heating system

According to the Rinnai installation and use manual, the solar heating system requires an installation to be carried out by a specialized company, as good as the equipment is, if it is poorly positioned and does not obey the correct distances, the yield will be much lower than expected. The respective system and its components are represented in the operating diagram as shown in figure 8.

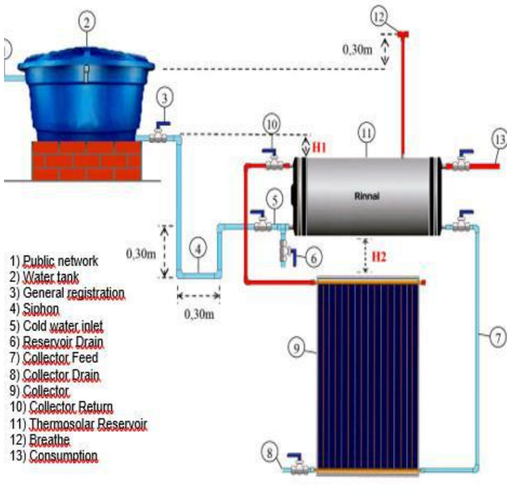

Fig.8: Operating diagram of SAS and its components

Source: Manual de instalação e utilização Rinnai.

Due to the architectural characteristic of the building, the circulation system adopted was a natural thermosyphon. As stated in the Rinnai installation and use manual, the movement of water inside the pipe occurs due to the thermal difference between the reservoir and the collectors, so only one power point will be needed next to the thermosolar reservoir, to use the electrical support when used. The exchange of hot water in the collectors and the reservoir takes place naturally without the need for any auxiliary equipment. To obtain the maximum pressure, consider the water sheet of the box at the top of the reservoir, figure 9.

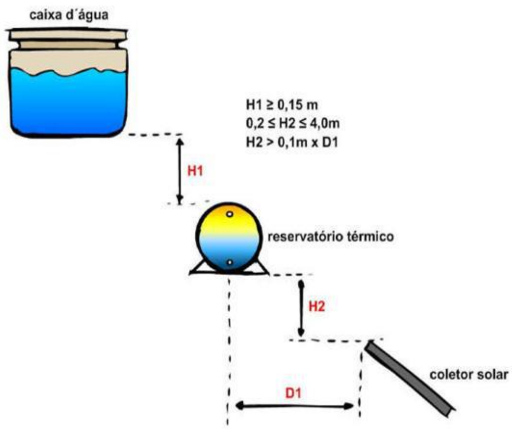

Fig.9: Thermosyphon natural circulation

Source: Manual de instalação e utilização Rinnai (2020).

1.4.2.1 Installation of solar collectors

1.4.2.1.1 Angle of inclination

According to ABNT NBR 15569 (2008), solar collectors must be installed with inclination angles equal to the local latitude plus 10º and never less than 15º as shown in figure 10. The Rinnai installation and use manual indicates which inclination angle should be the city's latitude increased by 10°, in cases where this sum does not reach 20°, adopt the 20° inclination so as not to harm the proper water flow, this inclination favors the best performance for the winter periods, as in the summer the incidence of solar radiation is higher.

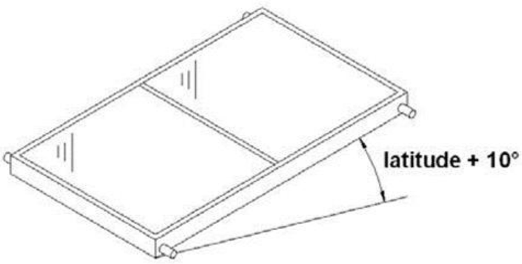

Fig.10: Angle of inclination of collectors

Source: ABNT NBR 15569 (2008).

1.4.2.1.2 Geographical orientation

In the Installation and Use Manual Rinnai highlights that in Brazil the collectors must be directed to the GEOGRAPHICAL north, figure 11. If the collectors are 30º out of phase with the geographic north, they must be added in the dimensioning at least 20% of the collector area. Installation with an offset above 30° is not recommended due to the drastic drop in performance.

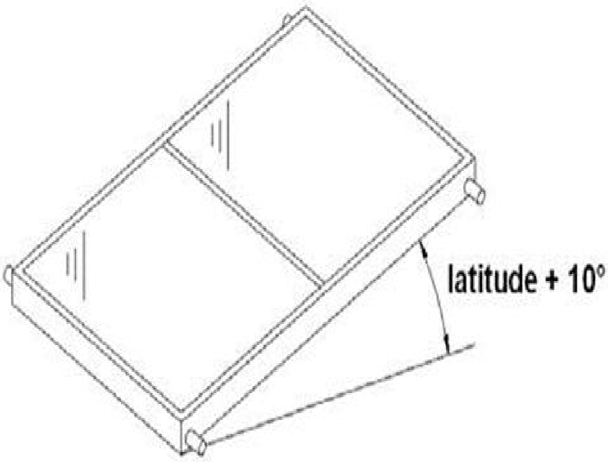

Fig.11: Geographic orientation of collectors

Source: ABNT NBR 15569 (2008).

The installation of the solar heating system of the project on screen was carried out in compliance with the recommendations of ABNT NBR 15569 (2008) and the Rinnai Installation and Use Manual.

Estimated cost for implementing the solar heating systemThe cost of implementing the solar heating system for the respective project is described in Table 2.

Table 2: Cost of implementing the solar heating system

UNIT	DESCRIPTION	UNIT VALUE	PARCIAL VALUE
1	Reservoir Termossolar Rinnai de 500 (l)	R$ 8.900,00	R$ 8.900,00
5	Solar Collector 1x1 Rinnai	R$ 1.682,00	R$ 8.410,00
1	Pressurizer Jacuzzi 1/2 CV	R$ 3.180,00	R$ 3.180,00
1	Expansion Tank Dancor	R$ 2.860,00	R$ 2.860,00
1	Safety Valve	R$ 380,00	R$ 380,00
1	Vacuum Break Valve	R$ 420,00	R$ 420,00
1	Retention valve	R$ 412,00	R$ 412,00
10	Aquatherm 22 tube	R$ 79,00	R$ 790,00
8	Copper Tube 22	R$ 458,00	R$ 3.664,00
10	Copper Union 22	R$ 78,00	R$ 780,00
5	Aquatherm Mixer	R$ 128,00	R$ 640,00
1	Connections Kit	R$ 3.250,00	R$ 3.250,00
-	**TOTAL VALUE**	**-**	**R$ 33.686,00**

1.4.3 Estimate of energy saved with SAS deployment

To calculate the estimated energy saved with the implementation of the solar water heating system, it was necessary to collect the following data:

- ✓ Solar fraction of energy consumed for heating water supplied by the solar system used: 73.50% obtained from the Solarimetric Atlas (2016 apud SALES, 2017).
- ✓ Average number of baths surveyed: 2 baths per day per person according to ABNT NBR 15569 (2008).
- ✓ Bathing time: 10 min, according to table C.1 which indicates the consumption of hot water points of use of ABNT NBR 15569 (2008).
- ✓ Electric shower used: Acqua Duo shower 220V 7800W, Lorenzetti.
- ✓ Number of days per year: 365 days.

To determine the amount of energy saved for years, the total number of daily baths must be obtained using equation 5.

NTB = Fu x NTPRE (5)

NTB = 2 x 6

NTB = 12 baths per day.

In which:

- ✓ NTB: Total number of baths per day;
- ✓ Fu: Frequency of bathing per person day;
- ✓ NPTRE: Total number of people residing in the building.

With the data obtained, it is possible to calculate the amount of energy saved per day in Kwh with the installation of the solar water heating system using equation 6.

EE = FS x PC x NTB x (T/60) x 10-5 (6)

EE = 73,50 x 7800 x 12 x (10/60) x 10-5

EE = 11,70 Kwh/day

In which:

- ✓ EED: Energy saved in kWh/day;
- ✓ FS: solar fraction of energy consumed for heating water supplied by the solar system (%);
- ✓ PC: Electric shower power watts;
- ✓ NTB: Total number of baths per day;
- ✓ T: Average time per bath.

1.4.3.1 Installation of solar collectors

For the respective calculation, a survey was carried out at the Amazonas Energia utility to verify the cost of the Kwh of energy consumed.

In this sense, it can be seen that for each Kwh of energy consumed, the amount of R$ 0.94559 is paid, Figure 13. Therefore, we obtained the pecuniary value saved for one year using equation 7.

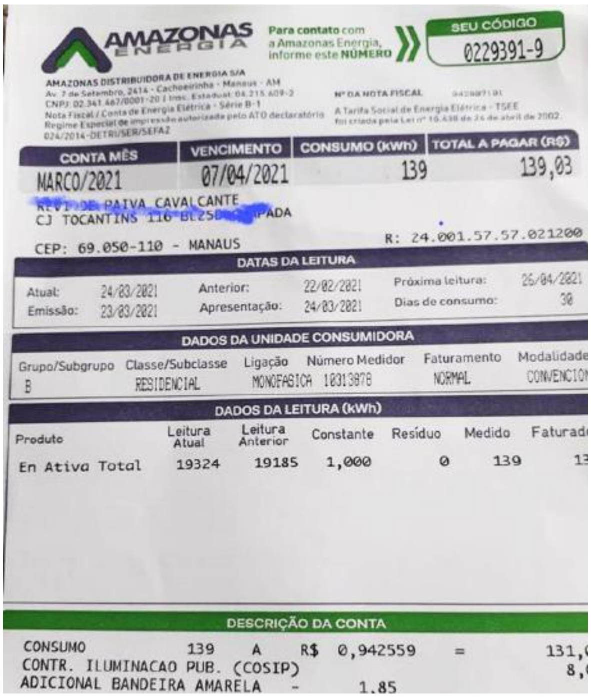

Fig.13: Kwh value of energy consumed

Source: The author.

The calculation was performed using the equation (7).

VPEDA = EED x Tax x 365 (7)

VPE = 11,70 x 0,942559 x 365

VPE = 4.025,20/year

In which:

- ✓ VPEDA: Cash value saved for one year;
- ✓ EED: Energy saved in kWh/day;
- ✓ Tax: Fee charged by Manaus energy per kWh of energy consumed.

1.4.4 Calculation of payback time

In order to better verify the economic feasibility of the project, we sought to determine the investment payback time, using the investment economic feasibility indicator called return (TR). For this procedure, the data described below was used:

- ✓ Value obtained for the investment: R$ 33.686,00;
- ✓ Cash savings with the implementation of the project (benefit): R$ 4.025,20;
- ✓ Interest rate (i): 1.18% p.m the equivalent of 15.16% a,a (using the rates charged by Banco Santander).

To calculate the internal rate of return, the equation used was (8)

$$TR = -\frac{\ln(1 - C \times i/P)}{\ln(1+i)} \quad (8)$$

$$TR = -\frac{\ln(1 - 33.686 \times 0{,}1516/4.025{,}20)}{\ln(1+0{,}1516)}$$

TR = 9 years and 3 months

In which:

- ✓ TR: Return time in year;
- ✓ C: Investment;
- ✓ i: Interest rate a,a;
- ✓ P: Billing of the year.

IV. RESULTS AND DISCUSSIONS

The object of the research was a development of a single-family residence located in the Flores neighborhood in the city of Manaus, in the state of Amazonas, having as a proposal the design and implementation of a system for heating water through the capture of solar energy.

The dimensioning of the hot water consumption, foreseen for the project indicated that a 500 liters reservoir meets the required demand for the residence.

The calculation to obtain the collectors area indicated that to compensate the useful energy demand, which is 243.60 kWh/month, a solar energy collecting area of 5.05m2 was necessary, which was supplied by 5 solar energy collectors with a generation capacity of 70.60 kWh of energy per month.

The cost of energy saved with the implementation of the solar water heating system indicates a positive economic result, buying that the project is economically viable with a payback time of approximately 9 years and 3 months.

V. CONCLUSION

As seen earlier, it is concluded that the project is economically viable since the results showed a significant reduction in the cost of energy consumed in the residence, thus contributing to a payback time of 9 years and 3 months for the investment after project implementation.

Other relevant factors with the implementation of the solar heating system is that it presents itself as a tool of fundamental social, economic, ecological and environmental importance, as it is aimed at the development of a project aimed at the use of a form of renewable energy which can contribute to an immediate valuation in the market.

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