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ANALYSIS OF THE THERMAL EFFICIENCY OF A SOLAR THERMAL COLLECTOR FOR LOW INCOME FAMILIES

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Abstract. *The use of solar collectors for water heating is increasing all around the world. Because it is a simpler and cheaper technology, it has been seen as one of the solutions for sustainable development goals and saving energy for the population, as it has been occurring in housing developments. The purpose of the present work is the construction of a low cost solar collector for low income families, the analysis of thermal efficiency and the use of an electronic system developed from the Open Hardware Arduino MEGA ATmega2560 microcontroller for the collection and storage of data. Partial results indicated a solar collector efficiency of approximately 50%.*

Keywords: *Solar collector, Low cost, Efficiency analysis.*

1. INTRODUCTION

Among the renewable sources of energy used until the end of 2015, investments were distributed between 2.3% in nuclear energy and 19.3% in all other renewable energies, demonstrating a huge energy potential from solar, wind and geothermal energy (Zervosand Lins, 2017). Thermal energy storage at the end of 2009 had a total installed capacity of 600 MW and by the end of 2013 a total of 3.6 GW (Van der Hoeven, 2014). In 2016 total production capacity expanded to 456 GWth distributed in 652 million m² of installed collectors (Pereira et al., 2017). In Brazil, the leading country in the development of renewable energy in Latin America, the solar water heating market is potentially growing, mainly because this technology is simpler and economically viable for the population.

The Rio+20 international conference has produced a document (United Nations, 2012), which mentions the construction of sustainable cities, including the rational use of energy, with effective control by the government.

In the study by Metz et al. (2007), the main use of solar energy is restricted to heating domestic water using solar collectors, because it has a low environmental impact and reduces the use of conventional energy matrices.

Due to the initial flexible investment, varying from R$ 1,500 to R$ 6,000.00, solar collectors for water heating have been used, mainly in collective housing constructions developed by governments as a way of financial and energy saving and for having great social impact, being a renewable and sustainable source of energy. In the *Minha Casa Minha Vida* (My home, my life) program, the installation of solar heaters in houses should generate savings of up to 30% for residents (CDHU, 2016). Fig. 1 shows the use of solar collectors in popular homes.

Figure 1. Solar collectors installed at houses of the program *Minha Casa Minha Vida.*

In general, within the residential sector, water heating generates an average expenditure of 24% of the total electric energy consumed (Oliveira et al., 2015; Pereira et al., 2017). The reduction of the family demand of electric energy causes social improvement, environmental preservation, conservation of energy, possibility of job generation, family and national financial savings between 8 and 9% of the electric demand, besides the significant reduction of emissions of greenhouse gases (Sociedade do Sol, 2001).

The flat-plate solar collector (FPC) is used in situations of moderate heating, taking advantage of the direct irradiation of the sun, with little maintenance, being applied in heating of building water and industrial processes (Duffie and Beckman, 2013; Kalogirou, 2009).

2. OBJECTIVES

The objective of this work is the construction of a bath solar heating system developed for low income families with PVC panels used in ceiling lining in environments, and the evaluating of the thermal efficiency of the solar collector by the incident irradiance multiplied by the collector area and amount of heat absorbed by the First Law of Thermodynamics. The characteristic curve of the solar collector will also be analyzed.

For this, an experimental bench was designed and developed, in which the temperatures of hot water inlet, cold water outlet, ambient temperature, mass flow of the circulating water by the solar collector and incident solar irradiation will be measured. An electronic system was also built using the Arduino® MEGA board for data collection and storage and further processing in an appropriate software.

3. MATERIALS AND METHODS

The built-in solar collector uses a PVC (polyvinyl polyvinyl chloride) collector plate, of alveolar structure and similar to a radiator, which the internal channels provide the proper distribution of heat from the plate to the water, according to Fig. 2.

Figure 2. PVC Honeycomb Plaque

At the ends of the board PVC pipes are also attached, connected to a water tank. The board is installed with a slope equivalent to the local latitude plus 10 °. In addition, the system was mounted so that water circulates between the water tank and the plate by term siphon.

Figure 3 (a) and (b) show the solar collector system and the schematic diagram of the water flow, respectively.

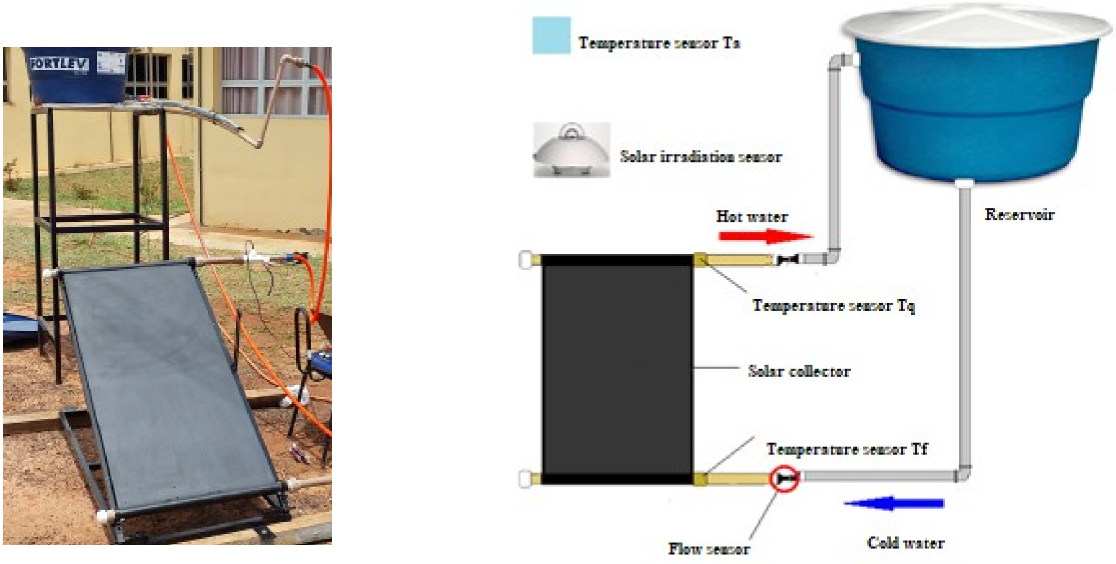

Figure 3. (a) Mounted solar collector system - (b) schematic diagram of water flow

For the measurement of cold water inlet, hot water outlet and ambient temperatures, Dallas sensors DS18B20 were used, while for the measurement of the incident irradiation indices on the plate, a pyranometer, according to the work developed by (Avallone et al., 2016, 2018) were used.

3.1. Mathematical Equations

For the evaluation of the amount of heat absorbed by the solar collector, the First Law of Thermodynamics were used, as defined in Eq. (1) and cited by (Kalogirou, 2009; Duffie and Beckman, 2010; Struckmann, 2008).

(1)

where, is the heat flow absorbed by the water inside the solar collector, [m³/min]is the mass flow of water flowing through the collector, [J/kg.K]the specific heat of the water at constant pressure and[°C]the cold and hot temperatures, i.e., water inlet and outlet in the collector, respectively.
The incident heat flux is measured by the pyranometer, inserted in the term and calculated using Eq. (2),

(2)

where, is the incident heat flux from the sun in the solar collector, the useful collector area [m²] andthe global radiation incident on the solar collector in [W/m²], measured by the irradiation sensor developed by (Avallone, 2018).
The thermal efficiency of the solar collector is defined by (Duffie and Beckman, 2013; Kalogirou, 2009) in the Eq. (3).

(3)

where, [%] is the thermal efficiency of the solar collector.

4. PARTIAL RESULTS

From data from a single day of experiment, some results were obtained, and will be complemented during the improvement of the collector e the measuring system. While setting the entire structure and making measurements, some arrangements and configuration of sensors had to be changed so that there was the less heat loss as possible. It was observed that air bubbles and the use of a hose with a minor diameter in the flow sensor could prevent the water from flowing through the reservoir and the solar collector. To solve such problems, a hydraulic bomb and a regulating valve were added, and the water could be perfectly heated.

The temperatures obtained during the experiment are shown at Fig 4. The highest ones were achieved by the time of the greatest irradiation.

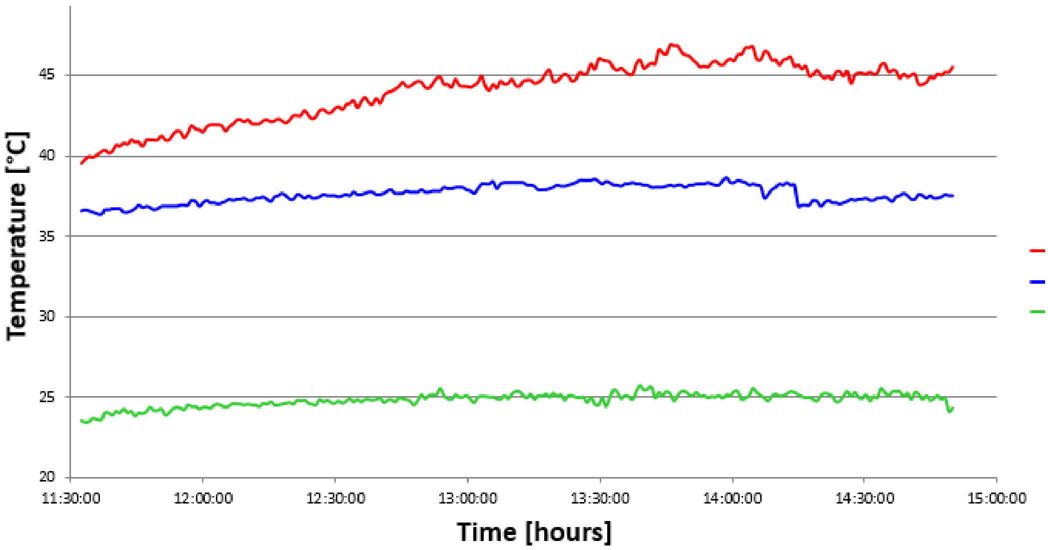

Figure 4. Graph of the obtained hot, cold and ambient temperatures

The highest irradiation, showed at Fig. 5, was about 940W/m². This value occurred during the afternoon, when it was about 14h06.

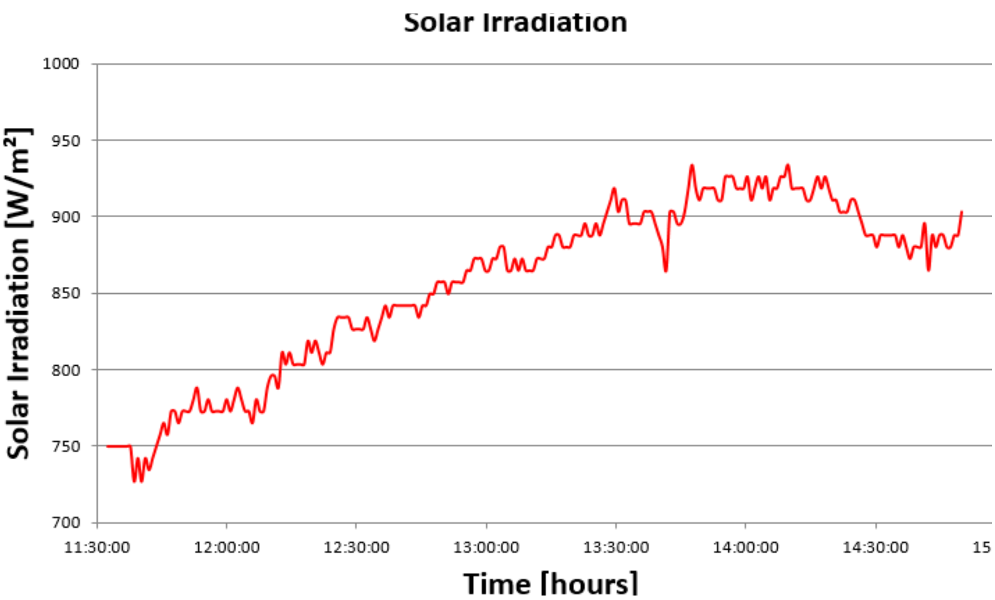

Figure 5. Solar irradiation as a function of time.

Due to temperature and radiation level, the thermal efficiency reached an efficiency of more than 31% at 14h07, according to Fig. 6. As a normal thermodynamic process, heat is lost to the environment, what leads to a less efficient water heating. This process and other causes that can decrease the efficiency of the collector shall still be studied and discussed during the tests for the improvement of the collector.

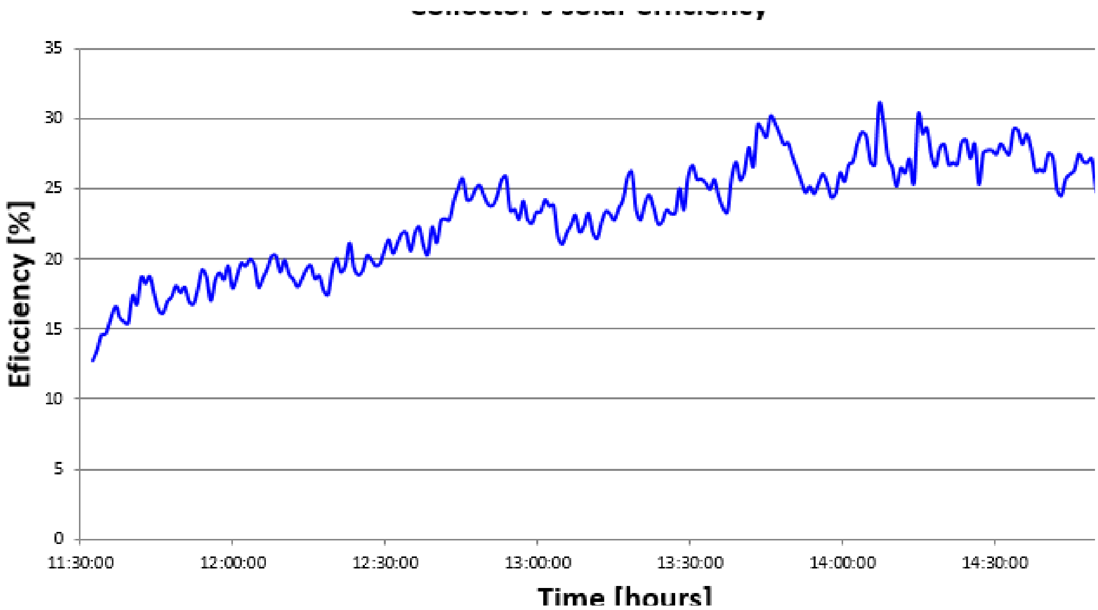

Figure 6. The collector's solar efficiency.

5. CONCLUSIONS

Due to the observation of the obtained data, it is possible to see that the highest temperatures the water achieved occurred during the same moments when the solar irradiation was at its peak, and also at these periods the efficiency of the collector was the highest.

One of the main objects of the project was that the solar collector could be built with an affordable price, so that families with a low income would have access to it. By the end of the developments made until now, this purpose was achieved, and the PVC plate, in comparative with the equipment offered in the market, was the most economic part.

Then, the process of heat exchanging between the solar collector and the water effectively occurred but can still be improved by upgrades in the configuration of the structure and the sensors. Also, the measurement system and means to solve sensor problems are in current study, with the objective of obtaining more accurate data. There is also a need to further analyze the characteristic curve of the solar collector, which must be done by more experiments and the sensors' calibration. Taking it into account, the results here presented are only preliminary and a series of experiments and improvements are to be done.

6. ACKNOWLEDGEMENTS

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1. RESPONSIBILITY NOTICE

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