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# THE DEVELOPMENT PROCESS INTEGRATED SUSTAINABLE PRODUCT APPLIED IN A SOLAR WATER HEATING SYSTEM

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**Abstract.** *The position in relation to manufactured products has been turning into a position for a more sustainable production without any loss of quality. The high current consumption results in heightened production of waste, so that it does not adversely affect the present and future, practices like recycling, reconditioning and reuse are examples that can done the current products part of the solution to achieve sustainability. This study focuses on sustainability as it takes in consideration the discarded material from the domestic disposal and, in parallel, uses renewable energy in its scope. With the idea of combine both subjects, the selected product was a Solar Water Heating System (SWHS) composed of discarded and recyclable materials. To delineate the product concepts such as eco-design, eco-efficiency, Design for Life Cycle and Integrated Product Development Process were studied. So that, the materials, tools and processes for the development of the SWHS prototype were selected considering these concepts. After the prototype assembly and test procedures, it was implemented the measurements data collection regarding to its efficiency. The preliminary results show that the SWHS fits the references and concepts found in the literature as it reaches a temperature of 333 K.*

**Keywords:** *Solar Water Heating System, Product Development, Discarded and recyclable materials, renewable energies.*

## 1. INTRODUCTION

The view and attitude towards manufactured goods were turning into a positioning for products that use manufacturing processes more sustainable, not only in the product conception but throughout all its life cycle, with no loss of quality (Manzini, 2002). To accompany these changes, companies searched for alternatives to their products according to the concepts of sustainability, i.e., to plan and produce reducing environmental impact while maintaining quality and low price (Kiperstok, 2005).

However, the high consumption results in the exacerbated waste production and in order that this problem does not affect adversely the present and future, it is provided measures that concern sustainability. Practices such as recycling, reuse and reconditioning are examples of the fact that the current products can be part of the solution to achieve sustainability (Back *et al.*, 2008). Meet the demands of the present without jeopardizing future resources is part of the concept of sustainability, and integrating the Integrated Product Development Process (IPDP) can serve society without necessarily compromising functionality or any relevant characteristic of the product (Goldenberg, 2007).

This research focuses on sustainable area as it takes into consideration the disposal from consumption and, in parallel, the use of renewable energy in its scope. With the idea of grouping both subjects, the chosen product was Solar Water Heating System (SWHS) composed of recyclables and disposables materials.

The Literature Review of the concepts used in this research was the IPDP, Clean Production, End-of-Pipe (Kiperstok, 2005), eco-design and eco-efficiency, Design for Life Cycle (DFLC) and Design for environment (DFE), in an environment of Concurrent Engineering in order to base the application of methods in a sustainable prospective. Thus, it was created the preamble to construct a SWHS and the selection of materials and tooling processes were investigated during the informational, conceptual and preliminary designs, respectively. After collecting the data related to the components and functionality, the prototype was assembled during the detailed design. The SWHS was, then, installed for measurements regarding its efficiency in an isolated from the water supply and sewage environment intending to analyze its temperature during different times of the day as well as to find if the temperature was dependent only on the incidence of sun or if the ambient temperature was also a determining factor.

The structure of this paper initially describes the explanation of the literature concepts that were relevant in the technical procedure of the research for the SWHS development, then the phases of the development process for the

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prototype elaboration, the prototype installation and data collection are exposed, ending with the analysis of the results and conclusions about the efficiency and development of sustainable product.

## 2. LITERATURE REVIEW

In order to unravel the concepts of sustainability and its influence on the development of sustainable products it was made a literature review about the themes involved in the research, such as eco-efficiency, eco-design and clean production that are concepts that contribute together with the coexistence of production and environmental preservation. The essence of a better quality of life for man is linked to the use of resources currently available (Canciglieri *et. al*, 2012).

### 2.1 Concurrent Engineering

The determination inherited from past ages, the possibilities of generating clean energy and the willingness to develop a product that aims to make sustainable the existing materials and waste discarded by humans, creating the preamble to the systematic integration of the ideas of eco-design and eco ace-efficiency to the virtues of concurrent engineering that allows the designer to run in parallel the different stages of the work, allowing a better use of planning time until the time of design implementation (Pigosso; Rozenfeld, 2011).

Therefore, it is known that the various influences experienced by a design can be worked simultaneously to better interpret their influences in an overview and to adequate more wisely the decisions making in conceptual design. In a more advanced design view, the Concurrent Engineering philosophy prevents errors and minimizes empirical decisions (Back *et al*., 2000).

The Concurrent Engineering is the work environment proposed for the article, it is possible within it to execute integrated product development processes and sustainability concepts at the same time.

### 2.2 Integrate Product Development Process

The IPDP is a tool that aims to integrate the phases of the design through the work of multi-functional teams comprised of members from different areas of knowledge and has the intention to increase the quality, reducing the product development cycle, lower costs, besides develop a product focused on market requirements (Miralles; Lucena, 2007) and it fits perfectly in the development of a sustainable product through other tools that pertain to engineering, such as Life Cycle Design, eco-design, eco-efficiency and Clean Production.

According to Rozenfeld (2006), the product development can be divided into Informational Design, Conceptual Design, Detailed Design, Preparation for Production and Product Launch. This article is focused on the analysis of the first three steps of the IPDP and one more step that precedes the Detailed Design, which is the Preliminary Design. The sequence for the development of the product is shown in Figure 1.


Figure 1. Sequence adopt for the SWHS development (Adapted from Rozenfeld, 2006).

Therefore, the SWHS proved to be a product capable of uniting clean energy, the concepts of eco-design and eco-efficiency, recyclable materials from domestic disposal and the IPDP tool, in an environment of Concurrent Engineering.

### 2.3 Sustainability

The survival is not a question of how many people inhabit the planet, but how much space each one occupies in it; how much is necessary to produced to meet individual consumption; how much energy each human consumes; or yet, the amount of waste generated in a period of time by one person. This is called the ecological footprint (Kiperstok, 2005). It is necessary to use wisely the natural resources in order that the shortage, from the lack of sustainable planning, does not affect future generations. Develop and produce does not mean degrade and pollute, to harmonize the two strands turns the socioeconomic an ally of the environment (Canciglieri JR., 2011; Silva; Souza, 2012).

At this point, José Goldemberg (2007) points for the necessity of to diversify the ways to get energy, as part of a long-term strategy to save the existing supply. The renewables sources become the best option for that diversification, searching meanings that pollute less that fit the proposition of the new millennium with renewable character and a view

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oriented to sustainability is truly fundamental. The big Brazilian advantage is in its high percentage of renewable energy, with 44.4% of total production in 2006, while worldwide, the renewable energy matrix was around 13.2% of total production in 2006 (Canciglieri *et. al,* 2012).

Within the concept of sustainability there are several possible approaches, this article uses those that relate to the development of sustainable products. The integrated concepts in the Concurrent Engineering environment are the Eco-design, Eco-efficiency, Design for Environment and Life Cycle Design, which guides the planning and the development processes of the product.

### 2.3.1 Eco-design

Eco-design can be conceptualized as a project model or design model oriented by ecological criteria. A wide number of other activities are covered by the concept of eco-design, synthesizing them for the design intended to the environmental issue (Manzini, 2002). Themes involving since the treatment of the pollution generated by the product until the impact from its production or the energy expenditure required to produce it as well as the source of this energy are part of the environment worked by eco-design. Each concept attempts to show the points needed for the environment integrating the industrial ambient as the activity called End-of-pipe which offers a destination to the waste from the production, avoiding a possible pollution of the environment. The use of clean technologies favors the process in order to positively affect the production. The encouragement of certain sustainable philosophies feeds the newly created culture of a clean consumption (Pigosso; Rozenfeld, 2011).

All requirements should be worked in communion, because thinking in the technicality of the clean production without considering social and cultural factors related to the cleaner consumption mentality can characterize the failure of the clean products design. Thus, the sustainable design development is every action that is based on a considerable reduction of environmental resources aiming the social well-being and allowing a response from the production system, that is, every action that leads the business sector not compromise their ability to manage, in a coordinated way, the strategies applied to the design and to the sustainability (Manzini, 2002).

### 2.3.2 Eco-efficiency

Energy efficiency is undoubtedly one of the most viable ways to reduce costs and local and global environmental impacts (Goldenberg, 2007). Solar energy is one of the energy sources that are listed among the best in the near future. There is great opportunity to capture solar energy in Brazil, with an average of six hours in some states, as illustrated in Figure 2, and the use of recyclable materials in product development to capture solar energy make the sustainability an action to control the day to enjoy the tomorrow (Silva; Souza, 2012).

A energia solar é uma das fontes energéticas que estão entre as mais bem cotadas para um futuro próximo. A grande oportunidade de captação de energia solar brasileira, com uma média de 6 horas em alguns estados, conforme ilustrado na Figura 1,

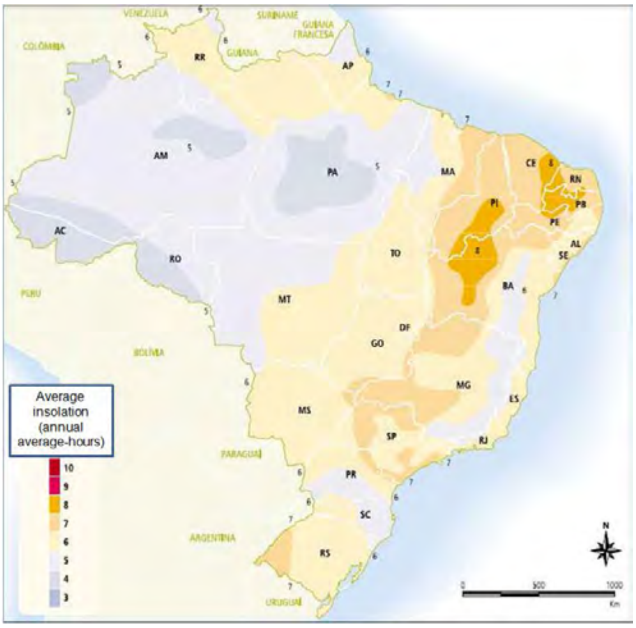


Figure 2. Annual hours average of insolation in Brazil (ATLAS Solarimétrico do Brasil, 2000).

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### 2.3.3 Design for Environment e Life Cycle Design

It is important pay attention to any possible impact generated by the product from its planning to its disposal. This attention aggregates environmental benefits of the pollution reduction to the methodology that is known by Life Cycle Design, which is one of the strands of Design for Environment. The Life Cycle Design can be understood as a way to minimize the negative impacts of industrial products in the environment, as how much energy is needed to produce a specific product, how long it will be useful, or what will be its destination after the end of its functionality. Therefore, the Life Cycle Design seeks to uncover elemental issues to the cleaner production through parallel operation of eco-design (Manzini, 2002).

## 3. SWHS DEVELOPMENT PROCESSES

According to Rozenfeld *et al.* (2006) the design scope construction added to the product features require information about the product and its definition, besides limitations relevant to this product. Therefore, in this research the design scope is divided into informational, conceptual, preliminary and detailed, based on existing solar heaters systems, such as the Solar Water Heating System of Discarded Materials (Alano, 2004), the Popular Solar Water Heating System (Silva; Souza , 2012) and the Low Cost Solar Heating System (Comunidade SOL, 2009).

### 3.1 Informational Design

The informational Design allows the knowledge of what are the components from human disposal, what is the pollution degree, how they may interact to benefit society and what are the possible products that can be created from them. The information of this phase was used to select the appropriate materials for the development of the components of the SWHS. It is worth noting that discarded materials cause damage at different levels to the environment, being the degree of impact related to their composition, manufacturing process, local where they are discarded, among other factors that influence their decomposition. A classic example is the PET bottles and aluminum cans, which are found in various shapes and volumes, as illustrated in Figure 3. This diversity provides different recycling processes for each specific material, and may even turn them into different products, as in the case of the PET bottles that is transformed in brooms, clothesline, rulers, hangers, fabrics, clocks, tiles, pipes, fittings, faucets and, finally, in the synthetic marble used in the production of countertops and sinks.

Figure 3. Samples from Disposal (Author, 2012).

The work done by this step becomes important when an alarming number of 6 billion PET bottles is discarded by society during a year (Gonçalvez-Dias, 2006). Considering the fact that each plastic bottle take over 500 years to degrade completely, the situation is even more desperate. A slow reconditioning in the current culture is seen through the growing concern about the impact of processes and products on the environment.

Other material as harmful as PET bottle is the Tetra Pak ® packing, when disposed in an improperly way. This is due to their insufficient forms of recycling, which is a consequence of the great difficulty in separating its components (Figure 4). Each sheet comprising a Tetra Pak ® packing has a specific function in the set: (1) Polyethylene protects the packing from outside moisture; (2) the paper provides stability and strength; (3 and 5) another piece of polyethylene that in this position acts as an adhesion layer; (4) Aluminum foil which prevents the entry of light, oxygen and aromas; and (6) the final layer of polyethylene which protects the product inside the packing. In the Tetra Pak ® disposal it is found as milk and juice packing, always shaped as boxes. However, there is a measurement difference in the edges of each type, for example, the juice packing is higher and the length is smaller than the boxes containing milk.

As the research has the intention of taking advantage of the concepts of sustainability, clean and renewable energy and materials from the disposal, it was studied which solar heating systems could achieve the objective of the product designed oriented to sustainability, among them it is found the Solar Water Heating System of Discarded Materials

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(Alano, 2004), the Popular Solar Water Heating System (Silva; Souza, 2012) and the Low Cost Solar Heating System (Comunidade SOL, 2009).

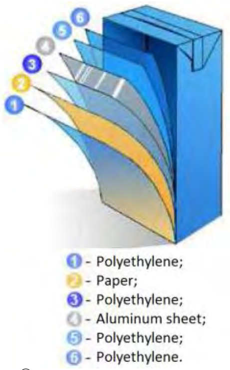


Figure 4. Tetra Pak® packing structure (Tetra Pak, 2012).

### 3.2 Conceptual Design

At the stage of conceptual design it was chosen one of the existing solar water heating systems, as well as the materials that will be used in the construction processes of the heating systems based on the literature. The guiding model chosen was the Solar Water Heating System of Discarded Materials (Alano, 2004), and from it the processes of the components of the SWHS were elaborated.

The Solar heaters from recyclable materials found in the literature used PVC pipe for water conveyance in the coil and as solar energy collector the two-liter PET bottles and Tetra Pak ® packing which were cut, folded and painted black. The role of PET bottles added to Tetra Pak ® packing is the creation of an environment isolated from the external forming boilers inside it. The pipes and Tetra Pak ® packing painting with flat black paint was made to avoid the reflection of sunlight and thereby to collect more efficiently the solar energy within the boiler.

The pipe layout is standard for the heaters: entrance of water at room temperature at the bottom and exit of hot water at the top. This structure is called a thermo-siphon, as it takes advantage of the density difference between the hot water (less dense) and room temperature water (denser). The research used Tetra Pak ® packing that contains juice instead the milk ones used in the literature for the manufacture of the Solar Water Heating System of Discarded Materials (Alano, 2004). The reason for the selection of juice packing was the standardization of the heaters due to the greater availability of these resources in the collection sites (Figure 5). It is important to remember that before handling any component from the disposal it is necessary the hygienic cleaning of for each one to avoid any kind of contamination or disease transmission.

Figure 5. Tetra Pak® packing Recyclable Center (Author, 2012).

### 3.3 Preliminary Design

The differentiation of each collected material and separation of the instruments that will be necessary for the construction of the SWHS prototype were studied in this design phase. In the SWHS prototype construction procedure the tooling used for cutting, construction, painting and cleaning processes were:

i) Scissors, stiletto, penknives and knives;

ii) Hammer, wooden planks, nails, sandpaper, PVC pipe of half-inch, connections "T", 2-liter PET bottles fully transparent, protective gloves, goggles and tape measure;

iii) Paint roller, brushes and 1 liter of matte black synthetic enamel paint, fast drying for interior and exterior;

iv) Cleaning Sponge and mild soap.

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In the model proposed by Alano (2004) it was used a 200 liters water reservoir, however, in this research it was used a smaller capacity reservoir made of 45 liters Styrofoam boxes, as the SWHS prototype was smaller than literature model. The main feature of the tank is to keep the hot water until the using time, non-deforming with a temperature of *333 K* and holding its constant volume even under the water vapor pressure variation. To achieve this, the reservoir was lined with heat resistant plastic sheet, found in the disposal of a refrigeration company. The reservoir, besides the internal lined, was painted black in order to not reflect sunlight and help to keep the water inside warm.

In the next topic is reported the SWHS components construction process and all steps that the materials suffered to generate the prototype, as all the tooling and components had already been provided in previous steps.

### 3.4 Detailed Design

The SWHS component manufacturing observed the following logic:

i) The cutting and folding of the Tetra Pak ® packing according to the literature;

ii) The cutting of the bottom of the 50 PET bottles completely transparent, so that they could fit;

iii) The construction of a template for cutting the PVC pipes in two different sizes, one with the measures related to the 5 already cut PET bottles queuing, and another smaller, with proportional measure to the distance between two parallel rows of PET bottles;

iv) The painting of the Tetra Pak ® packing, the cut PVC pipes and the adapted reservoir;

v) The assembly of the elaborated components.

The Tetra Pak ® packing after washed and dried must be unfolded enabling the cutting of its upper part (lid region), as shown in Figure 6. The bottom region was cut leaving two centimeters from the existing folded mark, then, with a pen, the bottom cut line was made. Next, both sides of the flattening region was cut, forming two absorption units (Figure 6). Each 1 liter packing can generate two absorption units throughout 5cuts and 6 folding, as shown in Figure 7.

Figure 6. Tetra Pak® packing sides and lid cutting (Author, 2012).

The template for folding the Tetra Pak ® found in the literature is not common for all types of packing found in the disposal, so it was necessary to create a template suitable for folding Tetra Pak ® soy juices packing within the design needs. It was adopted also, as a guideline, the lateral existing folds marks of the packing for applicability of the process of the developed template. It were cut 25 packing generating 50 absorption units.

**How to cut and fold the Tetra Pak packing**

1 –With Tetra Pak assembled packing , detach the lids of the top and bottom;
2 – Next press the packing down until is flat, cut 0,225 m of length and fold the sides, in the existing folding marks (b);
3 – Packing with the folding sides;
4 – Fold the edges in diagonally (d) to adjust it into the PET bottle and also fold the two edges of the 0,07 m cut (e) to fit the next bottle.
Observation: The edges were folded down.

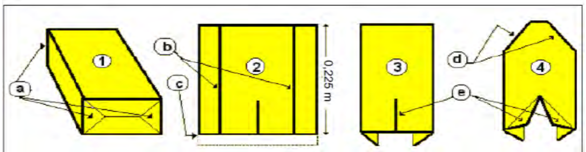


Figure 7. Tetra Pak® packing folding and cutting (adapted from Alano, 2004).

The next step was the cutting of the PET bottles bottom using stiletto, knives and scissors, as shown in Figure 8.

Figure 8. PET bottles cutting (Author, 2012).

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The PET cutting was facilitated by the existence of a line in relief that is a design characteristic of the bottles without the need for a specialized tool. Once the desired amount of cut bottles was obtained it was constructed a template for the half inch PVC pipe cutting. The solar energy collector of the SWHS developed has 12 vertical sets consist of 4 PET bottles each, positioned horizontally with all piping passing into the bottomless bottles. Thus, the cutting template consists of a long base and two short and thick guides. These guides have the purpose of supporting the base and enable a better fixation of the pins that is fixed on the base. The pins positions was made in order to immobilize the PVC pipe during the cutting process, providing a reference line for performing the process, that is, before each pin is set in the template, a vertical section should be done with a saw-stranded, as shown in Figure 9. In this way the eight inches smaller pipes that will be used horizontally and the larger pipes of eighty-four centimeters positioned vertically, could be obtained through the same template. It is worth noting that the time spent for the PVC pipes cutting with the template is reduced. The process has become more practical and got tubes in standard size.

Figure 9. PVC pipes cutting (Author, 2012).

Some measures were taken to isolate the components painting process made previously (PVC pipes and absorption units). Once the ambient was prepared, the paint was applied with rollers and brushes in the Tetra Pak ® packing already folded, in the reservoir and in the PVC pipes already cut and sanded. The paint used in the process is black color for better absorption of solar energy, and with matte characteristics it will reflect less sunlight. After the paint drying it was possible to mount the SWHS solar collector and reservoir. To assemble the one of the boiler five lines composed of PET and Tetra Pak ® it was fixed a eighty-four centimeters tube in one of the "T" connections. Next, in was placed in sequence a PET bottles and Tetra Pak ®, as illustrated by Figure 10, repeating this process four times.

In order to isolate the last PET boiler it was used the bottoms from bottles cut earlier. These bottoms were arranged in an inverted position for the optimization of the tube size. A circular cut was made so that the tube could pass through the bottom of the bottle.

Figure 10. Sequence for the collector construction (Author, 2012).

The boiler lines were united by the eight centimeters pipes finishing the SWHS collectors.

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### 3.5 SWHS instalation and Data Acquisition

To prove the product functionality and aiming the concepts studied it was installed a SWHS prototype of a unitary module, that was sufficient for the consumption of hot water from a person in a day (30 to 40 liters). The installation was done in a refrigeration company in the city of Araçatuba, São Paulo, which allowed the use of its space, as shown in Figure 11.

Figure 11. SWHS installed (Author, 2013).

The prototype was installed facing the north side, for better utilization of the Sun. According to the literature the best tilt angle for the collector has to be calculated by adding *10* ° to the latitude of the installation location ($\varphi_{lat}$), in this case *21º* (Araçatuba , SP), resulting in a tilt angle for the solar collector ($\varphi_{SC}$) of 31 °, as shown in Equation (1).

$$\varphi_{sc} = \varphi_{lat} + 10^{\circ} \quad (1)$$

The reservoir was positioned as close as possible to the collector in order not to disperse the heat in water transportation. It was placed on a support given by the same company that allowed the installation the SWHS in its space. The support was adapted from refrigerators disposal that were taken to a junkyard in the region. By integrating the reservoir support platform and collector platform (also made from discarded refrigerators), the system was installed successfully. This article is focused in the study of the efficiency of the SWHS.

For the water circulation between the collector and the reservoir were used six pipes: three feed the collector in the lower region with water at room temperature and three feed the reservoir with water already heated by the collector, keeping the water through the system without addition or removal of it in order to measure the temperature at different times of the day. The pipes are connected by *90º* elbows connections to facilitate the assembly of the components. The water flow is performed by thermo-siphon, that is, the density difference between the water in room temperature (denser) and the heated water (less dense) makes the water circulates within the system. Thus, in the reservoir is perceived the difference in density, the heated water accumulates at the top, while the lower temperature water accumulates in the bottom of the reservoir. The pipes that feed the system with water at room temperature have lengths of 1.09 m, 0.56 m and 0.08 m, and the pipes that feed the reservoir with hot water have lengths equal to 0.28 m, 0.32 m and 0.08 m, as shown in Figure 12.

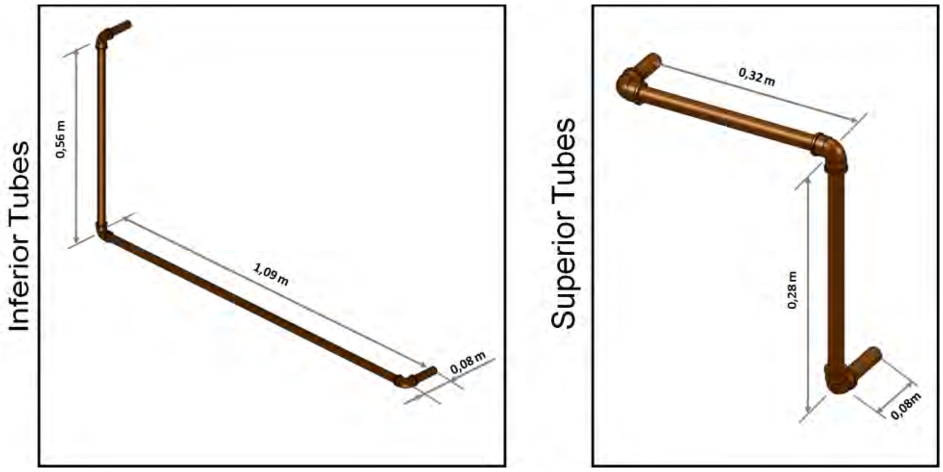


Figure 12.Dimensions of the SWHS and reservoir communication pipes (Author, 2013).

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The temperature acquisition was made during the entire period of insolation, every two hours, with the first at 7 a.m. and the last at 7 p.m. to obtain a reliable sample, according to the experimental design.

## 4. ANALYSIS OF THE RESULTS

Temperature measurements were carried out between the end of January and early February, with intervals of two hours, between 7a.m. and 7 p.m. The data showed that the prototype is consistent with the results reported in the literature (Alano, 2004), since reaching an efficiency of *333 K* for the water reservoir, that is, the eco-efficiency required in the research scope has been accomplished satisfactorily. The Table 1 shows the temperatures acquired.

The eco-design presented by the model proved effective in reusing discarded and recyclable materials into a product that benefits from renewable energy. The research approached the concepts and tools of product development process and Simultaneous Engineering, integrating the principles of sustainability, whose perspectives have focused on eco-efficiency, cleaner production and End-of-pipe to construct the components of a SWHS prototype from recyclable material based on the literature.

Studies from other components from human disposal are plausible alternative for the preparation of a SWHS that is compound only by discarded and recyclable materials without the necessity of acquiring any component of the system. Thus, other models of SWHS can be proposed using the concepts of eco-design and eco-efficiency, positioning themselves increasingly on sustainability concepts.

Table 1. Temperatures acquired between January 24th and February 18th, 2013, from 7am to 7 pm, every 2 hours. Temperatures in Kelvin (*K*). (Author, 2013).

| *Hour* / *Day* | 07:00 | 09:00 | 11:00 | 13:00 | 15:00 | 17:00 | 19:00 | Day Average |
|---|---|---|---|---|---|---|---|---|
| 24-jan | 312,1 | 308,7 | 314 | 320,5 | 327,3 | 329,5 | 326,3 | 319,77 |
| 25-jan | 315,5 | 315,4 | 313 | 316,3 | 322,1 | 320,5 | 320,1 | 317,56 |
| 26-jan | 310,5 | 310,3 | 312,9 | 317,8 | 323,7 | 325,6 | 328,1 | 318,41 |
| 27-jan | 311,8 | 311,3 | 310,5 | 316,7 | 321,8 | 326,2 | 326,4 | 317,81 |
| 28-jan | 316,2 | 315,1 | 315,2 | 319,9 | 320,5 | 320,5 | 322,5 | 318,56 |
| 29-jan | 312,9 | 312,6 | 315,6 | 317,9 | 327,5 | 329,9 | 328,5 | 320,70 |
| 30-jan | 316,7 | 315,7 | 314,7 | 317,3 | 324 | 327,4 | 327,5 | 320,47 |
| 31-jan | 317,6 | 317,3 | 316,6 | 317,2 | 317,5 | 318,4 | 317,1 | 317,39 |
| 1-fev | 311,6 | 310,6 | 311 | 316,3 | 324,5 | 325,3 | 324,1 | 317,63 |
| 2-fev | 315,9 | 314,6 | 314 | 321,7 | 330,6 | 333,3 | 331,4 | 323,07 |
| 3-fev | 320,6 | 319,8 | 317,4 | 318,6 | 321,9 | 319,3 | 317,7 | 319,33 |
| 4-fev | 307,5 | 306,9 | 307 | 314,1 | 318,7 | 320,4 | 320,5 | 313,59 |
| 5-fev | 313,3 | 312,1 | 313,8 | 323,7 | 329,4 | 328,9 | 327,5 | 321,24 |
| 6-fev | 317,3 | 316 | 316,4 | 320,7 | 325,5 | 323,6 | 322,1 | 320,23 |
| 7-fev | 312,9 | 311,8 | 311 | 312,9 | 314,9 | 319 | 316,5 | 314,14 |
| 8-fev | 306,9 | 306,3 | 305,1 | 304,9 | 304,2 | 304,5 | 304,4 | 305,19 |
| 9-fev | 300,7 | 300,5 | 300,5 | 303,5 | 305,6 | 311,9 | 313,1 | 305,11 |
| 10-fev | 310,9 | 307,9 | 310,8 | 321,1 | 327,1 | 330,1 | 329,4 | 319,61 |
| 11-fev | 320,1 | 317,9 | 319,4 | 322 | 324 | 327,1 | 326,9 | 322,49 |
| 12-fev | 317,3 | 315,9 | 319,3 | 324,6 | 330,8 | 331,4 | 330,9 | 324,31 |
| 13-fev | 320,2 | 318,1 | 320,2 | 322,9 | 324 | 325,3 | 324,5 | 322,17 |
| 14-fev | 320,5 | 319,2 | 321,5 | 325,8 | 326,1 | 327,8 | 325,1 | 323,71 |
| 15-fev | 322,5 | 320,8 | 323,7 | 326,8 | 327,8 | 327,8 | 328,8 | 325,46 |
| 16-fev | 317,7 | 316,5 | 316,5 | 326,7 | 328,8 | 328,9 | 326,9 | 323,14 |
| 17-fev | 322,5 | 320,8 | 323,7 | 326,8 | 327,8 | 327,8 | 328,8 | 325,46 |
| 18-fev | 317,7 | 316,5 | 316,5 | 326,7 | 328,8 | 328,9 | 326,9 | 323,14 |

## 5. CONCLUSIONS

The research's development followed the steps that worked simultaneously and sustainable for the manufacturing of each SWHS. During the informational design the recyclables materials were treated theoretically, being investigated their compositions, methods of recycling and disposal. Among the materials collected were PET bottles, Tetra Pak ® packing, polystyrene, PVC and Thermal canvas. The conceptual design elucidated how each material could be worked to create a sustainable product. In the preliminary stage was gathered all tooling needed to build the SWHS besides the confirmation of the usefulness of certain recyclable materials in the design. Finally, the detailed design presented the conception of each component, resulting in the prototype of the collector and reservoir of the Solar Water Heating System.

The research emphasizes that through designs oriented to sustainability is possible to develop products in a way that their processes meet the current and urgent demands of environmental and social sustainability, so that the trend will move to other spaces which still to be explored, such as the replacement of some materials by others. The selection of new materials is oriented to what material cause more impact to the environment and if it is removed would benefit the entire population, adding quality of life and increasing product value, this value both real and sustainable. One way to solve the issues inherent in choosing which materials, how they impact the environment and how to add sustainable value to the product is through the study of the processes of integrated product development, including concepts of eco-design and DFE to evolve in the research in order to unravel the questions that still unanswered.

The efficiency of the prototype met the expectations when reached a maximum temperature between *330 K* and *333 K*, making feasible its integration to the water system. The next step in the research is to define the best way of integration of the SWHS to the water supply of a common residence, since it can reach an acceptable temperature, and simultaneously explore how much energy this prototype can save for the consumption of hot water of a person, given it can reduce the amplitude of the temperature of the water that feeds the shower and the thermostat adjustment temperature. Therefore, the cost to raise the water temperature in an electric shower will be less than that required if the water were in room temperature.

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## 7. RESPONSIBILITY NOTICE

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