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Tomás de Jesús Guzmán-Hernández
F. Araya-Rodriguez
Castro Badilla
Javier Mauricio Obando Ulloa

Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10683 Athens, Greece

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Tomás de Jesús Guzmán-Hernández, Professor, Technology Institute of Costa Rica, Costa Rica,
F. Araya-Rodriguez, Costa Rica Institute of Technology, Costa Rica Guillermo Castro Badilla, Professor, Costa Rica Institute of Technology, Costa Rica Javier Mauricio Obando Ulloa, Professor, Costa Rica Institute of Technology, Costa Rica

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ABSTRACT

Drying, dehydration, sterilization and pasteurization are activities that are used for the processing and conservation of agricultural and agroindustrial products. In these processes different sources of energy are applied (electricity, fossil fuels, biomass, among others). With the support of the Local Pilot Program for the Use of Solar Energy in the Huetar Norte region of Costa Rica, executed jointly by the Technological Institute of Costa Rica (ITCR) and the Ministry of Agriculture and Livestock (MAG). It has been possible to design, apply and evaluate different solar thermal systems in the agricultural units of small and medium producers to replace the traditional options of energy generation for cleaner alternatives. For this reason, the objective of this work is to describe the solar thermal systems implemented in the Northern Huetar region of Costa Rica for the improvement of the drying process. In this sense, two systems (a forced hybrid system with air, water and LP gas and another passive system) were designed to dry and dehydrate agricultural products and different types of seeds. These systems were evaluated by monitoring the mass of cocoa beans and its moisture content during the drying process. The results have shown that these systems are efficient for the improvement of production efficiency and the reduction of processing time in agricultural units.

Keywords: carbon footprint, Costa Rica, productivity, solar energy, solar drying
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Introduction

The way to preserve seeds, fruits and other agricultural products over the years has been with various processes, linked to the decrease of microbial load and moisture content. These processes are part of the incorporation of added value that is applied to agricultural products to ensure and increase their shelf life.

The methods used for the conservation of agricultural products (drying, dehydration, concentration, blanching, etc.) use different types of energy (biomass, fossil fuels, electricity and solar). Among these methods, the dehydration food industry is a very important sector within the food industry spread throughout the world, so it should empower small and medium producers associated in small and medium enterprises in this type of work (Fito et al, 2016; Amruta, 2013).

In this industry, the production systems can be traditional or technological. Traditional systems, although effective and historically used, have the disadvantage to be a slow process, requiring large extensions and improperly controlled. In addition, the final products obtained show low sensory quality and its safety is not adequate (Bergues et al., 1996).

Currently, human activities are destabilizing biophysical systems and leading the planet to an irreversible situation (Rockström et al, 2009), so it is necessary to use renewable energy sources. Within these, the electromagnetic radiation of the sun can be used as an energy source in different ways and for different uses (González Velasco, 2009).

According to the VI National Energy Plan 2012-2030 (MINAET, 2011), Costa Rica has the renewable natural resources necessary for energy production, since it is in a privileged situation at global level since it presents a theoretical solar potential around 10,000 MW, although its use is only 0.1% (Guzmán-Hernández et al, 2016).

For this reason, the Research Group on Solar Thermal Systems for Agriculture of the Doctorate Program on Natural Sciences for Development (DOCINADE) of the San Carlos Regional Headquarters of the Technology Institute of Costa Rica (SSC-ITCR) has proposed to work with solar energy as a viable and effective alternative for small businesses in the Northern Huetar region. The use of this source could serve as a trademark in the regional, national and international markets and contributes to the reduction of the carbon footprint for the agricultural producers.

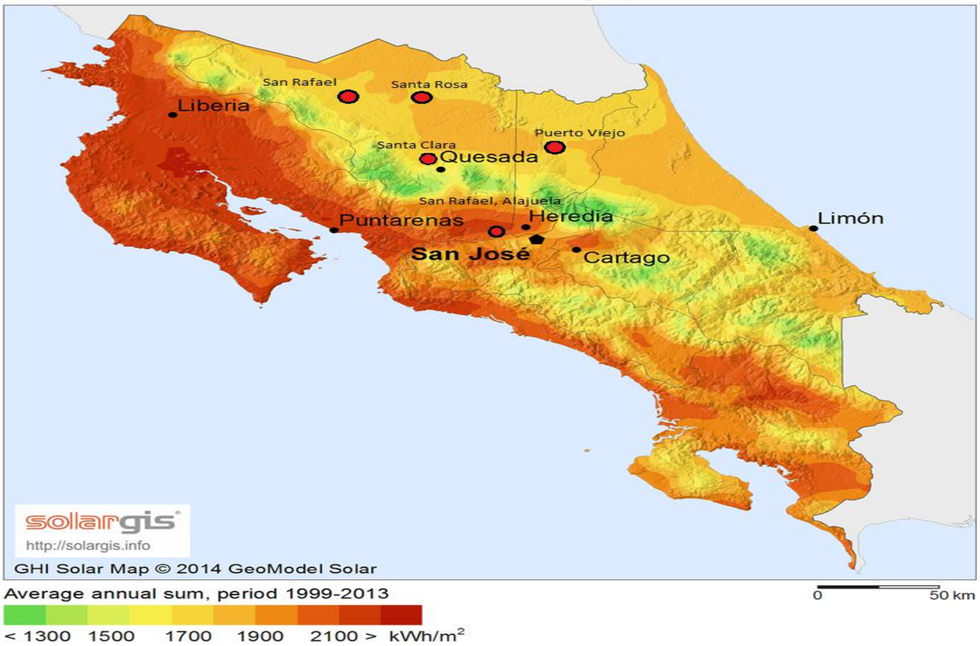
The objective of this work is to describe the solar thermal systems implemented in the Huetar Norte region of Costa Rica for the improvement of the drying process in small and medium-sized farms.

Materials and Methods

The work was developed in the Northern Huetar region of Costa Rica, which is characterized by receiving a solar radiation between 1700 and 1800 KWh/m^2. According to the Ministry of Planning and Economic Policy of Costa Rica (MIDEPLAN, 2013), this area has a very low social development index (IDS) and a human development index of 0.659, according to the United Nations Development Program (2013).

For this reason, three active solar thermal systems with air and hot water with auxiliary LP gas system were designed and implemented for the drying of cocoa beans, fruits and seeds in San Rafael de Guatuso, San Rafael de Alajuela and Santa Clara. In Santa Clara, a passive solar dryer was also implemented (Figure 1). The aim of these systems is to improve production efficiency and provide a commercial distinction as a competitive advantage in the local, regional and national markets to agricultural producers.

Figure 1. *Location of Solar Thermal Systems for the Improvement of Drying Process in the Global Horizontal Irradiation Map of Costa Rica*



Active Solar Thermal Systems with Air and Hot Water and Auxiliary LP Gas System

The Prototype 1 of the active solar thermal system (Figure 2) that was designed and implemented in the production units in the Northern Huetar region of Costa Rica, is equipped with air collectors in the upper part of the drying chamber and an hybrid thermal system forced, independently attached. On the other hand, in the Prototype 2, the air collectors are located on the side of the drying chamber and they are integrated to the hybrid thermal solar system. The Prototype 3 (Figure

4) is equipped with a control chamber. The air collectors are located on the side of the drying chamber and they are integrated to the hybrid thermal solar system.

In general, these systems have a system that has a series of solar collectors to heat the circulating air driven by a turbine through the pipes to the drying chamber where the hot air is uniformly spread by fans as length and width of the drying chamber to obtain homogeneity in the process. In addition, these systems have a forced solar thermal system to heat water that is stored in a tank, which is used when the temperature inside the drying chamber is lower than that required for the process. In those cases in which the thermostat notices that the solar energy is not enough to reach the required drying temperature, the auxiliary LP gas system comes into operation to achieve the required temperature and ensure a uniform drying. These systems are also equipped with a data storage system that records the temperature of different areas of the dryer to ensure optimal operation.

Figure 2. *Prototype 1 of Hybrid Solar Thermal System Forced with Air and Hot Water and Internal Radiator with Hot Air Absorber System and LP Gas for the Drying of Agricultural Products*

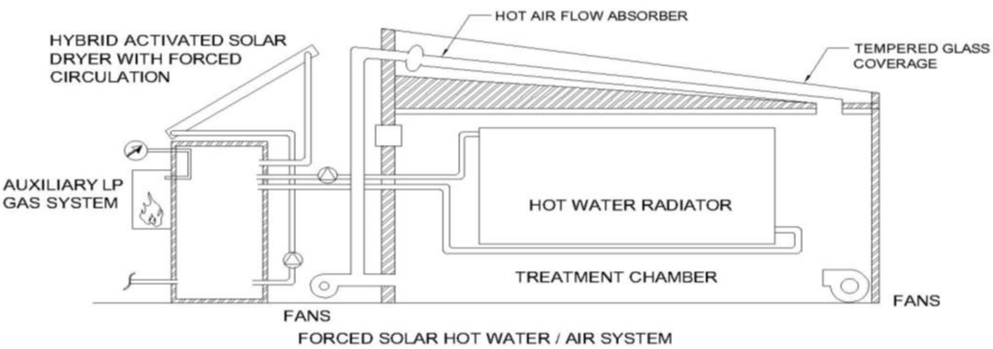


Figure 3. *Prototype 2 of Hybrid Solar Thermal System Forced with Air and Hot Water and Auxiliary System of LP Gas for the Drying of Agricultural Products*

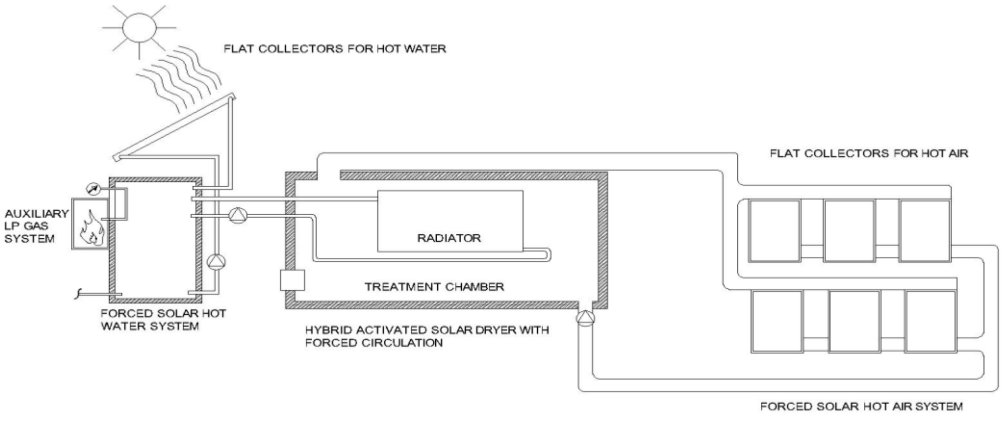
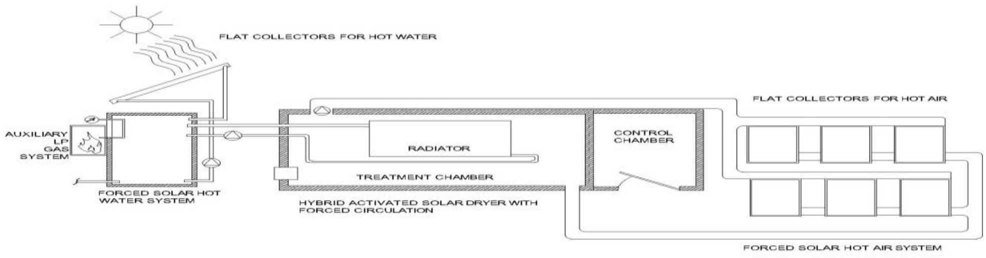


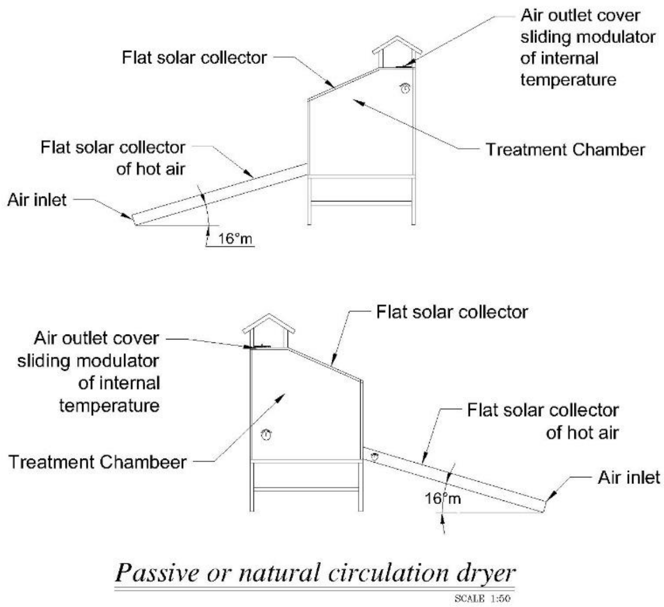
Figure 4. *Prototype 3 of Thermal Hybrid Solar System Forced with Air and Hot Water and Auxiliary System of LP Gas and Control Chamber for the Drying of Agricultural Products*



Passive Solar Thermal System

This system has a solar collector by which the air enters at room temperature and as it rises through the collector, its temperature increases and enters the drying chamber to pass in the middle of the trays with product, leaving by the top of the dryer (Figure 5).

Figure 5. *Passive Solar Thermal System for Drying Agricultural Products*



Evaluation of Solar Thermal Systems

To evaluate the efficiency of these solar thermal systems, 2 kg of cocoa beans were placed in the trays that each system has. The cocoa mass was monitored every 4 hours (from 8 a.m. to 4 p.m.) each day until each tray reached a constant value as a signal the process was finished. The mass was determined on a

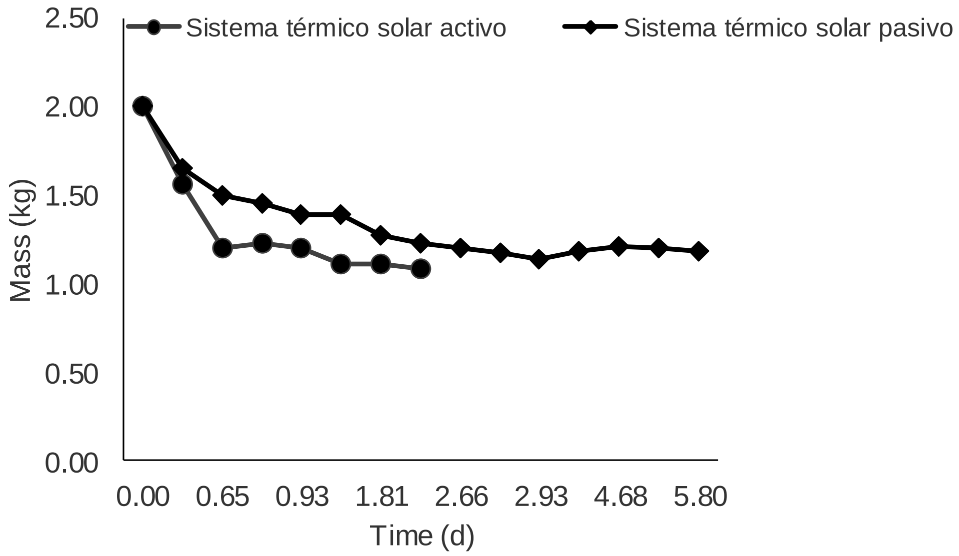
Brecknell digital hand scale with 45 ± 0.05 kg capacity (Electro Samson, Fairmont, MN, USA). The moisture content was daily measeured on a Precisa XM 60 Moisture Analyzer (Precisa Gravimetrics AG, Dietikon, Switzerland).

The internal temperature of the drying chamber of the thermal systems was set on a range to oscillate between 45-50 °C, while the external temperature fluctuated between 25-30 °C.

Results and Discussion

According to the results obtained by the evolution of the mass of cocoa, it was determined that the solar thermal system is more efficient for drying, due to the cocoa bean mass got a steady value after 1.97 d after the process started, while in the passive solar thermal system a constant value was reached after 5.80 d (Figure 6), which was verified by means of the moisture content.

Figure 6. *Evolution of the Cocoa Mass Subjected to the Drying Process in Solar Thermal Systems*



The fresh cocoa beans had a moisture content of 56% at the beginning of the process, while it was around 5% at the end of the process (Table 1).

Table 1. *Evolution of Cocoa Moisture Content Subjected to the Drying Process in Active and Passive Solar Thermal Systems*

Time (d)	Moisture content (%)	
	Active solar thermal system	Passive solar thermal system
0.00	57.58	57.58
0.65	14.85	25.96
1.63	6.04	14.91
2.66		4.78
5.80		5.19

The moisture content reached is within the ranges allowed by international standards (INCAP, 2012) and it is consistent with the previous results obtained by the research group in an active solar thermal system located in an area in central Costa Rica (Guzmán-Hernández et al, 2017). According to the cocoa producers of the Northern Huetar region, by applying this technology, it is possible to reduce the processing time, according to the conditions of the area (rainy and humid weather), it takes around 15 d to dry its product directly laid under the sun or in improvised dryers with plastic sheets.

Conclusions

This work allows verify the use of solar energy through combined systems as a viable option for the drying of agricultural and agroindustrial products due to it reduces the time of the process and therefore improves the efficiency. In addition, the use of this technology would serve as allow a distinctive seal to producers as a commercial advantage for the local, regional and national markets.

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