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SIMULATION OF A CONTROL FOR AIR CONDITIONING SYSTEM OPERATED BY SOLAR ENERGY

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Abstract

Among different strategies available technologically to reduce energy consumption and environmental impact in buildings, there is the use of new thermal-operated air conditioning systems. An available alternative is absorption refrigeration systems, which can operate with renewable energy sources such as solar energy, and use environmentally friendly refrigerant substances.

In Colombia, this type of systems have not been investigated thoroughly nor have carried out developments, because the field of solar energy is emphasized in the use of thermal energy, to be used on a refrigeration cycle that allows to condition an environment of a determined compound, and besides that, this air conditioning going to achieve through intelligent control, it has not been subject of considerable advances, neither in the part of applied research, nor its implementation. According to this, the idea is to use developments of these systems that have been simulated and implemented in other countries, including Spain, for the start in the UPB with research, development and implementation of those after making a literature review about the systems.

To develop the aforementioned system, a comprehensive literature review of the technologies has been made to be implemented in terms of automation and control. A simulation in the TRNSYS® software of the system to be implemented in a building on the campus of the UPB, which requires air conditioning for the comfort of the people who inhabit, is developed. The system will be regulated by a control system that receives information from various parts of the plant with temperature and flow sensors. To carry out the control of this system, classical control techniques are going to be use for some water systems that constitute the demonstrative installation, but for the part of chilled water and air conditioning, intelligent control techniques will be handled, which allows to meet the needs of the air conditioning system that is intended to implement, as this part is quite complex for the management of different variables. This system will operate automatically acting on valves, pumps, fans, Fan-coil and/or mats of water (they act as radiant walls) for correct operation by previously established set points.

Keywords: *Absorption cycle, Air conditioning, Control system, Renewable energy, Solar energ*y.

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1. Introduction

Buildings have an impact on the lives of people and the planet's health. In developed countries, buildings use one third of the total energy, two thirds of the electricity and one eighth part water, and transform land that provides valuable ecological resources. The use of these resources and their impact on the environment may be more relevant in developing countries, such as Colombia, where the technology used for the construction and operation of most buildings is not as advanced. In this context, it has defined "sustainable building" or "green building" has been defined as a final standard that is given by an environmental performance over the life cycle of a building, which is seen and understood as a whole (LEED, 2008).

This situation has caused different institutions, associations, governments and companies to take interest in implementing measures aimed to rationalize the use of natural resources in buildings and make these important structures of society to be in harmony with the environment. The vast majority of current air conditioning systems operate on the principle of the refrigeration cycle vapor compression (El Aire Acondicionado, 2015). It has been found that these contribute significantly in an opposite direction to the concept of sustainable development.

In Latin America the main initiative was the *RIRAAS* network (*Red Iberoamericana de Refrigeración y Aire Acondicionado Solar*), which arose before 2001, with the aim of promoting and disseminating the cold production technologies with solar energy. It was financed by the program *Ciencia y Tecnología para el Desarrollo (CYTED)* and the *Consejo Nacional de Ciencia y Tecnología de México (CONACYT)* until 2004. In Latin America the main facility in solar air conditioning operation currently operates in Mexico, but besides this, there is a lot of prototypes of universities and research centers used for research and development of different technologies for solar cooling (Sparber et al., 2007).

This article aims to present an alternative to the use of air conditioning systems to reach the standard of "sustainable building" in Colombia (LEED, 2008). Under the standard of "sustainable buildings", cold production with unconventional heat sources, such as absorption cooling systems powered by solar energy, energy are potentially attractive in the tertiary sector to meet the cooling demand through air conditioning systems in buildings, important chain stores and shopping malls, among others. Such buildings include institutions such as hospitals, universities, schools, government buildings and offices, where the air conditioning systems represent a large percentage of energy consumption. In the hotel sector, absorption equipment are widely accepted as air conditioning systems, given the publicity that implies offering environmentally friendly facilities (LEED, 2008). In the literature there is not a lot information about this type of systems in which involve research and developments in Colombia.

The Artificial fluids were commercially used in systems of air conditioning in buildings, such as chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC) they have been considered largely as spoilage of the earth's ozone layer. Favor the greenhouse effect and to some extent, the increase in global average temperature of the planet. Since the 1987 Montreal Protocol, it have been signed international treaties to reduce emissions of these refrigerants; Colombia is part of the Montreal Protocol after the approval of Law 29 of 1992 (Wuebbles, 1994).

The conventional refrigeration cycles operated by electricity contribute significantly to the consumption of electricity and fossil fuels. The International Institute of Refrigeration (IIR) estimated that approximately 15 % of all electricity produced in the world is used in some process of cooling and air conditioning (Pérez, 2013).

Whenever there is the possibility of using thermal energy from renewable energy or effluents from industrial processes or cogeneration systems, the application of absorption systems for cold production will be competitive and interesting, which is why this article seeks to bring out the design and simulation of an air conditioning system operated by solar absorption refrigeration cycle with classic control techniques, some of which later become intelligent control techniques. This approach is intended to experiment with this type of system to find efficient ways of operation and low cost, in the future, to be competitive in the commercial field.

2. Materials and methods

The increased cost of electricity generation and environmental restrictions have strengthened in the scientific research of air conditioning systems and cooling using solar resource as a source of motive power (Vidal and Colle, 2009). The energy consumption of the world's population is constantly growing, as a result bringing the scarcity of natural resources and generate environmental problems, such as thinning of the ozone layer and the greenhouse effect. These effects generate an environmental impact hardly be solvable, therefore it becomes a matter of great concern to many countries, governments and the society. Within this reality, industries hone their processes to include control systems in order to meet the demands of energy efficient, environmentally friendly and more competitive teams. This is the case of systems operating on solar energy and absorption refrigeration cycle. The purpose of the control systems in a plant with absorption refrigeration cycle is focused on providing automatic operation where control is too complex for manual operation. These systems maintain control of the conditions that could be achieved by manual operation, providing maximum efficiency and economy in the process (Trott and T. Welch, 2000).

The process of producing cold is to reduce and maintain the temperature of a space or material below room temperature. For this to happen, it is necessary to remove heat from a low temperature source and transfer it to a high temperature source. Under the second law of thermodynamics, for the process of transfer heat from a cold to a warm body to be made, it is necessary to do a work, because spontaneously, this may not occur (Vidal and Colle, 2009). Some forms of cold production using thermal energy transfer: collection system solar energy, waste heat source, fuel (biomass or fossil) or just an electrical resistance of a transformation system and the energy received refrigeration system using solar energy are available (Vidal and Colle, 2009).

The absorption refrigeration system bases its principle in the affinity of certain substances to absorb each other on contact. Two pairs of substances are commonly used in this type of facilities: bromide water-lithium ($LiBr$-H_2O) and ammonia-water (NH_3-H_2O). The first of these combinations is mostly used for solar assisted applications due to non-toxic and non-flammable properties of water as a coolant and efficiency in terms of energy expenditure (Vidal and Colle, 2009).

The absorption refrigeration systems of single-effect (with a single generator), powered by solar energy require the union of several components for proper operation is achieved. The main components are: Solar Collectors, the Absorption Machine, the Cooling Tower, a Tank of Hot Water, an Auxiliary Heater, Chilled Water Tank and the control system. Figure 1 shows the components required for the operation of an absorption system operated by solar energy.

The use of solar energy in air conditioning systems require to test or develop new economic and efficient equipment for collection of solar radiation; thermodynamic cycles specially adapted to operate under the conditions proposed, refrigerants and refrigerant mixtures with special additives and absorbents capable of achieving high yields in the operation cycle, evaluate, simulate and improve specific cycle processes such as the operation absorption of the process itself; in addition to control systems that enable excellent integration of systems: Solar Collectors, energy storage, production of cold, heat rejection, cold storage and auxiliary or backup subsystem.

Current technology for air conditioning consumes a lot of power, so it is necessary to establish principles and strategies conducive to efficient energy use, this topic directly influence the intelligent control technique that is applied to the system. Furthermore, it is known that certain refrigerants such as Freon, produce an environmental impact when released into the environment, which affect the stratospheric ozone layer and contributes to the greenhouse effect (Edmonds et al., 1987).

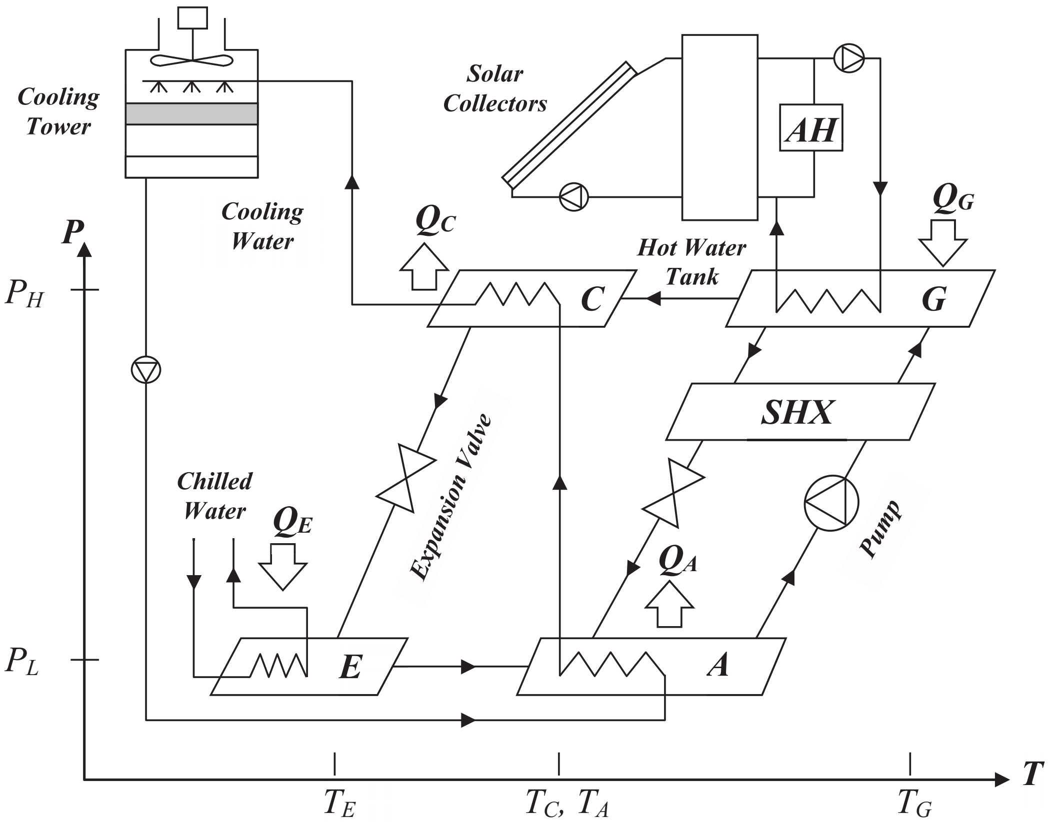

Fig. 1: Schematic diagram of a refrigeration system with single-effect absorption LiBr/H_2O, operated with solar energy

Generator (*G*).

Condenser (*C*).

System Expansion (*Expansion Valve*).

Evaporator (*E*).

Absorber (*A*).

Auxiliary Heater (*AH*)

Hydraulic pump (*Pump*).

Heat exchanger between dilute and concentrated solution (*SHX*).

In addition, the production of cold thermal energy can make future projects more attractive to be converted to natural gas, since the products of combustion of natural gas are particularly suitable (low dew point temperature) for heat recovery applications, so it is possible to integrate production processes of heat and cold with the same energy source; by including in some cases the production of electricity from diesel, gas turbines, steam cycles and even fuel cells engines; configurations that are best known as CHP (Cooling, Heat and Power) (Duarte, 2011).

The system shown in this article is intended to be implemented practically, for this reason, has been made quotes of various elements that make up the solar air conditioning system, among them are the Absorption Chiller and Solar Collectors. These components were listed in the company Shandong Lucy New Energy Technology Co., Ltd (LUCY, 2015) of China, which beside offer these products, offers to install the solar air conditioning system with absorption refrigeration cycle in any building, this structure is shown in the

Figure 2 is very similar to what is wanted to implement in the UPB, where it is noted the use of three-way valves or two-way and pump to control the flow of water from the system and to generate cooling or heating according to the configuration set you want to allow or not allow the flow of water through different circuits of the system. In this case, a heat exchanger is used, but with the kind of climate of *Medellín*, which is warm, is not need to use it.

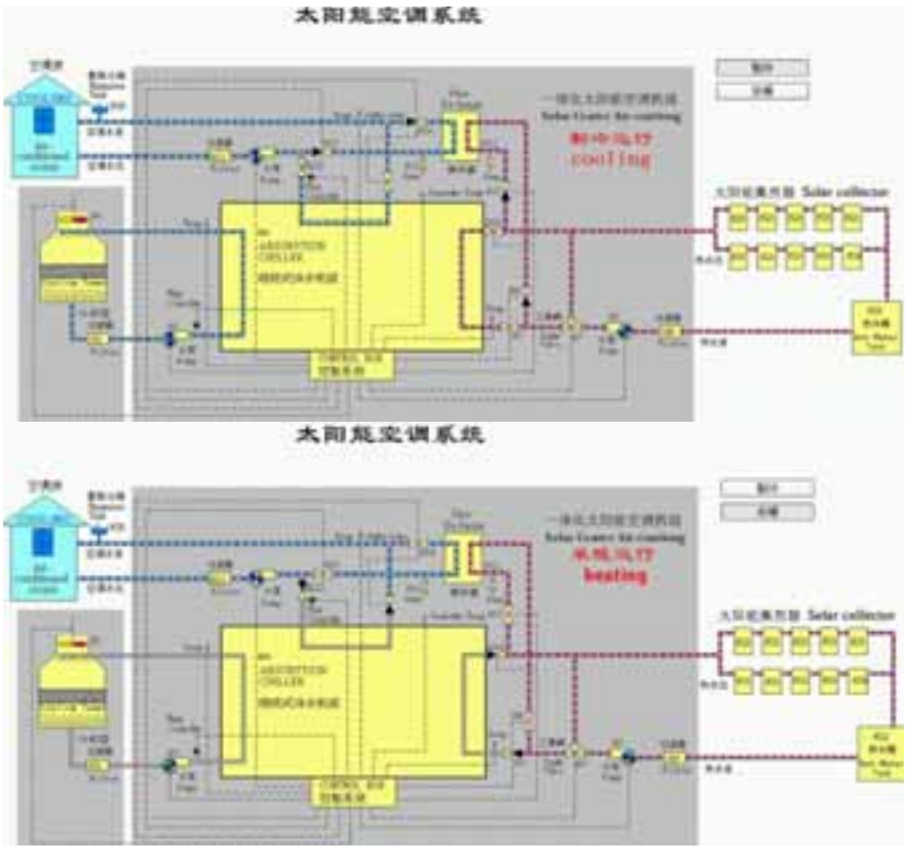

Fig. 2: Structure of solar air conditioning system for cooling and heating, installed by the Chinese company Shandong Lucy New Energy Technology Co., Ltd. Taken from LUCY (2015)

3. Results and discussion

For system simulation results of the evaluation of the thermal load integrated with the cycle of single effect absorption $LiBr/H_2O$ and subsystems Solar Collectors, Cooling Tower, chilled water distribution and accumulation of chilled water and hot; TRNSYS® using the computer program. The modeling was carried out using the parameters of the components offered by the program in the TESS library, and the following components were used: 12 modules of Solar Collectors each of 20 tubes, the area of each module is 3 m^2, they are connected in series and form a total area of 36 m^2; an Auxiliary Heater of 20 kW; two tanks of 250 l, one of hot water and other chilled water; it has several pumps and several three-way valves in the different circuits of water from the system, there are several pipes with standard parameters set; an Absorption Machine with a COP of 0.72 and cooling capacity of 11.5 kW; a Fan-coil 36000 BTU/hr (think also experiment with mats of water) and an enclosure to simulate the building of the campus of the UPB to which this system is installed.

For the meteorological data it has been processed actual data of *Medellín* through software Meteonorm® obtained in CALAIRE Laboratory by the *Universidad Nacional de Colombia*, near the UPB, TRNSYS® to understand them in the required formats.

In the simulation model that was held, the following results were obtained:

It was determined that the system will be installed in a building on the campus of the UPB, *Medellín*, air conditioning is needed for the comfort of the people who live there; installing the system in this building allow one to perform actual tests to achieve concrete results and set a starting point for the use of such systems in Colombia. The building that is selected will be used for research and laboratory purposes, it is possible that the building to be selected can be compared with a conventional system and identify pros and cons of both systems.

The simulation presented in this article (see Figure 3) of the demonstrative installation, using TRNSYS® software, shows the application of two PI controls, one for the variation of the fan speed of the cooling tower and the other for varying the flow of chilled water through a three-way valve which is connected to the handling unit (Fan-coil) of chilled water; and two ON-OFF controls, one to pump hot water from the Solar Collector, which is off at night so they are not underutilized and one for the auxiliary heater is always on to reach a temperature of 90 °C on the generator of the Absorption Chiller unless the Solar Collectors can actually reach this temperature in the day, in this case, the auxiliary heater is switched off immediately.

Tests of the preliminary simulation are done in the first week of June 2014 in *Medellín*, where high radiation was obtained, and a consumption of 14.76 kWhr in the Auxiliary Heater is produced by solar thermal energy generated in the Solar Collectors (see Figure 4), an oscillating but relatively acceptable performance air conditioning system around 22 °C (see Figure 5) and a good performance in the cooling tower, where it achieves lower cooling water temperature input 35.11 °C to 30.34 °C (see Figure 6).

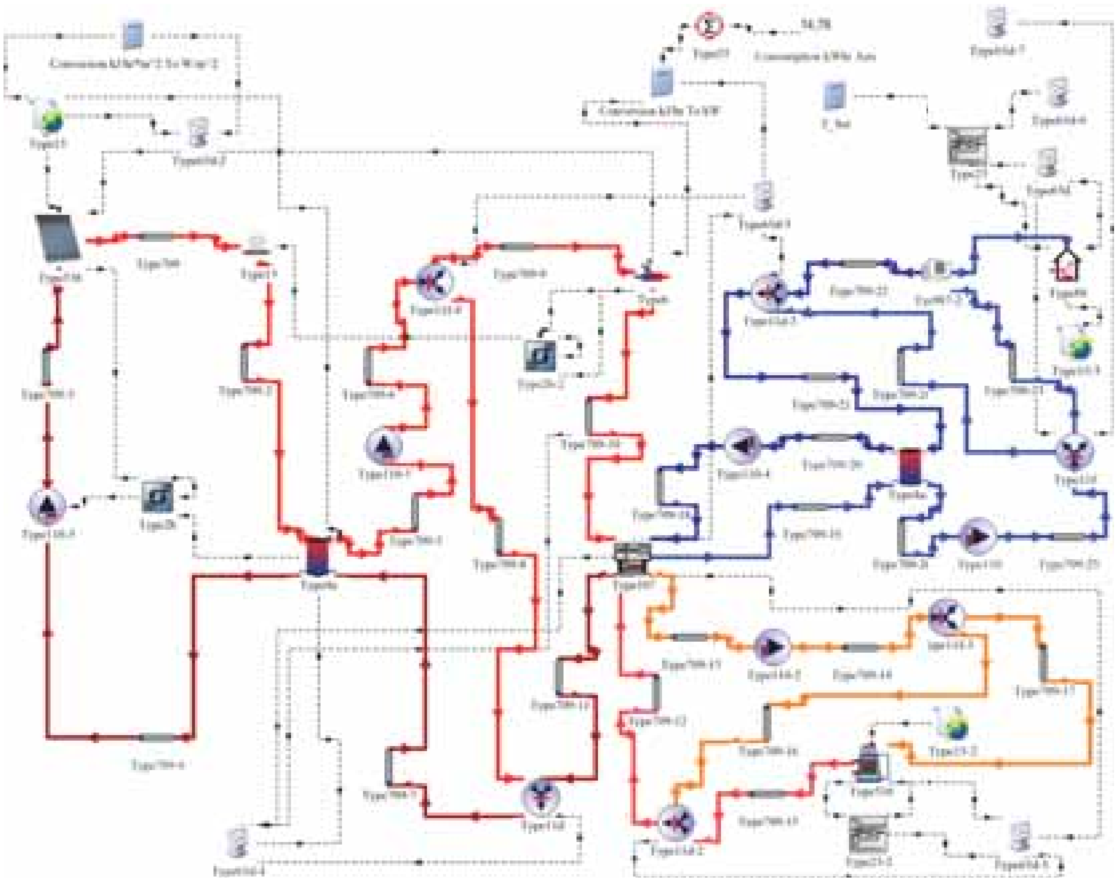

Fig. 3: Simulation of solar air conditioning system and absorption refrigeration cycle

Control techniques applied in this simulation techniques are classic control (ON-OFF and PI), and through these techniques is desired to implement intelligent control schemes. It is determined that the technique of intelligent control required to apply to the part of the air conditioning system is a control technique Fuzzy Logic, which vary PI control then PI Fuzzy control being developed will be applied using the MATLAB® software that has direct connection with TRNSYS®. To achieve this control, heuristic design experimenting with the TRNSYS® simulation software to operate in a relatively wide range model is obtained. The hot water circuit will continue with two ON-OFF controls and the cooling water with PI control in which a constant flow of water will remain. To the chilled water circuit constant water flow in the circuit pumps is maintained, but is changing the flow of water through the three-way valve installed at the inlet of the Fan-coil with PI control, the idea is to further apply a PI Fuzzy control, whether the final control element is the Fan-coil, currently used, or mats of water.

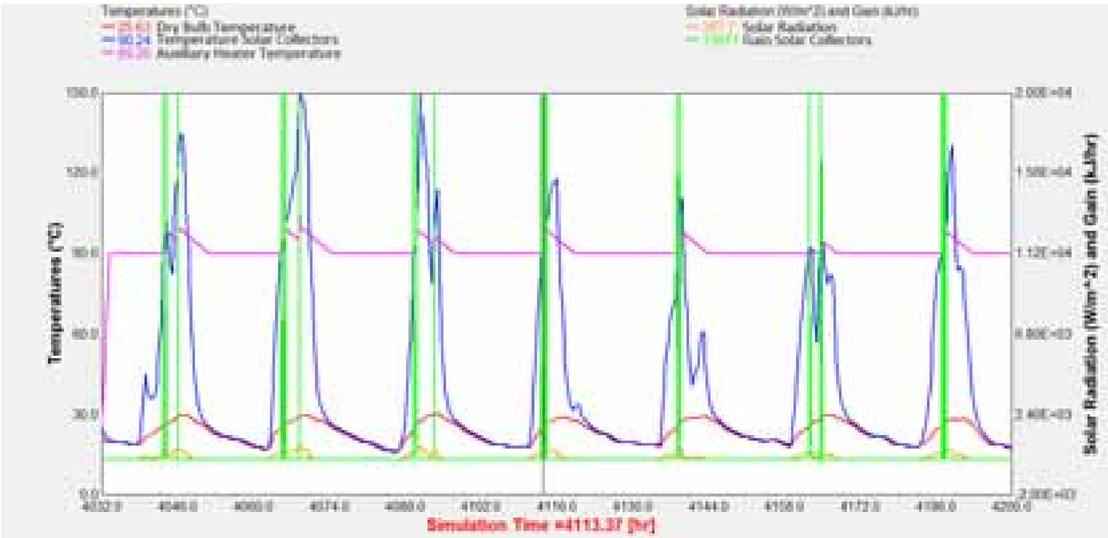

Fig. 4: Auxiliary Heater and Solar Collectors in running during the first week of June 2014 in *Medellín*

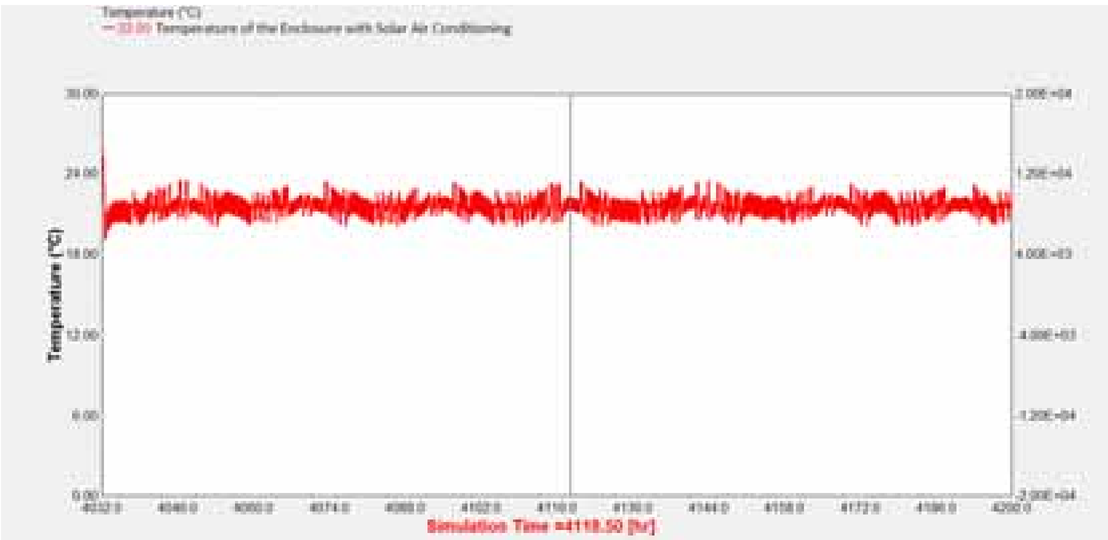

Fig. 5: Temperature of enclosure controlled by PI control

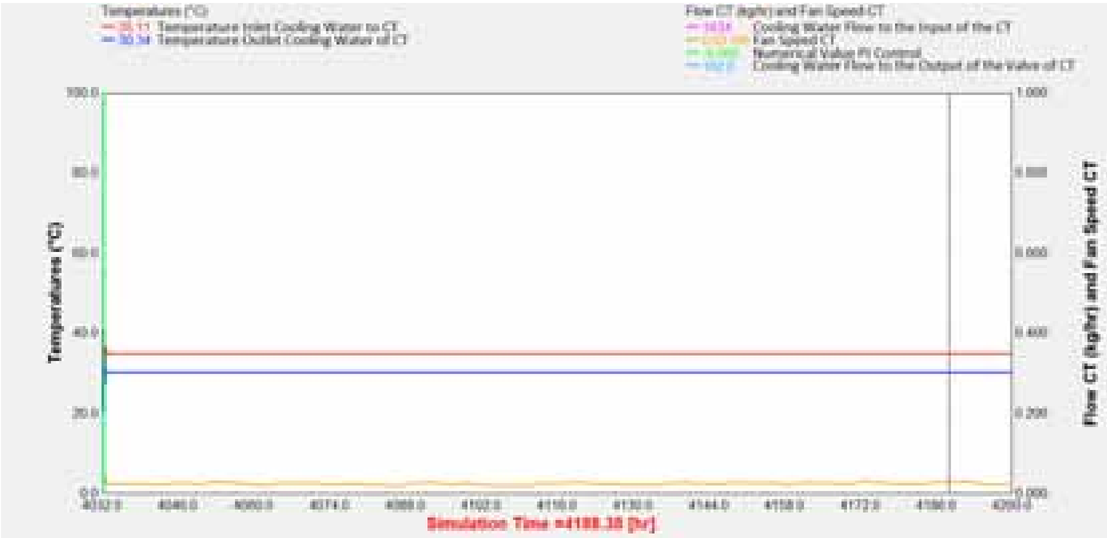

Fig. 6: Inlet and outlet water temperature of the cooling tower and fan speed controlled with PI control

In each figure can be observed the performance of the simulation previously shown in Figure 3 in the software TRNSYS®. In Figure 4, the ON-OFF control applied to the auxiliary heater operates when the Solar Collectors temperature reaches 90 °C reference and immediately turns off the auxiliary heater, this generates energy savings in the operation of the system; in Figure 5 the outlet temperature of the chilled water from the Absorption Machine and how does the PI control applied to Fan-coil to the enclosure is achieved a temperature which is around 22 °C is observed; and Figure 6 shows how does a PI control the fan speed of the cooling tower, to control the cooling water temperature from 30.34 °C to a water inlet 35.11 °C from the Absorption Machine.

4. Conclusions

Making this project generates technological breakthroughs for the industry of refrigeration and air conditioning in Colombia, as a method of renewable energy is obtained, such as solar energy, which is practically infinite and generates no pollution to the environment.

The solar air conditioning system has a nonlinear simulated behavior on the part of the air conditioning, because environmental conditions and thermal loads influence, disrupt and constantly change over time, which is why intelligent control technique (PI Fuzzy) is quite determining, since generates a lower consumption of electrical energy for soft control action applied to the actuators, furthermore it stabilizes in less time the temperature variable, which is the controlled variable.

For many applications in buildings and industrial processes can be considered that cooling through an absorption system is an environmentally responsible choice.

By using water as a coolant, mixed with salt and non-toxic chemical corrosion inhibitors, avoids the use of CFC, HCFC and HFC and management, availability and transport.

The simulation of solar air conditioning system in the TRNSYS® software, thanks to the library TESS and its focus on solar-operated systems, and meteorological data processed in Meteonorm® allow obtaining answers very close to reality and create a solid base to carry out this type of installation in reality without hesitation.

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