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Development, design, and implementation of a Solar Cooling System

Desarrollo, diseño e implementación de Sistema de Refrigeración Solar

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Abstract

Variations in extreme temperatures seriously affect crops, making it necessary to maintain a stable temperature inside the greenhouses between 17°C and 24°C. The conventional air conditioning systems used by the producers are electricity and gas, both highly polluting and expensive. Considering the benefits of alternative energies, this project is developed, which consists of the design, development, and start-up of an experimental research prototype that works with solar energy. The objective is to create a refrigeration system using a parabolic channel with a solar tracker, complemented with an absorption machine that allows maintaining the temperature of a greenhouse at 24°C, an interface in specialized software, and data collection with compact RIO. It is concluded that the prototype performs the heat transfer in such a way that it generates cold with the heat accumulated by the parabolic trough. Operational limits of the parabolic trough, the absorption machine, and the system's feasibility to scale to one- hectare greenhouse was established. It is recommended to continue investigating and implementing strategies that use alternative energies that contribute to reducing polluting emissions into the environment.

Parabolic trough collector, Cooling system, Alternative energies

Resumen

Las variaciones de temperaturas extremas afectan gravemente los cultivos, siendo necesario mantener una temperatura estable en el interior de los invernaderos de 17°C a 24°C. Los sistemas de climatización convencionales utilizados por los productores son, electricidad y gas, ambos altamente contaminantes y costosos. Considerando los beneficios de las energías alternativas se desarrolla el presente proyecto que consiste en el diseño, desarrollo y puesta en marcha de un prototipo de investigación experimental que trabaja con energía solar. El objetivo es crear un sistema de refrigeración utilizando un canal parabólico con seguidor solar, complementado con una máquina de absorción que permita mantener la temperatura de un invernadero a 24°C, se integra al diseño una interfaz en software especializado y la recolección de datos con CompactRIO. Se concluye que el prototipo realiza la transferencia de calor de manera que genera frio con el calor acumulado por el canal parabólico. Se establecieron límites de operatividad del canal parabólico, de la máquina de absorción y la viabilidad del sistema para escalar a un invernadero de una hectárea. Se recomienda continuar con la investigación e implementación de sistemas que utilicen energías alternativas que contribuyan a la disminución de emisiones contaminantes al medio ambiente.

Canal parabólico, Refrigeración, Energías alternativas

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Introduction

In regions such as the northern states of Mexico with extreme climates where temperatures vary over the course of the year from -10°C to 50°C (INEGI, 2023), farmers see their harvests continually affected, necessitating the creation of artificial climates. A common practice used by some farmers is the creation of greenhouses where temperature and humidity are controlled. The climate control systems conventionally used to maintain a stable temperature inside a greenhouse, which fluctuates between 21°C and 24° (Franco, Valera, & Peña, 2014), work with electrical energy and gas, unfortunately they are expensive and highly polluting systems.

Considering the benefits of alternative energies, this project consists of the design, development and implementation of an experimental research prototype that works with solar energy, which is environmentally friendly.

The objective is to create a cooling system using a parabolic trough with a solar tracker, complemented by an absorption machine that allows a greenhouse temperature of 24°C to be maintained. Considering that the optimum temperature inside a greenhouse depends on the geographical location, climate and type of crop, the prototype is designed to sustain the maximum recommended temperature (24°C), in support of the conventional cooling system.

The system is mainly composed of a parabolic trough with a mirrored surface that concentrates the sun's rays and directs them onto a copper tube that runs along the length of the trough (Cano M, 2002). To follow the movement of the sun's rays, a solar tracker is integrated, which is a device designed to orient the parabolic trough according to the position of the sun, with the characteristic that, when it gets dark, it returns to the starting point. Another indispensable element is the heat transfer unit consisting of an absorption machine that produces cold from the heat generated by the parabolic trough (Duffie & Beckman, 2005).

The receiver tube, which runs through the entire parabolic trough, circulates the fluid that receives the sun's rays and raises its temperature.

Another important element is the expansion valve that regulates the injection of the liquid refrigerant through compression or expansion according to the pressure required by the cooling system.

The overall performance of the system depends to a large extent on the materials, dimensions and speed of the circulating fluid. For the monitoring phase an interface is used in LabVIEW (Laboratory Virtual Instrument Engineering Workbench), a graphical programming language for the design of data acquisition, instrumentation and control systems, allows the design of user interfaces through an interactive console, it has its main application in measurement systems, such as process monitoring and control applications with real-time processing (NI, 2023).

Data logging is performed by a CompatRIO, this system has high-performance processing capability, sensor-specific conditioned I/O and a tightly integrated software toolset that makes it ideal for Industrial Internet of Things (IIoT), monitoring and control applications. The real-time processor offers reliable and predictable behaviour, ideal for long-term data acquisition (NI, 2023). Other modules used for monitoring and control operation were the NI9219, to measure thermocouple signals, the NI 9263 which is an analogue output module, for data acquisition the wireless sensor network Gatewey was used. (NI, 2014).

For monitoring temperatures in the parabolic trough, Pt100 sensors were used, for readings from the absorption machine thermocouples were used, to monitor humidity a HX93AV series transmitter was used and to monitor wind speed the FMA900A series sensor was used.(Serna, 2010).

Materials and Methods

1. Determination of variables to be considered

It is determined that the variables to be measured are temperature, humidity, wind speed.

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Greenhouse temperature

– The required internal temperature for the greenhouse is 20-24ºC, maximum 35ºC and minimum 8ºC, plants such as sweet pepper and aubergine, outside these ranges there is an effect on the product.

– Positioning of the sensors, they were placed at a height of 1.20m considering that the height of the product is a maximum of 1.50m and this is the region of interest to be sensed.

– The greenhouse must maintain a comfortable temperature between 20 to 24°C, so it is sensed every 15 minutes.

– The system operates under an On-Off control.

– Once the temperature oscillates between 27°C and 30°C the system is activated until it reaches 23°C for deactivation.

Greenhouse humidity

The relative humidity of the air in the greenhouse depends on the type of plants to be housed. 40-60% is recommended.

Greenhouse ventilation

Greenhouse ventilation varies depending on the seasons. In winter, it is recommended to ventilate for 1 hour at midday to renew the oxygen. In summer, the function of ventilation is to help expel hot air (Franco, Valera, & Peña, 2014).

The ventilation is placed in low and high positions to establish an adequate air flow.

2. Development of the automated system in LabVIEW

Linking LabVIEW with CompactRIO

The specialised software was installed, activating the LabVIEW FPGA modules, the LabVIEW Real-Time Module and the NI-RIO controller on the PC (NI, 2023). The modules were connected, the system was wired, and the modules were configured.

Programming in LabVIEW:

The programming with which the variables such as humidity, wind and the different temperatures of the environment, parabolic trough, cooler and absorption machine will be controlled was carried out using the different modules of the CompactRIO.

Figures 1 and 2 show the block diagram of the connections for sensing each of the variables to be considered for monitoring and control.

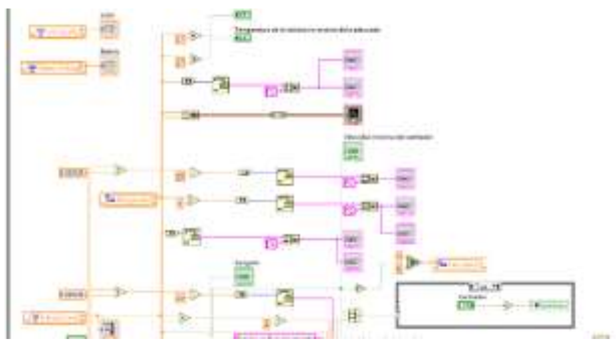

Figure 1 Programming block diagram

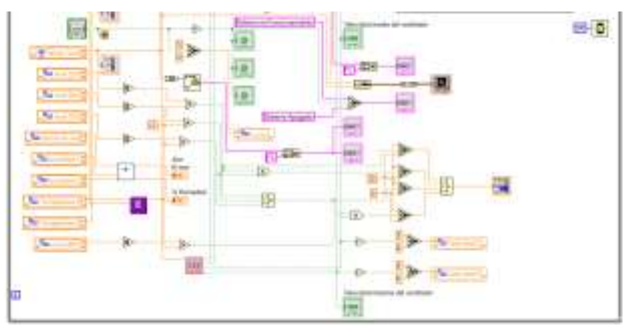

Figure 2 Programming block diagram 2

Programming in LabVIEW (interface)

Figure 3 shows the elements of the system where the controls and indicators that record the measurements of the sensors are observed, as well as the graphical representation of the system, the piping system, the parabolic trough, the pump, the accumulator, the fan and the location of the different types of sensors.

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Figure 3 Graphical interface of the system 1

The following image shows the monitoring interface (Figure 4) where the indicators of the variables used are observed, as well as the graphs where the temperatures are compared, such as room-refrigerator and parabolic channel-environment**.**

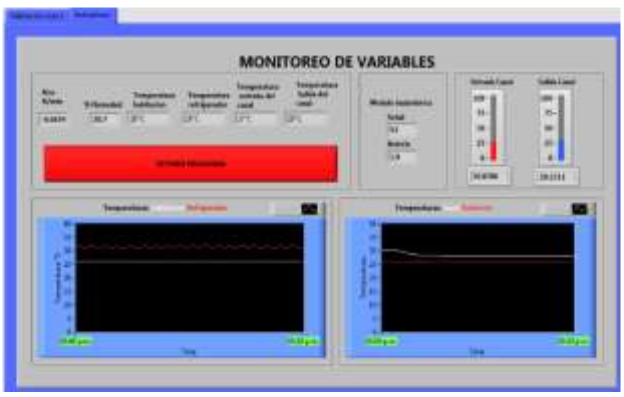

Figure 4 System graphical interface 2

3. Equipment design

Parabolic channel

The function of the parabolic trough is to concentrate solar energy into a small area, increasing the energy intensity (Duffie & Beckman, 2005). The base structure for the solar collector is designed to support the weight of the collector, movement, wind, snow and rain loads, ensuring anchorage and attachment to the support base.

As it is a prototype, the system is designed to cover an area of 140 m3, the resulting dimensions of the collector are 3m long and 80cm wide, the dimensions of the collector support are 3.35 m long, 1.01 m wide and 78cm high, the dimensions of the aluminium sheet are 3m. long by 1.2m wide.

The absorber used is a copper tube 2 inches in diameter by 3.5m long, with bell type reductions, from 2 to 1 inch and from 1 to ¾ inch to be able to couple the system with the plus pipe lines used.

Figure 5 Parabolic trough

Absorption machine

An absorption machine was used which, by means of the hot coolant produced by the parabolic channel circulating through it, generates the evaporation and condensation of the coolant located inside the machine.

4.- Connection of sensors and CompactRIO.

For the acquisition of data from the temperature, humidity and wind sensors, the connections were made to the National Instruments modules used, as shown in Figure 6.

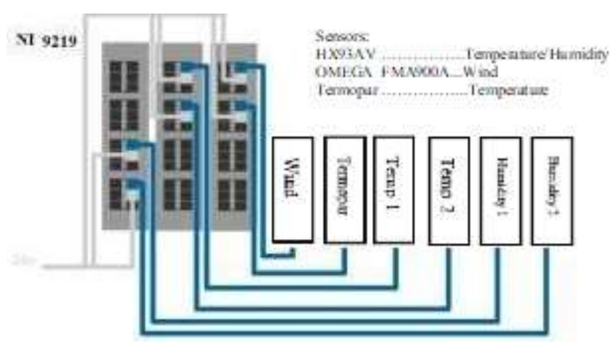

Figure 6 Universal Module Connections

As can be seen in the image, in the universal module 1 (NI-9219) the humidity sensor 1 was connected in channel 2, while in the same module, but in channel 3, the humidity sensor 2 was connected, both are connected in pins 4 and 5 of their respective channels, while pin 4 is where the signal is connected, pin 5 is where the neutral is connected.

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It can also be observed that in the universal module 2 (NI-9219) the temperature sensor 1 was connected in channel 0 while in the same module, but in channel 1, the temperature sensor 2 was connected, in the same way that the humidity sensors are only connected in pins 4 and 5 of their respective channels. In the universal module 3 (NI-9219), the wind sensor was connected to pins 4 and 5 of channel 0, while in the same module, but in pins 4 and 5 of channel 1, a thermocouple sensor was connected to monitor the temperature in the absorption machine.

The sensors are connected to the different modules, which can be directly manipulated as double signals by means of the LabVIEW software, so that they can be monitored and, with the help of the different programming structures, assigned an important action for the correct operation of the solar cooling system. The following figure shows the connection of outputs which activate the relay boards to which they are connected (fan speed, pump start and ON/OFF lights). This helped to be able to handle high voltages not supported by the CompactRIO modules such as 127V AC.

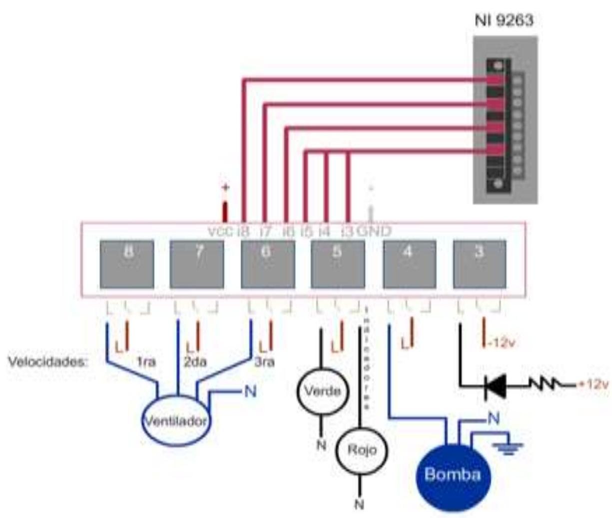

Figure 7 NI-9263 Module Connections

4. Tests

The system is tested under different circumstances to see what temperatures were reached in the parabolic trough, cooler and room, all these readings are automatically recorded in an Excel sheet through LabVIEW, the scenarios are with auxiliary boiler located in the accumulator, with auxiliary boiler located in absorption machine, without auxiliary boiler, with sun, cloudy, etc.

01/05/2019							Room		Machine Input	Meteorological		
	Colector Input		Colector Output		Absorption machine							
Time	rogra m	yrome ter	rogra m	yrome ter	rogra m	yrome ter	rogra m	yrome ter	yrome ter	Wind	Tempe rature	Status
13:30												
13:45		33		32.8		30.4		30.5	33	0	29	Cloudy
14:00		32.4		32.8		29.6		29.8	33.1	8	30	Cloudy
14:15	35	31.9	35	32.4	32	29.9	30	30.1	31.9	13	30	Cloudy
14:30		32.5		35.3		31		31.3	32.9	13	30	Cloudy

Table 1 Temperature recordings in the parabolic trough, chiller and room with auxiliary boiler located in the storage tank

05/04/2019												
	Colector Input		Colector Output		Absorption machine		Room		Entrada máquina	Meteorological		
Time	Program	Pyrometer	Program	Pyrometer	Program	Pyrometer	Pyrometer	Program	Pyrometer	Wind	Temp	Status
13:15		28		30.3		29.4		29.1	49.4	8	28	Cloudy
13:30	32.8	30.7	31	30.2	28.5	29	27.6	28.5	95.5	8	28	Cloudy
13:45	33.4	30.7	31.1	30.1	28.1	28.2	27.6	27.8	95.1	8	28	Cloudy
14:00	33.8	31	31.2	30.4	28.8	27.4	29	27.5	88.3	10	28	Cloudy
14:15	34.4	30	31.5	29.3	28.7	27.5	27.9	27.2	90.5	10	25	Cloudy
14:30	34.4	29	30.7	28	28.5	27.5	27.4	27.4	55	15	25	Cloudy
14:45	33.5	28.5	30	28	28	27	27.8	26.6	56.4	10	25	Cloudy

Table 2 Temperature recordings in the parabolic trough, chiller and room with auxiliary boiler located in the absorption machine

Results

A cooling system was designed using a parabolic trough with a solar tracker, complemented with an absorption machine to maintain the temperature of a greenhouse at 24°C, a specialised software interface and data collection with CompactRIO is integrated into the design.

The system allows the monitoring and control of temperature, humidity and ventilation of a room with a volume of 140m^3.

The behaviour of the system shows favourable results in the control of the established variables of interest, which are humidity, ventilation and temperature, which was the main objective at the beginning.

Given the characteristics, the size of the prototype and the volume to be covered, the feasibility and viability of using the system on a larger scale to cover larger volumes is determined.

Conclusions

It is concluded that the prototype performs the heat transfer in such a way that the absorption machine generates the required cooling with the heat accumulated by the parabolic trough. Operational limits of the parabolic trough, the absorption machine and the feasibility of the system to scale up to a one hectare greenhouse were established.

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Recommendations

It is recommended to continue with the research and implementation of systems that use alternative energies that contribute to the reduction of polluting emissions to the environment.

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