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Article

Viability of an earth/air heat exchanger applied in Mérida city, Yucatan, Mexico through the internet of things

Viabilidad de un intercambiador de calor tierra/aire aplicado en la ciudad de Mérida, Yucatán, México mediante internet de las cosas

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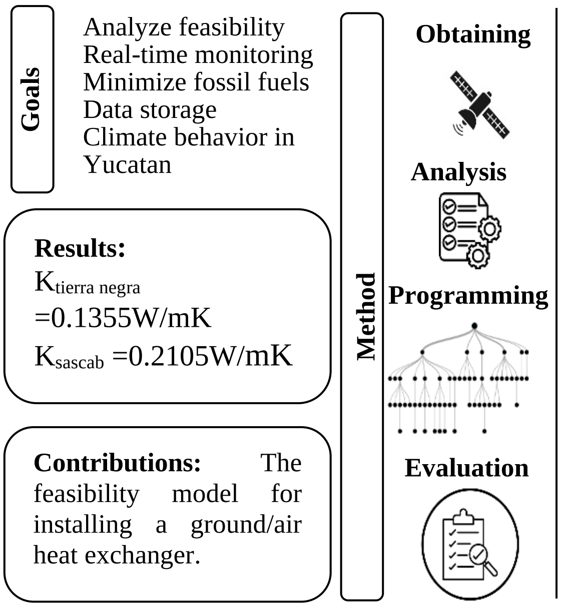
Abstract

An analysis of the feasibility of installing a ground-to-air heat exchanger (ICTA) was carried out under meteorological conditions in the city of Mérida, Yucatán, Mexico, with a low-cost IoT (internet of things) system for time monitoring. real. The thermal inertia of the subsoil is used to minimize the demand for fossil fuels and support environmental conservation. The energy potential and thermal properties of the environment and subsoil in the Yucatan Peninsula were identified. Measurements were carried out in real time with a microcontroller programmable wifi (ESP8266) to store the data obtained for later analysis. A study of the behavior of the climate in situ was carried out with the help of a meteorological station. The analysis focused particularly on a house in the city of Mérida, Yucatán, Mexico. The results were, Ktierra negra 0.1355 W/mK and Ksascab, 0.2105 W/mK.



Goals

- Analyze feasibility
- Real-time monitoring
- Minimize fossil fuels
- Data storage
- Climate behavior in Yucatan

Results:
$K_{\text{tierra negra}} = 0.1355 W/mK$
$K_{\text{sascab}} = 0.2105 W/mK$

Contributions: The feasibility model for installing a ground/air heat exchanger.

Method

Earth-air heat exchanger, canadian wells, internet of things, IoT

Resumen

Se realizó un análisis de la viabilidad de instalar un intercambiador de calor tierra-aire (ICTA) en condiciones meteorológicas de la ciudad de Mérida, Yucatán, México, con un sistema IoT (internet de las cosas) de bajo costo para el monitoreo en tiempo real. Se utiliza la inercia térmica del subsuelo para minimizar la demanda de combustibles fósiles y apoyar a la conservación medioambiental. Se identificó el potencial energético y las propiedades térmicas del ambiente y del subsuelo en la península de Yucatán. Las mediciones se realizaron en tiempo real con un microcontrolador programable wifi (ESP8266) para almacenar los datos obtenidos para su posterior análisis. Se realizó un estudio del comportamiento del clima in situ con la ayuda de una estación meteorológica. El análisis se centró particularmente en una casa-habitación de la ciudad de Mérida, Yucatán, México. Los resultados fueron, Ktierra negra 0.1355 W/mK y Ksascab, de 0.2105 W/mK.

Objetivos

- Analizar viabilidad
- Monitoreo en tiempo real
- Minimizar combustibles fósiles
- Almacenamiento de datos
- Comportamiento del clima en Yucatán

Resultados:
$K_{\text{tierra negra}} = 0.1355 W/mK$

Contribuciones: El modelo de viabilidad para la instalar un intercambiador de calor

Métod

Intercambiador tierra/aire, Internet de las cosas, IoT

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Introduction

Global warming and heat waves around the world in recent years have caused high electricity consumption and consequently high costs associated with the use of cooling equipment for air conditioning in hot and hot humid climates, particularly in the Yucatan Peninsula, Mexico. This represents a very strong social problem because low-income families are suffering the inclement weather because they do not have sufficient economic resources to maintain the operation of air conditioners. In this sense, different academic and research sectors have set themselves the task of finding more economical alternatives for air conditioning. Among these strategies has been the possibility of using the thermal potential of the subsoil to absorb heat and thus condition the air naturally; it has gained very good acceptance in recent years due to the economic savings that have been achieved in the energy requirements necessary to thermally condition them. The implementation of air-to-ground heat exchangers (AWHE) for heating and/or cooling of buildings has been increasing (Lesino, 2000)(Hummood et al., 2024)(Mahmoud et al., 2024).

The benefits of the thermal behaviour of the subsoil have been known for centuries. In the traditional dwellings of Provence in the south of France, underground ducts of rectangular cross-section known as Provençal wells were built to cool the air to cool the interior of the houses. Similar systems were also built in Canada, but to heat the air to achieve thermal comfort inside the houses, combating their low temperatures; therefore, the ground-air heat exchangers are known as Provençal wells or Canadian wells (Arcos Feria, 2016).

He also describes that the construction of these systems was based on empirical knowledge possessed by the people. The lack of a theoretical and scientific basis to validate the efficiency of these constructions opened a new opportunity for study. In recent times, multidisciplinary researchers have focused on carrying out studies to provide scientific support for the use of earth-air heat exchangers for their implementation in modern constructions to ventilate and condition homes naturally and efficiently, without generating onerous expenses for low-income families.

In prehistoric times, humans used natural caves for thermal comfort, which have quite acceptable thermal conditions, cool in summer and protected from the cold in winter (Martín, 2018). The same author mentions that later the so-called cave houses were known, dwellings artificially excavated in the ground, as an example in Turkey in the caves of Cappadocia, where up to 36 underground cities were built over the centuries, where everything necessary for daily life was available. The thermal inertia provided by the ground gave a comfortable thermal stability against the variation of the outside temperature during the day. In Guadix (Spain) around 2000 dwellings were excavated in clay soil. Many of them are still inhabited, due to the temperature stability of the site, between 18 and 20 ºC. These caves were built around the 15th and 16th centuries with walls more than one metre thick, rooms about three metres in diameter, as well as vaulted ceilings (Martin, 2018). In Italy, Villas Costozza, there is another example of the thermal exploitation of the subsoil, constructions from the mid-16th century are built on a hillside over large natural caves. These hollows in the ground were connected to the outside by various openings in the hill, which in turn led to grilles in the cellar floors of the houses, the latter creating wind tunnels in the caves. The air entered from outside, cooled through these wind tunnels and heated the interior of the houses (Martín, 2018).

Box 1

Figure 1
Ventilation diagram Villas Costozza

Source: (*Martin, 2018*)

Nowadays, the application of so-called Canadian or Provençal wells has been developed and they are called earth-air heat exchangers (EWAH), the physical process that occurs in them. The construction of these systems is achieved by placing one or more buried tubes (with good thermal conductivity) at a certain depth.

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The system is connected to the inside of buildings and to the outside through air intake grilles. Outside atmospheric air is blown into the building through these buried ducts, where it exchanges heat with the subsoil, thus thermally conditioning it. The aim is to reduce energy consumption. These systems are not yet being used on a daily basis in the construction of houses because it is necessary to have a large enough space to be able to install them. However, there are applications in Madrid in a housing project located in Móstoles where several bioclimatic systems are linked to achieve almost zero energy consumption. In the city of Merida, Yucatan, Mexico there is an increase in electricity consumption, due to the use of air conditioning systems (A.C.) mainly used during spring and summer, the hottest months of the year. As a consequence there is a high cost for this electrical service. It is primarily a problem of energy efficiency. There is the possibility to solve part of the problem with alternative cooling technology, taking advantage of low enthalpy geothermal energy, by using ground-air heat exchangers in order to reduce the use of conventional systems (air conditioning and fans). To achieve this as a first step it is necessary to evaluate the temperature of the subsoil, as well as its thermal properties (thermal conductivity, relative humidity, types of materials among others) and other factors that directly influence the system, such as the diameter, length and material of the buried pipe and thus quantify that this technology is viable and effective (MOLAR-OROZCO, María Eugenia, RÍOS-ARRIOLA, Juan & Gonzalo and REYES-LÓPEZ, 2020).

The Air-to-Earth Heat Exchanger (AEHE)

The thermophysical properties of a soil depend on the volumetric content of water in the soil, the volume fraction of air and the volume fraction of soil solids, but is also related to the depth of the subsoil (FAO). In the buried tube system (ICTA), work was carried out at shallow depths where the soil is kept at a constant temperature throughout the year. Research done by Kusuda in the USA (1965), determined that the temperature at a depth greater than 2 metres no longer has variability and corresponds to the mean annual temperature (Molar-Orozco, María Eugenia, Ríos-Arriola, Juan & Gonzalo and Reyes-López, 2020).

Similarly, Francisco Valbuena mentions that, from a depth of 1.5 metres, the ground is stable enough to develop a ground-air heat exchanger, and can also manipulate the surface of the ground in such a way that the system is more efficient with simple actions such as irrigation, planting grass or vegetables, thereby modifying the thermal conductivity of the ground (Chamorro, 2019). Recall, heat conduction in steady state heat transfer in a certain direction is driven by the temperature gradient in that direction (Cengel, 2011).

At the moment that human beings stop perceiving the sensation of heat or cold, we reach a state of thermal comfort, i.e. when we are in a place where indoor conditions such as relative humidity, air movement and temperature, make the room more comfortable is when we can say that we have reached the state of comfort. It must be taken into account that this sensation is individual and depends on many factors, such as the perspective of each individual and their subjectivity; the physical activity that the person is carrying out, the clothes they are wearing, the environment, the temperature inside, the humidity, the air speed, among others. Since the implementation of global agreements such as the Montreal Protocol, the Kyoto Protocol and the Paris Agreements, which seek to mitigate the effects of global warming and raise awareness about the use of energy so that in the future we are conscious of using renewable technologies. And this extends to the obligation to develop architectural projects that adapt to the specific climate, from their conception and design, to their execution, taking into account the use of natural resources and the optimisation of natural ventilation systems (Iordache et al., 2019).

Natural ventilation emerged as an option to mechanical ventilation; it focuses on taking advantage of natural resources and is an option to improve thermal comfort inside the place, which optimises air quality, as well as being viable for application in different climatic zones. It is an alternative that reduces the harmful effects on health generated by mechanical air systems, such as noise, economic cost, maintenance, among others.

Justification

Today, there is a strong and growing dependence worldwide on energy in all its manifestations, but particularly on electrical energy. This is driven by demographic and socio-economic growth, the increase in the number of consumers, and the amount of electrical energy consumed by each of them to satisfy their basic needs for space and comfort. This has resulted in a considerable increase in electricity consumption. Most of the greenhouse gases emitted come from the burning of fossil fuels in the process of obtaining mechanical or electrical energy. Therefore, it is important to apply new sources of energy generation from the use of renewable energies.

In the city of Merida, Yucatan, Mexico there is a tendency to population explosion, gentrification, which has caused a considerable increase in electricity consumption, because people demand more conventional air conditioning systems (A.C.) whether inverters, high efficiency or others. They are mostly used during the spring and summer seasons, which are the hottest months of the year.

Let's remember that Merida is a city in the Yucatan Peninsula that has a warm-humid climate. This humidity causes the heat to be of the humid type and therefore large amounts of energy are required, first to dehumidify the atmospheric air and then to cool it down to the comfort temperature (for the Peninsula it is generally 25 C); therefore, there is a high cost in the electrical service.

Having said that, there is the possibility of solving the problem with alternative cooling technology, where we can take advantage of low enthalpy geothermal energy by using ground-to-air heat exchangers in order to reduce the use of conventional systems.

To make this possible, it is necessary to evaluate the temperature of the subsoil, as well as its thermophysical properties (thermal conductivity of the subsoil, relative humidity of the subsoil, types of subsoil materials) and other factors that directly influence the system, such as the diameter, length and material of the buried pipe used.

Objective

To carry out a study of the thermal performance of the subsoil with the help of the Internet of Things (IoT), under the climatic conditions of the city of Mérida Yucatán, to assess the feasibility of implementing and installing a prototype earth/air heat exchanger in residential homes. As well as providing low-investment energy strategies,

Hypothesis

By carrying out the instrumentation, measurement of thermodynamic variables, the energy potential and the thermophysical properties involved (temperatures of the environment and subsoil, thermal conductivity of the soil, relative humidity of the air and subsoil, types of subsoil materials, direction and predominance of the air, thermophysical properties of the ambient air, solar radiation) with the help of the Internet of Things (IoT), in the place where it is intended to implement a ground/air heat exchanger, the feasibility of its future installation can be determined.

Problem statement

Geothermal energy is a renewable energy obtained from the heat produced underground (inside the earth), without the need for any process that requires combustion, it is a form of clean energy without carbon dioxide emissions. According to the theory, the temperature in the inner layers of the earth remains constant throughout the different seasons of the year. Generally, the inner layers are warmer in winter than the outer layers and colder in winter and cooler in the summer (Jimenez, 2020).

A ground-air heat exchanger harnesses geothermal energy, it can be passive or active, depending on whether the convective heat transfer is natural or whether the air flow is forced by mechanical means. The ground-to-air heat exchanger (GTAE) is a system of pipes buried in the ground with a depth that varies depending on the desired temperature to be reached, usually buried at a depth of 1 to 4 metres. The system is installed horizontally, with a slight slope to facilitate the drainage of water that may condense inside the system.

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The ICTA consists of an atmospheric air inlet, or atmospheric air mixed with air from a previously conditioned room, a fan that drives or extracts the air flow, through the piping system and finally has an outlet to the area to be conditioned, improving the thermal comfort conditions of the place (Arias Olave & Aya González, 2016).

When the air is transported through the duct, a thermal difference is generated between the subsoil and the air; this difference is the one that is used for air conditioning. As mentioned above, the ultimate purpose of the system is to cool or heat the air that circulates through the buried pipes, in order to air-condition the room to which it is attached, directly impacting the thermal comfort conditions of the building. On the other hand, the second purpose of the ground-to-air heat exchangers is to ventilate and improve air quality, thanks to the renewal of the air inside the room. By improving the ventilation of the rooms, pollutants and suspended particles that may exist are reduced, leading to improve the quality of the air inside the room, reducing the discomfort caused by excess pollutants in the air such as irritated eyes, respiratory problems, allergies, among others (Arcos Feria, 2016).

Proposed methodology to determine the feasibility of a ground/air heat exchanger applied in the city of Merida, Yucatan Mexico using the internet of things

Determination of the location and installation of the system (ICTA)

A house in the city of Mérida, Yucatán, Mexico was analysed for the installation of a ground-air heat exchanger, figure 2.

Box 2

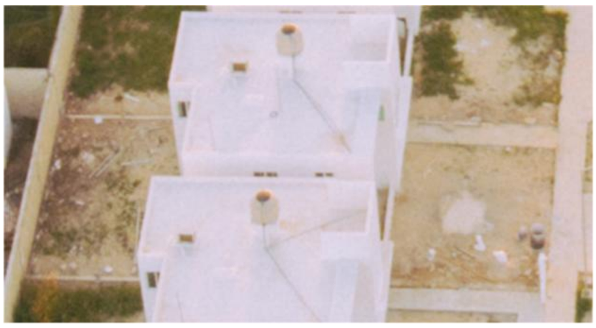

Figure 2

Location of the ICTA system installation in the city of Merida, Yucatan, Mexico

It was determined that the ideal area to install the system (ICTA) is in the backyard of the house, because it is the largest area of the land, in the front yard there are drainage pipes that crosses almost the entire garage, as can be seen in Figure 3. Similarly, it is considered that the backyard is the best proposal, since it is oriented to the north, position from where the prevailing winds of the region come and is hidden from direct solar radiation. It has the best capture of the prevailing north winds, due to the location and orientation of the house.

Although the suggested location does not take advantage of the entire backyard, because there are trees planted that occupy part of the land, it is still considered to be the largest and most ideal area to achieve the most efficient system possible.

Box 3

Figure 3

ICTA in the city of Mérida, Yucatán House layout plan of the system installation, Mexico

Soil study. In situ soil type

Two types of soils were selected, which are very common in the city of Merida, Yucatan. Black earth and sascab (Mayan word known in the construction industry as fine concrete). The proposed soils were collected and sent to the Centro de Investigación de Materiales Avanzados subsede Durango (CIMAV), figure 4. A detailed study of the thermophysical properties of the soil samples was carried out at CIMAV, figure 5, to determine if there is any difference between the two types of soils or if their behaviour is exactly the same based on the meteorological conditions of Merida, Yucatan.

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Box 4

Figure 4

White clay known locally as finely sifted sascab (Mayan word)

Box 5

Figure 5

Collect and proposed soils (black soil and sascab) from the installation of the ICTA system in the city of Merida, Yucatan, Mexico

Installation, programming and visualisation of temperature sensors

A preliminary exploratory excavation was carried out to bury two pairs of temperature sensors at two different depths, without the existence of any type of object that would hinder or promote changes in their thermophysical properties (stones, rubble or rubbish) and to analyse the behaviour of each of the soil samples, based on the meteorological conditions of Merida, Yucatan. A previous investigation of the different types of sensors was carried out to determine the ideal sensor to install outside the house, inside and underground. It was concluded that the sensor model DS18B20 is the right sensor to place on the outside of the house as it is water resistant. The DS18B20, figure 6a, is a digital temperature sensor using the one-Wire protocol. This sensor needs only one data pin to communicate, figure 6b. This allows us to connect more than one sensor on the same bus, taking into account that this sensor can measure temperatures from -55°C up to 125°C.

Box 6

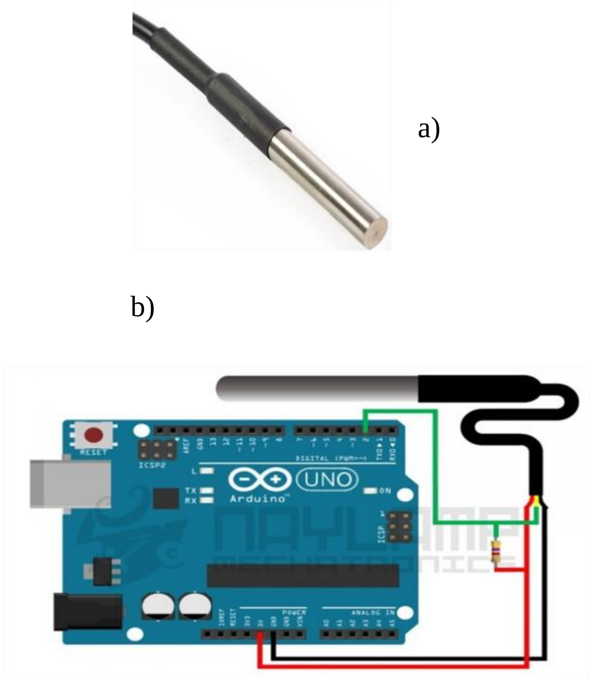

Figure 6

a) Temperature sensor model DS18B20. b) Connection of the temperature sensor in the installation of the ICTA system in the city of Merida, Yucatan, Mexico

Box 7

Table 1

Technical specifications of the temperature sensorDS18B20.

DS18B20 Sensor Specifications
Supply voltage: 3V a 5.5V
Encapsulation: TO-92-3
Technology: Through-Hole
Temperature range: –55°C a +125°C (–67°F a +257°F)
Operating supply current: 1.5 mA
Input current DQ: 5 µA
Output: Digital sensor
Resolution:12 bits
1-Wire communication interface, with multi-drop capability.

To program the DS18B20 in Arduino two libraries are necessary: OneWire library, in which the whole 1-wire bus protocol is implemented, this can be used for the DS18B20 as well as for any other 1-wire device. And the DallasTemperature library, particularly in this library are implemented the necessary functions to perform the readings or configurations of the DS18B20.

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Microcontroller with ESP8266 WiFi connection

ESP8266 is a module with Wi-Fi system on chip (SoC) figure.7. This microcontroller is mainly used for the development of IoT (Internet of Things) embedded applications. The possibility of connecting a microcontroller to the internet allows us to see the data in real time from wherever we are, as long as we have an internet connection.

Box 8

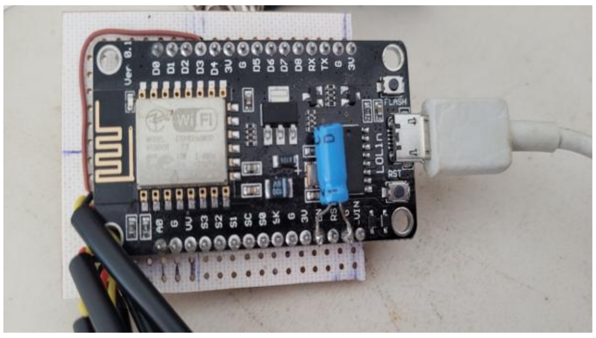


Figure 7
ESP8266 WIFI microcontroller connection arrangement

To configure it, it is necessary to have the datasheet. An important point in the programming is that when programming the ESP8266 microcontroller, when loading the code, sometimes it does not connect and a type of error appears; in order to solve this, it was necessary to place a capacitor to help us maintain the circuit voltage, as shown in figure 7.

Display page

A freely accessible website called thingspeak was used to store and export data in csv files. It allows us to have data available in the cloud and access from anywhere we are, as long as we have access to the internet, as shown in figure 8.

Once the account is created on this website, the ESP8266 programming is loaded by placing the channel ID that appears in the created thingspeak account, as well as configuring the Wifi data.

Box 9

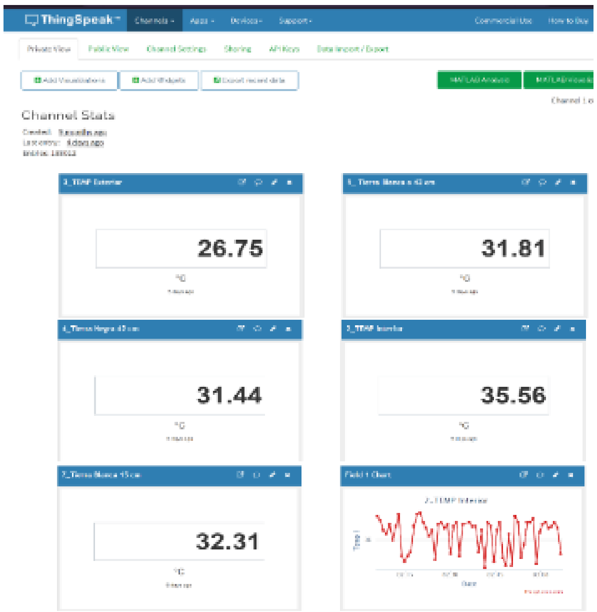


Figure 8
Website Thingspeak

Weather station

A weather station (figure 9) was purchased and demonstrated successful performance. It provided us with accurate data. Compared to other models, this one had an internet connection. The weather station was used to know different climatological parameters such as: air temperature, humidity, barometric pressure, solar radiation, precipitation, UV level, wind speed and direction.

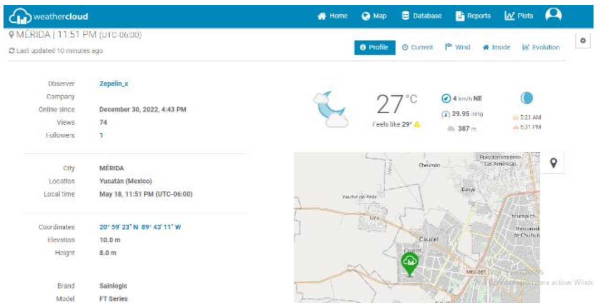
Box 10

Figure 9
NicetyMeter weather station

NicetyMeter, is a professional 0320, Wifi, wireless, outdoor weather station with 7 in 1 outdoor sensor. It contains rain funnel, solar panel and transmission module, wind vane, UV and light sensor, as well as a level indicator and a high speed anemometer. This station transmits real-time information. It has the ability to measure indoor temperature: 0°C to 60°C, outdoor temperature: -40°C to 60°C, rainfall: 0 - 9999 mm, wind direction: 0 - 360 degrees, wind speed: 0 - 50 m/s, pressure: 8.85 - 32.5 inHg, transmission frequency: 433 MHz, transmission capacity: up to 328 feet outdoors (100 m).

To visualise the weather station information in real time from anywhere we used two different websites: weathercloud and weatherunderground, both of which provide us with all the data in real time, as well as history by day, week or month. It was only necessary to register our weather station and create an account on these two sites with an email address. On the weather cloud website (figure 10) we could see the date and time, as well as the location of the weather station in coordinates and with a visualisation map.

Box 11



MÉRIDA | 11:51 PM (UTC-06:00)
Last updated 10 minutes ago

Observer Zepelin_x
Company
Online since December 30, 2022, 4:43 PM
Views 74
Followers 1

City MÉRIDA
Location Yucatán (Mexico)
Local time May 18, 11:51 PM (UTC-06:00)

Coordinates 20° 59' 23" N 89° 43' 11" W
Elevation 10.0 m
Height 8.0 m

Brand Sainlogic
Model FT Series

27 °C
Feels like 29°
4 km/h NE
29.95 inHg
387 m
5:21 AM
5:31 PM

Figure 10

NicetyMeter weather station data in weathercloud

Theoretical framework

Ground/air heat exchanger design ratios

As we know there are three types of heat transfer, convection, radiation and conduction. We can use equipment or systems such as: heat exchangers, boilers, condensers, heaters, furnaces, ovens, refrigerators, radiators and solar collectors. We know that the transfer of energy occurs from the medium with the higher temperature to the medium with the lower temperature; the transfer stops when the objects reach thermal equilibrium.

Heat transfer occurs through the interaction between a building, external environmental factors, an occupant, as shown in Figure 11 below (Juarez & Steve, 2019).

Box 12

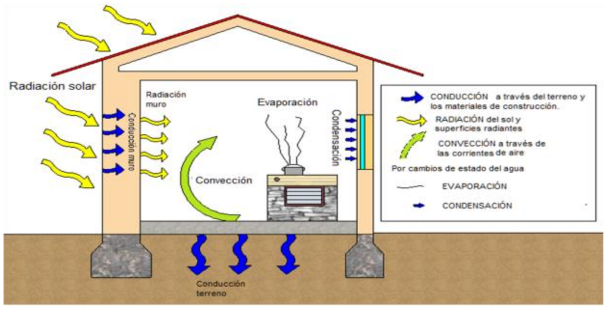


Figure 11

Modes of heat transfer in buildings

Source: (Juarez & Steve, 2019)

Conduction heat transfer

Heat transfer by conduction is the transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between them. The rate of conduction $\dot{Q}_{cond}$ (W) of heat through a medium will depend on the geometrical configuration, as well as the thickness of the materials and the temperature difference across it, figure 12. In this work a steady-state heat conduction through a large flat wall of thickness (m) and area A (m^2) is considered. The temperature difference from one side of the wall to the other is represented as $\Delta T = T_2 - T_1$; the rate of heat conduction through a flat layer is proportional to the temperature difference across it, as is the area of heat transfer, but is inversely proportional to the thickness of that layer, equation 1. The constant of proportionality is a transport property known as thermal conductivity, characteristic of the wall material. The minus sign is a consequence of the fact that heat is transferred in the direction of decreasing temperature (Cengel, 2011).

Box 13

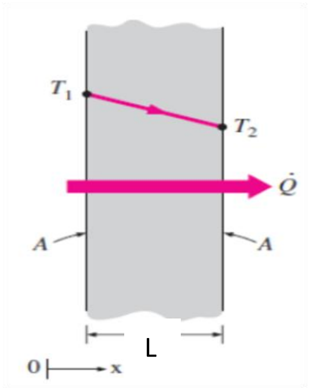


Figure 12

Heat conduction through a flat wall of thickness and area A

Source: (Cengel, 2011)

Convection heat transfer.

Convective heat transfer is the transfer of energy between a solid surface and adjacent moving fluids; it involves combined effects of conduction and fluid motion. The faster the movement of a fluid, the greater the convective heat transfer (Cengel, 2011). The rate of convective heat transfer $\dot{Q}_{conv}$ [W] is proportional to the temperature difference; it is expressed by Newton's law of cooling, equation 3, where h_c [W/m²°C], is a constant of proportionality called the convective heat transfer coefficient,A_s [m²] is the surface area across which convective heat transfer takes place,T_s [°C] is the surface temperature and , T_∞ [°C] is the temperature of the fluid far enough from this surface.

$$Qconv = h_c A_s\,(Ts - T\infty) \qquad (2)$$

Heat transfer area.

The total area available for heat transfer. The surface area of a shell and tube heat exchanger is calculated by finding the surface area of the tube, multiplying it by the number of tubes and by the number of shell passages.

Mass Flow

It is the mass flow in and out of the system. It works as a mechanism of energy transfer, equation 8. When mass enters a system, the energy of the system increases because the mass takes it with it.

Similarly, when an amount of mass leaves the system, the energy of the system decreases because the mass leaving takes something with it. Mass flow is the amount of mass flowing through a cross section of a flow apparatus, per unit time.

$$\dot{m}_i \rho_i * V * A \qquad (3)$$

Temperature difference

It is defined as the difference between the outlet and inlet temperatures of the ground-air heat exchanger, equation 4. It is the driving force, where heat is transferred from a source to the receiver.

$$\Delta T_i = T_{i\,salida} - T_{i\,entrada} \qquad (4)$$

Net heat transfer flux

It is the product of the mass flow rate of the fluid, the specific heat and the temperature difference of the system. The mathematical expression is given in equation 5.

$$\dot{Q} = \dot{m}_i * Cp * \Delta T_i \qquad (5)$$

Logarithmic mean temperature difference LMTD.

The Log Mean Temperature Difference (LMTD) is a design method, in which it is necessary to know the inlet and outlet temperatures, as well as the mass flow of the fluids, since it is possible to determine the heat transfer area following a logical and adequate procedure, equation 6.

$$LMTD = \frac{(T_2 - T_{I\,salida}) - (T_3 - T_{I\,entrada})}{\ln(\frac{T_2 - T_{I\,salida}}{T_3 - T_{I\,entrada}})} \qquad (6)$$

Mathematical model of the heat transfer of the earth-air heat exchanger.

The mathematical model on which we rely, figure 9, is described in Yunus' book on heat and mass transfer, in chapter 3, heat conduction in cylinders and spheres [reference]. Recalling that steady-state heat flux is defined as the multiplication of the overall heat transfer coefficient (U) by the temperature difference (ΔT) and the cross-sectional area (A). The coefficient U is the reciprocal of the equivalent resistance.

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DOI: https://doi.org/10.35429/JCA.2024.8.22.1.15

In turn, the equivalent thermal resistance, figure 13, is made up of a network of conductive and convective resistances in a cylindrical reference frame. Equation 7. Resistance one (R1), corresponds to the resistivity to the transit of heat flow through a fluid. Equation 8. Resistances two and three (R2, R3), correspond to the difficulty of transit of heat flow through solids. These resistances depend inversely proportional to the thermal conductivity of the solid (k) multiplied by the cross-sectional area of the heat flow and directly proportional to the natural logarithm of the quotient of the internal and external radii of the solid (rint,rext) through which the heat flows. Equations 9 and 10. Table 1 shows the nomenclature used for the ICTA mathematical model of heat transfer (own elaboration).

$$\dot{Q} = \frac{T_{\infty in} - T_{\infty ex}}{R_{equivalente}} = \frac{T_{\infty in} - T_{\infty ex}}{R_1 + R_2 + R_3} = \frac{T_{\infty in} - T_{\infty ex}}{\frac{1}{h_{in}A_1} + \frac{ln\frac{r_{ex}}{r_{in}}}{2\pi K_{pvc}L} + \frac{ln\frac{r_{ex}}{r_3}}{2\pi K_{tierra}L}} \quad (7)$$

$$R_1 = R_{conv} = \frac{1}{h_{in}A_1} \quad (8)$$

$$R_2 = R_{cond} = \frac{ln\frac{r_{ex}}{r_{in}}}{2\pi K_{pvc}L} \quad (9)$$

$$R_3 = R_{cond} = \frac{ln\frac{r_{ex}}{r_3}}{2\pi K_{tierra}L} \quad (10)$$

Box 14

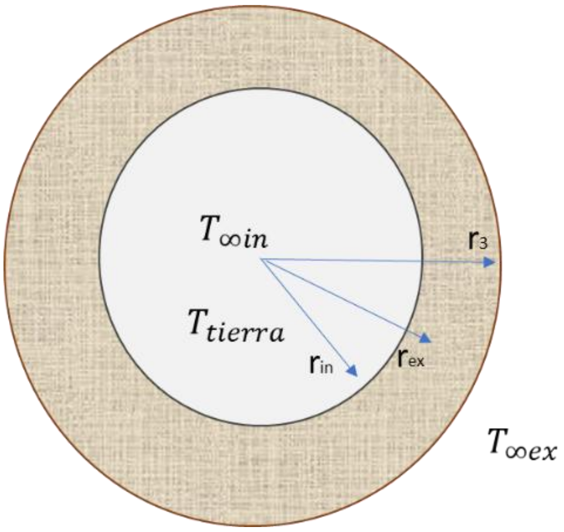

Figure 13
ICTA Mathematical Heat Transfer Model

Source: Own elaboration

Box 15

Table 2
Nomenclature used for the ICTA mathematical model of heat transfer

Nomenclature	
A_1	Area
$\dot{Q}$	Specific heat
h_{in}	Heat transfer coefficient
K_{pvc}	Thermal conductivity PVC
K_{tierra}	Thermal conductivity earth
L	Length
r_{ex}	External radius
r_{in}	Radio interior
R_{cond}	Conductive Resistance
R_{conv}	Convective Resistance
R_1, R_2, R_3	Thermal Resistances
$R_{equivalente}$	Sum of resistances
$T_{\infty ex}$	Outdoor temperature
$T_{\infty in}$	Temperature Interior
T_{tierra}	Ground temperature

Source: Own elaboration

The mathematical model is based on (Cengel, 2011), heat conduction in cylinders and spheres. The steady-state heat flux is defined as the multiplication of the overall heat transfer coefficient (U) by the temperature difference (ΔT) and by the cross-sectional area (A). The coefficient U is the reciprocal of the equivalent resistance.

The equivalent thermal resistance is calculated as a lattice of conductive and convective resistances in cylindrical coordinates. Equation 7. R1, corresponds to the resistance of heat flow through a fluid. This resistance is inversely proportional to the convective heat transfer coefficient (h) multiplied by the cross-sectional area of the heat flow.

The value of h is usually empirical provided in the literature and depends strongly on the type of fluid, its temperature and its flow velocity. Equation 8. Resistances two and three (R2, R3) correspond to the heat flow through the solid; they are inversely proportional to the thermal conductivity of the solid (k) multiplied by the cross-sectional area of the heat flow and directly proportional to the natural logarithm of the quotient of the inner and outer radii of the solid.

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DOI: https://doi.org/10.35429/JCA.2024.8.22.1.15

Results

Study of the thermal conductivity of the earth by CIMAV-Durango

Soil samples from the soil of Merida, Yucatan, Mexico were subjected to laboratory tests at CIMAV- Durango to determine their respective thermal conductivities. They were placed in an insulated aluminium mould in order to estimate the thermal conductivity of the black and sascab soil samples, figure 14.

Box 16

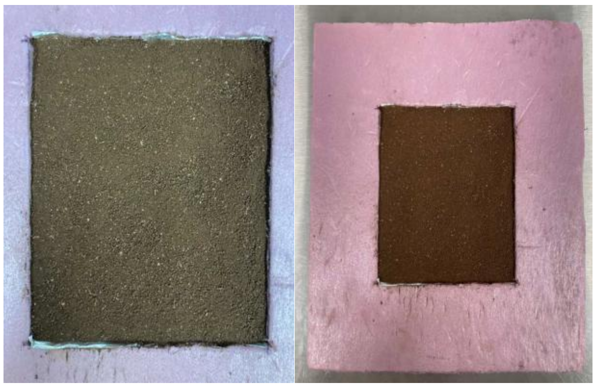


Figure 14
Mould with black earth for thermal conductivity study at CIMAV-Durango

The determination of the thermal conductivities were as follows: the first sample (dark clay) average conductivity, K¯_(black earth), 0.1355 W/mK and the second sample, K¯_sascab, 0.2105 W/mK. The estimation was performed in triplicate at an average temperature of 24 °C; hot and cold plate temperatures of 16.5 and 31.5 °C, respectively.

Behaviour of temperatures in the subsurface (results from sensors)

A temperature study was carried out for both types of soil: black and white soil (sascab) at two different depths; the outside and inside temperature of the house in Merida, Yucatan, Mexico was monitored. It can be observed in figure 15 that the temperature of both soils seems to have a very similar behaviour with a difference of ± 0.2° C. On the other hand, it was observed that the temperature at 15 cm remains similar to the outside temperature. We can observe that the curves in the graph with both the outside temperature and the temperature of the two sensors at that depth have the same curve trend.

On the other hand, at a depth of 40 cm, there is a considerable difference in temperature compared to the outside temperature.

Box 17

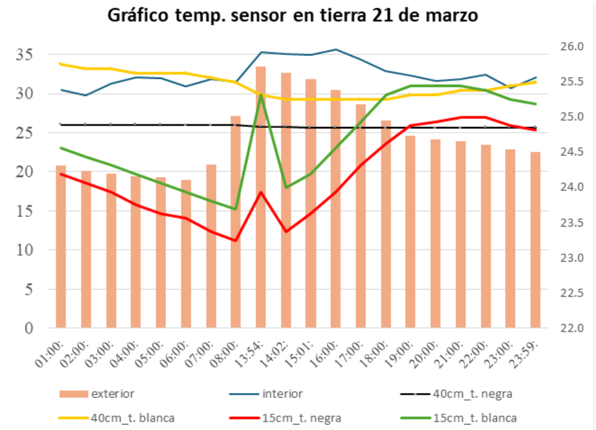
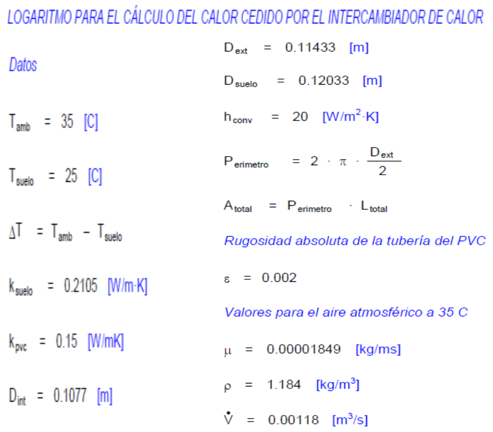


Figure 15
Graph of the behaviour of the earth's temperature in one day

EES Programme

Using the EES software, calculations were performed to analyse an earth-air heat exchanger design with respect to the resulting conditions and parameters obtained, figure 16. Calculation of heat transferred by the ICTA (EES). For values for atmospheric air at 25°C, taken from table A-15 heat transfer book by Yunus Cengel, Edition 4 (Cengel, 2011).

Box 18



LOGARITMO PARA EL CÁLCULO DEL CALOR CEDIDO POR EL INTERCAMBIADOR DE CALOR

Datos

$T_{amb} = 35$ [C]

$T_{suelo} = 25$ [C]

$\Delta T = T_{amb} - T_{suelo}$

$k_{suelo} = 0.2105$ [W/m·K]

$k_{pvc} = 0.15$ [W/mK]

$D_{int} = 0.1077$ [m]

$D_{ext} = 0.11433$ [m]

$D_{suelo} = 0.12033$ [m]

$h_{conv} = 20$ [W/m²·K]

$P_{erimetro} = 2 \cdot \pi \cdot \frac{D_{ext}}{2}$

$A_{total} = P_{erimetro} \cdot L_{total}$

Rugosidad absoluta de la tubería del PVC

$\varepsilon = 0.002$

Valores para el aire atmosférico a 35 C

$\mu = 0.00001849$ [kg/ms]

$\rho = 1.184$ [kg/m^3]

$\dot{V} = 0.00118$ [m^3/s]

Figure 16
Data for the scheduling logarithm in the EES software

The mathematical heat transfer model of the earth-air heat exchanger system presented above was simulated. It was possible to visualise, figure 17, the heat flow with respect to its length and also the friction losses that this represents.

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It can be seen that, with respect to the length of the heat exchanger, the heat flow (Q) increases, but also the primary losses (h_L) increase. In other words, the larger our system is, the more friction losses we will have.

Box 19

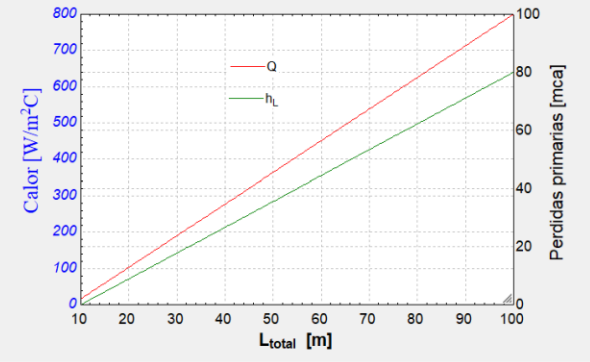
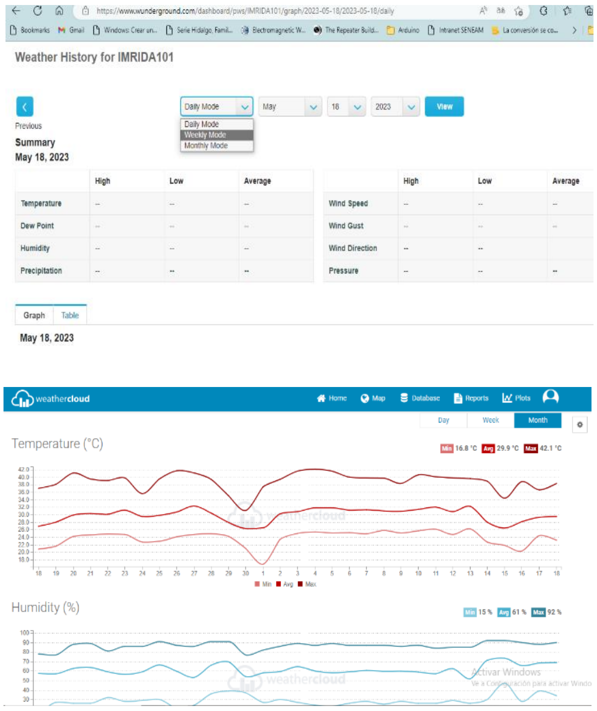


Figure 17

Heat flux with respect to its length

Box 20



Weather History for IMRIDA101

Summary
May 18, 2023

	High	Low	Average		High	Low	Average
Temperature	--	--	--	Wind Speed	--	--	--
Dew Point	--	--	--	Wind Gust	--	--	--
Humidity	--	--	--	Wind Direction	--	--	
Precipitation	--	--	--	Pressure	--	--	--

May 18, 2023

Figure 18

Weathercloud weather station data on weathercloud, temperature and humidity

On the weather cloud website, we can see on the main screen: date, time, location of the weather station in coordinates and a visualisation map. Also in weather cluod, we can visualise each of the parameters provided by the weather station graphically and in a data table, having a better understanding and visualisation of the climatic behaviour of the place, by hour, day or month (figures 18, 19 and 20).

Box 21

Figure 19

Weather station data in weathercloud, wind speed and wind direction

Box 22

Zepelin_x May 2023

May 2023	30.2	62.1	29.91	9.0	12.6	SE	18.3	0.0	204.4
	^42.1 v16.8	^92.0 v23.0	^30.10 v29.75	Sun 14 27.0	Sun 14 42.8	Calm 0%	Sun 14 15.6	Sun 14 59.4	1379.5

Date	Temperature (°C)	Humidity (%)	Atmospheric pressure (inHg)	Wind speed (km/h)	Gust of wind (km/h)	Wind direction	Rain (mm)	Rain rate (mm/h)	Solar radiation (W/m²)	Evapotranspiration (mm)
Mon 1	26.5	58.0	29.92	5.6	27.4	NE	0.0	0.0	197.1	-
Tue 2	30.2	59.4	29.85	8.8	26.3	SE	0.0	0.0	240.1	-
Wed 3	30.8	64.6	29.84	8.9	28.4	SE	0.0	0.0	214.7	-
Thu 4	31.8	60.0	29.88	9.8	32.0	SE	0.0	0.0	200.7	-
Fri 5	31.8	58.1	29.92	9.8	29.9	SE	0.0	0.0	198.3	-
Sat 6	31.2	59.1	29.95	10.8	31.0	SE	0.0	0.0	184.7	-
Sun 7	31.3	60.5	29.95	10.2	29.9	ESE	0.0	0.0	255.6	-
Mon 8	31.0	59.7	29.93	9.7	31.0	SE	0.0	0.0	170.2	-
Tue 9	30.9	59.8	29.92	10.2	27.4	SE	0.0	0.0	228.7	-
Wed 10	31.4	58.9	29.87	11.6	32.0	SE	0.0	0.0	179.5	-
Thu 11	32.0	57.2	29.85	12.3	29.9	SE	0.3	0.0	188.9	-
Fri 12	30.8	62.5	29.87	11.3	34.6	ESE	0.6	0.0	208.0	-
Sat 13	32.2	51.9	29.87	12.7	39.2	ESE	0.9	0.0	204.8	-

Figure 20

Weather station data on weathercloud, downloaded as an editable table

On the other hand, we can download the weather station data from the weathergroud website in csv extension files, by day, week or month. Figure 21.

Box 23

Summary
April 1, 2023 - April 30, 2023

	High	Low	Average		High	Low	Average
Temperature	41.7 °C	18.3 °C	29.1 °C	Wind Speed	37.5 km/h	0.0 km/h	9.2 km/h
Dew Point	24.6 °C	4.4 °C	19.7 °C	Wind Gust	48.6 km/h	--	12.5 km/h
Humidity	93 %	14 %	61 %	Wind Direction	--	--	ESE
Precipitation	51.32 mm	--	--	Pressure	1,019.98 hPa	1,004.74 hPa	--

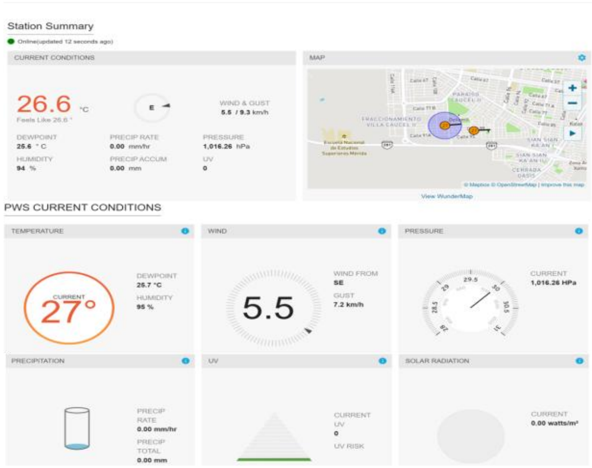
April 1, 2023 - April 30, 2023

Figure 21

Weather station data in weathercloud, downloaded as editable files in csv extension

A very attractive feature of the weathergroud page is its main visualisation; the graphics it displays are more user-friendly compared to weathecloud, figure 22.

Box 24



Station Summary
Online(updated 12 seconds ago)

CURRENT CONDITIONS
26.6 °C
Feels Like 26.6 °
WIND & GUST 5.5 / 9.3 km/h
DEWPOINT 25.6 °C
PRECIP RATE 0.00 mm/hr
PRESSURE 1,016.26 hPa
HUMIDITY 94 %
PRECIP ACCUM 0.00 mm
UV 0

PWS CURRENT CONDITIONS
TEMPERATURE: CURRENT 27°
DEWPOINT 26.7 °C
HUMIDITY 95 %
WIND: 5.5
WIND FROM SE
GUST 7.2 km/h
PRESSURE: CURRENT 1,016.26 HPa
PRECIPITATION: PRECIP RATE 0.00 mm/hr
PRECIP TOTAL 0.00 mm
UV: CURRENT UV 0
UV RISK
SOLAR RADIATION: CURRENT 0.00 watts/m²

Figure 22
Main screen of the weathercloud page

Conclusions

The following points are presented as conclusions of this work:

- A data acquisition system was designed, planned and built by means of a Wifi ESP8266 microcontroller, to which DS18B20 temperature sensors were integrated and programmed, to monitor the temperature of the soil samples (black and white soil) at two different depths, as well as the interior and exterior temperature of the house.

- A mathematical heat transfer model of the earth-air heat exchanger system was made, where with the help of the EES software the heat flow of the heat exchanger was graphically visualised with respect to its length.

- It was determined that the ideal area for the installation of the ground-to-air heat exchanger was the backyard of the house, as it faces north, where the prevailing winds come from, and the house protects the backyard from the sun's rays. In the front yard there is a drainage pipe that runs through practically the entire garage.

- A weather station was installed and configured in situ on two different websites: weathercloud and weatherunderground in order to have a real-time visualisation of the weather conditions of the house, which is located in the city of Mérida Yucatán, Mexico. This database can be accessed from anywhere, wherever we are on the internet of things, as long as we have access to the internet.

- With the help of the weather station, tests were carried out on the data acquisition system, resulting in very accurate data according to the temperature set by the sensors that were installed.

- At the Centro de Investigación de Materiales Avanzados (CIMAV) in Durango, they experimentally determined the thermal conductivity of the two predominant soil types in Mérida Yucatán, Mexico. The dark clay resulted in an average thermal conductivity of 0.1355 W/mK and the white clay, 0.2105 W/mK. The estimation was carried out in triplicate at an average temperature of 24 °C; hot and cold plate temperatures of 16.5 and 31.5 °C, respectively.

- A study was made of the temperature behaviour of both types of soil: black and white (sascab) at two different depths, as well as the exterior and interior temperature of the house in Merida, Yucatan, Mexico. The temperatures of the two soils appear to have a similar behaviour with a difference of ± 0.2° C. On the other hand, it was observed that the temperature at 15 cm with respect to the soil surface remains similar to the outside temperature, they have the same curve tendency. On the other hand, at a depth of 0.40 m we observed a considerable difference in temperature compared to the outside temperature.

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- With the help of the sensors that were buried in the two types of soil (black and white or sascab) it was verified that the subsoil temperature remains constant, even considering that it was only possible to reach a depth of less than 0.50 m; this was not an impediment to have good temperature results compared to the outside temperature of the house. It was not necessary to reach a depth of 1 metre to have an acceptable temperature difference, as we had as a result a temperature difference of ± 4 ºC. The sascab (white soil) was kept at a lower temperature compared to the black soil. It should be taken into account that, in the city of Merida Yucatan, sascab is cheaper and easier to obtain.

Recommendations

It is recommended for future work to limit the amount of data to be acquired from temperature sensors connected to the IOT (Internet of Things), due to storage space and operational logistics. Consideration should be given to the number of data to be acquired, whether for a few hours, a full day, a week, a month or months. Depending on the area in which we find ourselves, we may encounter different problems such as having electricity and internet access without interruptions, in order to have all the readings from the sensors. We depend on them to get the data information we want every second. Similarly, the robustness and capacity of the system where the data is going to be stored.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Chan-Gonzalez, Jorge J. contributed to drafting the article, proposing and revising the mathematical model, putting together and summarising all the ideas of the project, overseeing the methodology.

Gallegos-Sánchez, Selene, developed and implemented the methodology for the instrumentation of the on-site measurements made during the development of the project. Carried out all the measurements and their subsequent processing of the information and put it online.

Andrade-Durán, Juan Edgar. He supported the project in the definition of the appropriate instrumentation (types of sensors and suitable ranges), as well as the programming in Arduino and the ESP8266 WIFI microcontroller connection array.

Lezama-Zárraga, Francisco. Checked mathematical models, reviewed writing styles, contributed to the structuring of the paper

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Abbreviations

A	Área m^2
A_s	Área superficial m^2
Q	Calor
Cp	Capacidad térmica *J/Kg·K (calor especifico a presión constante)*
h	Entalpía (Coeficiente por transferencia de calor) $W/m^2 °C$
k	Conductividad Térmica *W/m·K*
D	Diámetro de la tubería *m*
LMTD	Diferencia de temperatura media logarítmica
e	Espesor del PVC *mm*
$\dot{m}$	Flujo másico *Kg/s*
H	Humedad gramos de agua/gramos de aire seco
HR	Humedad relativa unidimensional
I	Irradiancia w/m^2
LMTD	Media logarítmica diferencial de temperatura *adimensional*
Nu	Número de Nusselt *adimensional*
Pr	Número de Prandtl *adimensional*
Re	Número de Reynolds *adimensional*
R	Resistencia térmica $m^2 \cdot °C/W$
$Er=e/D$	Rugosidad relativa *adimensional*

T_s	*Temperatura de la superficie °C*
T_∞	*Temperatura del flujo °C*
	Letras griegas
ρ	*Densidad kg/m^3*
ΔT	*Diferencia de temperaturas $T_2 - T_1$*
ν	*Viscosidad cinemática m^2/s*
μ	*Viscosidad dinámica Pa·s*
	Subíndices
In	*Entrada*
Ext	*Exterior*
Int	*Interior*
out	*Salida*
∞	*Suficientemente alejado de la superficie*
s	*Superficie*

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