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Energy Balance in a Greenhouse: Temperature and Humidity Monitoring

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Abstract. Currently, the world is in a necessary stage of energy transition due to the high rates of pollutants emitted into the environment. The agricultural sector contributes only 7\% of these to the environment, a figure that is not alarming but certainly intervenes in the generation of pollution \cite{1}. Environment offers some properties that can be considered such as the radiation provided by the sun, which is used today in greenhouses ranging from small and rustic to others of large dimensions and sophisticated systems of control and monitoring. This study consists of the supervision with a data acquisition system which (temperature and relative humidity sensors), thus allowing to know which physical magnitude varies faster through time.

Keyword(s): Energy balance, horticulture, greenhouse, sensors

1. Introduction

The use of radiation systems provided by the sun to the planet directly benefits farmers’ production. Although there are basic parameters such as temperature and relative humidity to know what type of system should be used for a greenhouse, no more precise analysis is made to know the behavior of the energy gain towards the greenhouse, and thus to know the amount of heat needed to bring to the greenhouse in the winter season or simply at dusk, as well as to know how much heat should be removed from the greenhouse, that is, the cooling needed during the day or in seasons of higher radiation \cite{2}\cite{3}.

According to the First Principle of Thermodynamics \cite{4}.

\begin{equation}
R_n + \dot{Q}_{\text{clima}} = \dot{Q}_{cc} + \dot{Q}_{ten} + \dot{Q}_{sup} + \dot{Q}_{sus}
\end{equation}

Where:

\begin{itemize}
\item \textit{R}_n: Gross radiation (W)
\item \textit{Q}_{\text{clima}}: Heat of air conditioning (W)
\item \textit{Q}_{cc}: Heat lost by conduction-convection (W)
\item \textit{Q}_{ten}: Sensitive and latent heat lost by the renewal of indoor air (W)
\item \textit{Q}_{sup}: Latent heat consumed by evapotranspiration from plants and soil (W)
\item \textit{Q}_{sus}: Heat lost through the ground (W)
\end{itemize}
For the calculation of the radiation balance at the level of the greenhouse, it can be considered that the net radiation that heats the greenhouse is equal to the energy absorbed by the soil and plants minus the radiation emitted by the roof, as can be observed in Figure 1 [5] and equation 2.

\[ R_n = S_S \cdot [I \cdot (\alpha + \tau \cdot \alpha_S)] + S_C \cdot \sigma \cdot \tau_{ter} \cdot [\varepsilon_{atm} \cdot T_{atm}^4 + \varepsilon_{ter} T_c^4] (W) \]  

Where:
- \( S_S \): Solar radiation collection area (m\(^2\))
- \( I \): Incident solar radiation (W/m\(^2\))
- \( \alpha \): Coefficient of absorption of the roof for solar radiation
- \( T \): Transmission coefficient of the roofing material for solar radiation
- \( \alpha_S \): Soil and plant absorption coefficient
- \( S_C \): Covered floor area (m\(^2\))
- \( \Sigma \): Stefan-Boltzman constant (5.67 \times 10^{-8} W/m\(^2\)-K\(^4\))
- \( \tau_{ter} \): Transmission coefficient of the roofing material by thermal radiation
- \( \varepsilon_{atm} \): Emissivity of the atmosphere
- \( T_{atm} \): Temperature of energy emission from the atmosphere
- \( \varepsilon_{ter} \): Emission of the roofing material for thermal radiation
- \( T_c \): Absolute deck temperature

![Figure 1. Radiation balance in a greenhouse.](Retracted)

In the energy exchanges by conduction-convection between the interior of the greenhouse and the outside environment, the heat that passes through per unit of surface area of the greenhouse and per unit of time, can be expressed by equation 3 [6]:

\[ \dot{Q}_{cc} = S_d \cdot K_{cc} \cdot (T_i - T_o) (W) \]  

Where:
- \( S_d \): Surface area of the greenhouse roof (m\(^2\))
- \( K_{cc} \): Overall conduction-convection heat loss coefficient (W/m\(^2\)-°C)
- \( T_i \): Temperature inside the greenhouse (°C)
- \( T_o \): Temperature outside the greenhouse (°C)

For the calculation of the sensible and latent heat lost by the renewal of the indoor air, it can be calculated with equation 4 [7].

\[ \dot{Q}_{ren} = V_{me} \cdot \frac{R}{\gamma_{H_2O}} \cdot \rho \cdot [c_{pa} \cdot (T_i - T_o) + \lambda_0 \cdot (x_i - x_o) + c_{pv} \cdot (x_i \cdot T_i - x_o \cdot T_o)] (W) \]
Where:

\( V_{inv} \) : Volume of the greenhouse (m\(^3\))

\( A \) : Greenhouse air renewal rate or index (h\(^{-1}\))

\( P \) : Air Density

\( c_{pa} \) : Specific heat of the air (at 0 °C is 1,006.92540 J-kg\(^{-1}\)-K\(^{-1}\))

\( c_{pv} \) : Specific heat of overheated steam (at 0 °C is 1,875.6864 J/kg- K)

\( \xi_{i}, \xi_{e} \) : Absolute humidity indoors and outdoors, respectively

\( \lambda_{0} \) :Latent heat of vaporization (J-kg-1)

The heat absorbed by the evapotranspiration of the crop is denoted by equation 5 [8].

\[
\dot{Q}_{evap} = \lambda_{0} \cdot ETc \left( W/m^2 \right) \tag{5}
\]

Where \( ETc \) is the evapotranspiration of the crop.

A part of the heat losses in the greenhouse, about 10%, are

\[
\dot{Q}_{conv} = k_{e} \cdot S_{e} \left( \frac{\xi_{i} - \xi_{e}}{p} \right) \left( W \right) \tag{6}
\]

The heat that needs to be supplied by heating systems or removed from the greenhouse by cooling systems is deducted from the energy balance (equation 7).

\[
\dot{Q}_{total} = \dot{Q}_{evap} + \dot{Q}_{conv} + \dot{Q}_{solar} - R_{n} \left( W \right) \tag{7}
\]

1.1 Sensor network

Currently, there is the possibility of selecting between a wired and a wireless network depending on different factors that help select the best option. One of the most important factors is the distance between the sensors and the monitoring station depending on the surface to be monitored. In a study on the application of WSN (Wireless Sensor Network), [9] applies a wireless monitoring system for greenhouse crops in which humidity, temperature, light and the volumetric content of water in the soil are measured. The WSN sends the collected data to an embedded device that stores the information in a database in order to visualize in a graphic way and in real time the values obtained in the crops. The sampling time used was 5 minutes without having previously experienced the thermal and humidity behavior of the studied greenhouse.

A network of sensors, whether wired or wireless, is a flexible and powerful tool for monitoring complex systems, where the placement of sensors may be impossible in any other way. The objective of the data collection by the sensors in the monitoring, is to obtain the data having as only limitation the characteristics of the sensors [10].

In his research, [11] developed a system to monitor the temperature in a greenhouse through wireless communication between sensors and a computer located 200 m away. The design involves the design and construction of a transceiver circuit. In this work, the computer program was developed in LabVIEW and is capable of establishing temperature levels established by the user as well as the sampling period. However, a previous analysis was not carried out to determine this last parameter, in addition to not considering the effect that the crop has in terms of humidity.

1.2 Embedded Systems

Embedded systems usually have, in one of their parts, a computer with special features known as a microcontroller which is the brain of the system. This is nothing more than a microprocessor that includes input/output interfaces on the same chip. Usually, these systems have an external interface to monitor the status and make a diagnosis of the system. The main characteristics of an embedded system are low cost and energy consumption. Since many embedded systems are designed to be produced in thousands or millions of units, the cost per unit is an important aspect to consider in the design stage [12].

The use of embedded systems for monitoring systems in greenhouses is increasing because sometimes
they use free hardware and software. An example of this is the use of Arduino boards. In his study [13], the author controls and monitors a greenhouse through a mobile application. He uses the Arduino board as a system controller card and data acquisition from selected humidity and temperature sensors as well as a hazardous gas detector. The system is capable of controlling temperature and relative humidity levels by activating or deactivating a fan, lighting system, activation of a led that simulates the irrigation of the enclosure and finally a piezoelectric buzzer that creates an acoustic alarm. With the development of a mobile application in Android, the user can visualize the information about the behavior inside the greenhouse as well as to carry out the corresponding activations. It is worth mentioning that this study was done at scale in a model. This system is practical due to the use of free hardware and software, although in the real industrial environment, previous parameters must be taken into account for the implementation of a control system [14].

2. Methods

In order to calculate the energy balance of a greenhouse, it is necessary to acquire values of the thermal behavior between the exterior and interior of the greenhouse, as well as the relative humidity. With these values varying over time, each heat can be calculated and then the calculation can be made to show how the greenhouse behaves and how it can be heated or cooled. These variables of temperature and relative humidity, as well as the inputs and outputs of the system are shown in Table 1.

| Observable variables            |
|--------------------------------|
| Temperature outside            |
| Temperature inside             |
| Temperature on the deck        |
| Soil temperature               |
| External relative humidity     |
| Indoor relative humidity       |

In order to establish the sampling time for each variable, it is necessary to visualize which temperature or humidity changes the fastest, the time in which this will be taken, the one that must be established for the other variables, thus guaranteeing that the program is capable of performing the balance, and takes the necessary samples in time and form. Data acquisition from the sensors can be done through an embedded computer as shown in Figure 2, capable of receiving the signals from the sensors, processing them and saving them for further processing. Raspberry Pi® is a low cost and energy efficient embedded computer which is capable of performing this task [15].

Temperature measurement requires a sensor capable of tolerating the humidity conditions within the site as well as the misting systems, which is why the Dallas Semiconductor DS18B20 encapsulated sensor was used. It has an accuracy of ± 0.5 °C and a user-adaptable resolution of 9 to 12 bits. The relative humidity samples inside and outside the greenhouse were acquired by the DHT11 sensor from Ausong Electronics Co., which has an accuracy of ± 5 % RH and a resolution of 16 bits [16].
To carry out this study, there is a research greenhouse (Figure 3) located at km 36.5, in the municipality of Texcoco in the State of Mexico, belonging to the Hydro Science Research Section of the College of Postgraduates, Montecillos Campus with a location: 19°27'59.60¨ N; 98°54'59.43¨ W, elevation of 2239 m. It is a Venlo-type greenhouse with polycarbonate surface cover and thermal polyethylene sides and with an area of 30 m wide by 35 m long.

Figure 3. Interior of the greenhouse.

3. Results

Readings were taken for both variables in order to establish which of them changes most rapidly, thus obtaining the following graphs for each different variable.

By placing the temperature probe at a distance of 7 meters from the Raspberry Pi ® embedded computer, and taking 4,500 samples, the graph in Figure 4 was obtained.

Placing the temperature probe at a distance of 27 meters from the Raspberry Pi ® embedded computer, and taking 4,400 samples were obtained graphically from Figure 5.

Figure 4. Temperature vs Sample outside the greenhouse

Figure 5. Temperature vs Sample inside the greenhouse

By placing the temperature probe on the greenhouse deck and at a distance of 15 meters from the Raspberry Pi ® embedded computer and taking 4,500 samples, the graph shown in Figure 6 was obtained.
Figure 6. Temperature vs. Sample on the cover of the greenhouse

For taking the temperature in the soil, a 20 cm excavation with respect to the surface was made. The sensor was located 27 m from the embedded computer. 2,000 samples were taken and the graph shown in Figure 7 was obtained.

Figure 7. Temperature vs Sample on the soil of the greenhouse

The outdoor relative humidity sensor was placed 7 m from the embedded computer and at a height above the ground of 2.5 meters. 1,500 samples were taken and the graph in Figure 8 was obtained.

Figure 8. Relative Humidity vs Sample outside the greenhouse

Finally, the relative humidity sensor inside was placed 25 m from the embedded computer and at a height above the ground of 2.5 meters. 1,500 samples were taken and the graph in Figure 9 was obtained.

Figure 9. Relative humidity vs. sample inside the greenhouse
4. Discussion

The sampling time for taking the temperatures involved was 375 ms to note how sudden the change was; however, it was noted that it is not necessary to sample with such a small value. To take the Relative Humidity, the sensor used shows the value taken every 2 seconds. However, as the temperature sensor can be given more time for each sample due to wind variations, the measurement is altered, but it is restored again.

For implementing the network of relative humidity sensors, a higher accuracy in terms of humidity percentage is desired, therefore and based on what was obtained, a network with sensors of the same DHT family will be implemented but with 22 series, which offers an accuracy of 0 to 100 %RH.

5. Conclusions

Each graph shows the way in which each variable behaves, both in terms of temperature and relative humidity, noting that the ones that vary most with respect to time are the temperature and relative humidity outside the greenhouse, this due to sudden changes in wind speed or the presence of clouds. It can be observed that, in the roof, as well as in the interior of the greenhouse, the temperature is kept within a range without abrupt alterations, having to consider that the enclosure remains closed in its main door, while zenithal and lateral vents remain open for air circulation.

For the soil temperature, a decrease in temperature was observed, this is due to the fact that the temperature was taken immediately after having buried the sensor at the established depth. However, the values converge to an average of 27 ºC, thus showing that about 10 ºC is lost between the interior of the greenhouse and the soil.

The relative humidity inside the greenhouse did not exceed 12%, which sounds natural because the greenhouse does not currently have the presence of evapotranspiration from plants and soil, nor the activation of foggers.

The monitoring of environmental variables of greater consideration in a greenhouse such as temperature and relative humidity is possible thanks to an embedded computer such as Raspberry Pi® that provides a real solution to be used as a data acquisition system of low cost and energy consumption.

The time of sampling for both variables; temperature and relative humidity outside, according to the experience will have to be bigger than 2 s. The maximum time will be determined according to the range of temperature and relative humidity supported or optimal by the own culture.

Once the sampling period has been defined for all the variables that enter the system, such as exterior and interior temperatures, greenhouse and soil cover, as well as exterior and interior relative humidity, it is possible in a future project to export this data to a computer algorithm capable of performing the calculation corresponding to the energy balance.

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