Usage of Arduino-based Datalogger for thermal comfort variables monitoring

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Abstract

Environmental monitoring is an effective tool to identify problems in anthropic areas, and the emergence of cyber-physical sensors contributes to technological advances in this area. This paper introduces a device based on the Arduino cyber-physical platform to monitor air temperature and relative humidity in real-

time with high efficiency. With the relationship between these two environmental variables, it will be possible to calculate the Heat Index (CI), the Temperature and Humidity Index (ITU), the Effective Temperature Index (ET), and the Thermal Discomfort Index (IDT). The Datalogger developed is easily programmable and easy to assemble and presented stable operation and proper functioning.

Keywords: Arduino; effective temperature index; thermal discomfort; monitoring.

1. Introduction

The monitoring of environmental variables plays an important and effective role in observing and understanding phenomena that directly and indirectly affect the dynamics of a given physical space. Souza and Santos (2018) present in their study that monitoring is a powerful mechanism for environmental control policies. It allows to determine the imbalance level, and consequently, enables the systematic monitoring of environmental quality within a region, providing subsidies for evaluation and implantation of control strategies. In this context, developing new cyber-physical sensors and contributing to technological innovation would also provide a scientific advance in the area.

Cyberphysical systems consist of a network of elements that interact between the physical environment and computational tools (hardware and software), therefore being creative devices that design intelligent processes to meet a certain objective Lee (2016) and Silvia (2018). However, the most commercialized systems for measuring environmental variables present a big problem: proprietary equipment, high cost, closed-source code, and interoperability with equipment from other manufacturers (HERLAL et al., 2018). The present study focuses on applying an alternative electronic device capable of efficiently collecting and storing data from anthropized environments.

Regarding this issue, Muniz-Gäal (2018) emphasizes that populational growth as one of the inducers of the whole urban climate change cycle, for it leads to the densification and to the verticalization of urban areas already endowed with installed infrastructure, affecting climatic conditions even further. Some natural landscape changes, such as reducing green areas, the impermeabilization of urban surfaces through intensive paving and building constructions, may cause the increase of anthropogenic heat released into the atmosphere Fernandes (2020) e Santamouris (2015).

Assessing thermal comfort implies defining indexes whose results are grouped into classes that intend to translate the human-perceived comfort level, Bracarense (2018). To obtain these results, an environmental data collection station was developed utilizing the Arduino platform. The device was programmed to perform real-time temperature and relative humidity readings; after processing, the data is sent to a notebook via USB (Universal Serial Bus) port. Relating both environmental variables, it was possible to calculate the Heat Index (HI), Humidity and Temperature Index (HTI), Effective Temperature Index (ETI), and the Thermal Discomfort Index (TDI) of an urban environment, located at the center of the city of Belém, Pará state.

2. Datalogger Architecture

The experimental development of this proposal was implemented in the best-known open-source and low-cost platform in the market, Arduino, which consists of hardware designed for the construction and programming of electronic circuits, in a quick way, associated with an open-source IDE (Integrated Development Environment). Arduino has a microcontroller from the AVR 328P family, of great reliability, that can achieve a 20 MHz speed, 8 bits and 32 kB of flash memory, in addition to 1 kB of EEPROM memory, 2 kB of RAM memory, also having an internal 10-bits analog-to-digital converter Rocha (2019). The sensor utilized for data collection was the BME280 by Bosch Sensortec, which simultaneously measured three variables: Air temperature, relative humidity, and atmospheric pressure. However, to fulfill this work's goal, it was only necessary to store temperature and relative humidity data. The BME280 ranges from -40ºC to 85ºC for temperature and 0% to 100% humidity. The sensor provides the measured values through a serial bus utilizing the I2C (Inter-Integrated Circuit) protocol.

2.1 Hardware Assembly

The electronic circuit was designed from the Arduino acquisition board; afterward, the BME280 sensor was attached to the I2C bus through electrical wires. Available voltage and current in the circuit were provided by the USB (Universal Serial Bus) serial port of a notebook, where it was possible to save the data to an Excel file for further analyses. Figure 1 presents an illustration of the electronic circuit and its components.

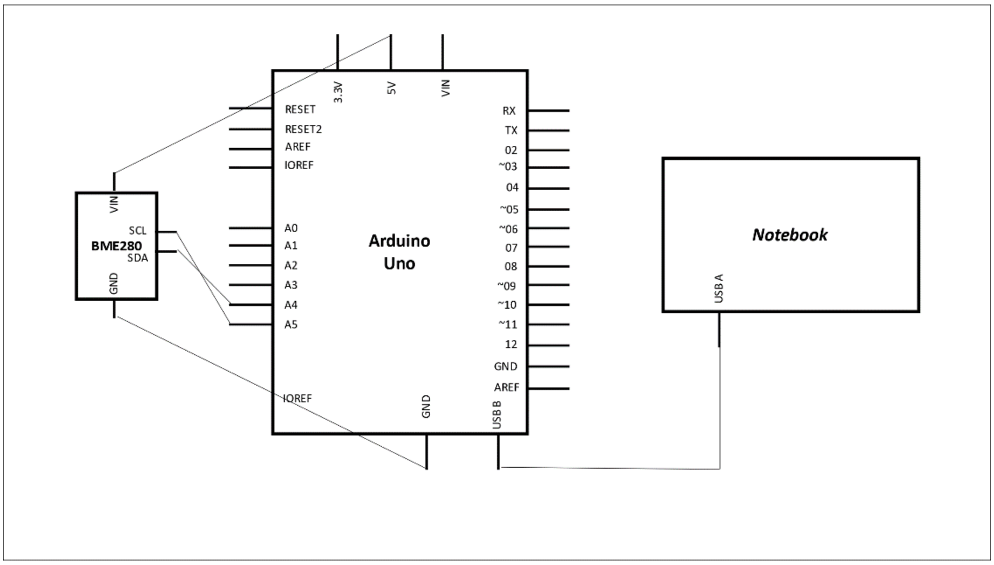

Figure 1. Electronic circuit scheme.

According to the WMO (World Meteorological Organization) standards, the meteorological sensor must be protected from direct sunlight and from the possibility of ventilation and heat dissipation so that the obtained values represent the conditions of the local environment in a more realistic fashion. Figure 2 presents the hardware housing.

Figure 2. System housing box.

After assembling the system, the BME280 was fixed to a plastic recipient with a lid.

2.2 Implementation and functioning of the data treatment algorithm

The operational logic of the system was developed in the built-in microcontroller language, based in the "C / C++" language. The programming ambient used was the Arduino IDE. The algorithm controls all processes related to collecting and sending data to the notebook storage. Figure 3 contains the programming flowchart developed and embedded in the board.

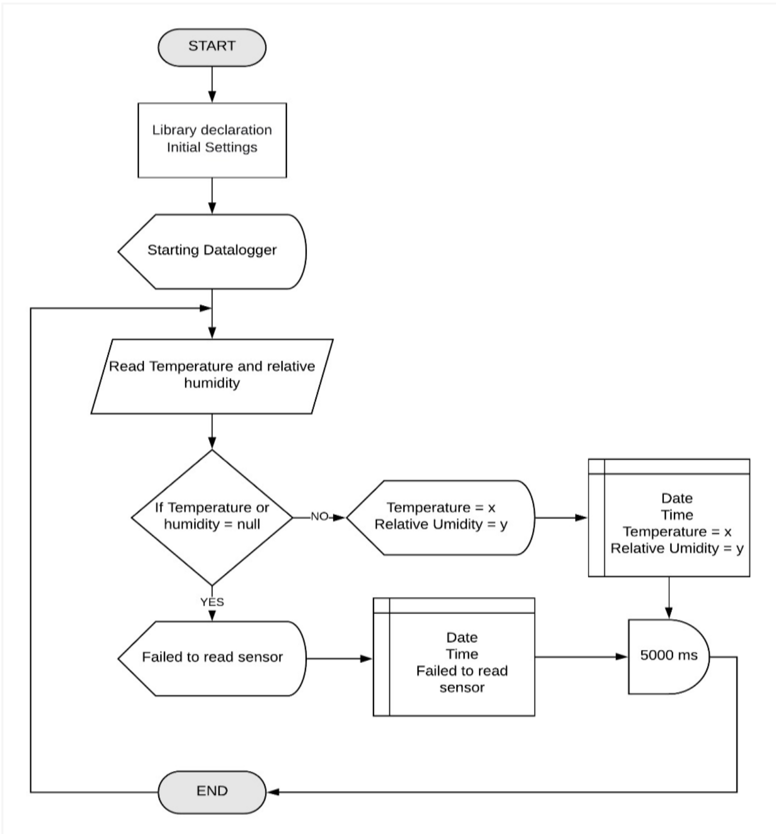

Figure 3. Flowchart of the programming embedded in the board.

3. On-site data collection

This study was carried out in the Amazon region, in the city of Belém (1°27'21" S, 48°30'14" W), capital of the Pará state - Brazil. Belém is known as the "town of the mango trees" for having some avenues and parks tree-lined with the species *Mangifera indica.* However, in the last decades, the city has been presenting a fast urban growth, rapidly transforming its original landscape. The city has an area of 1.059,466 km² and a population of 1.499.641 inhabitants (IBGE, 2021).

Measurements were performed in a residential village with little urban afforestation, and the location was chosen as it is an anthropized area with a high demographic density. The village is situated in the Cremação district, at Belém city, more precisely at latitude 1°27'42.36" S and altitude 48°28'46.99" W, as referred on the WGS84 datum. Figure 4 demonstrates the collection point location.

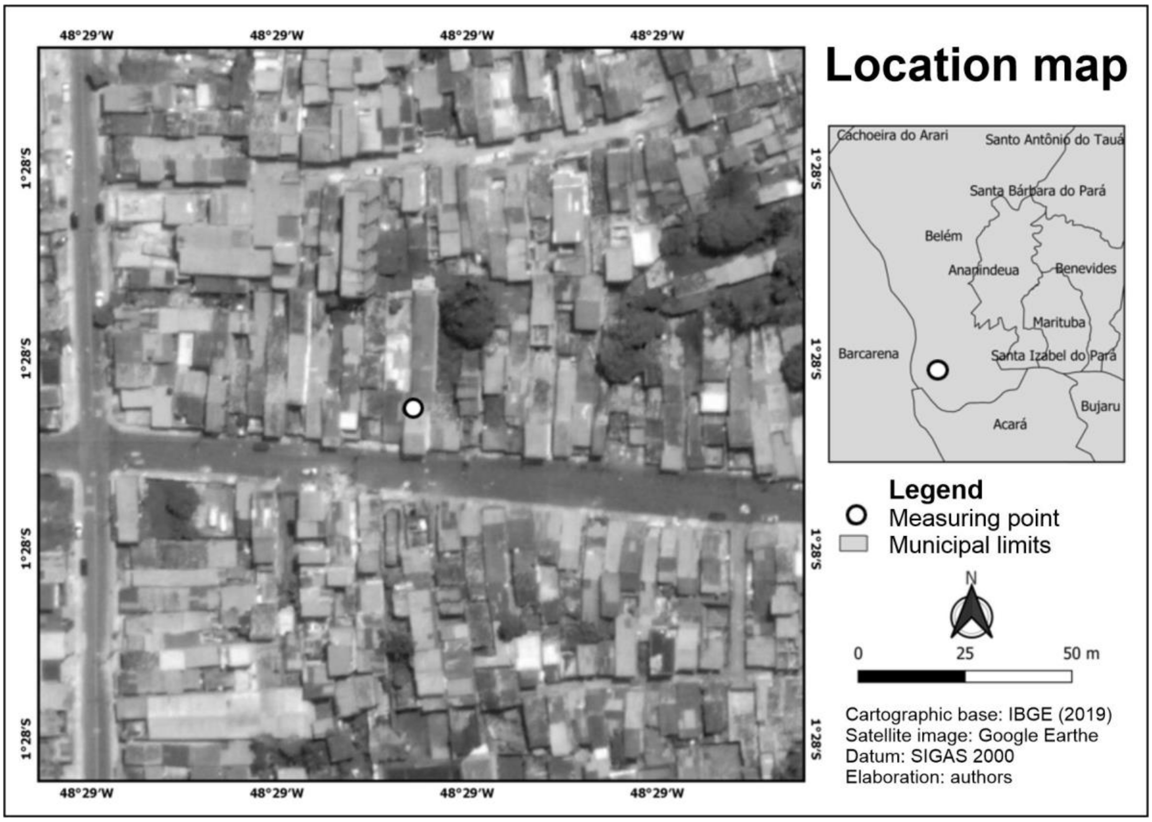

Figure 4. Map of the collection point location.

4. Thermal Comfort Indexes

In this study, calculations were developed from four different methodologies of thermal comfort evaluation, and each methodology use variable combinations, making these indexes unique.

4.1 Heat Index (HI)

The Heat Index utilized here was adapted from the works of Steadman (1979). HI was elaborated from subjective measures of how hot it feels for given temperature and relative humidity values, when in situations where temperature values are high, with an individual in the shade and in light wind conditions, Junior et al. (2013).

HI formulation is presented in Equation 1. Alert levels and their consequences to human health are illustrated in Table 1, which was developed by NOAA (National Oceanic Atmospheric Administration).

Adapted by Nóbrega (2021).

$$HI = \frac{5}{9}\begin{pmatrix}(c_1 + c_2T + c_3H + c_4TH + c_5T^2 + c_6H^2 \\ +c_7T^2H + c_8TH^2 + c_9T^2H^2) - 32\end{pmatrix} \quad \text{(Eq.1)}$$

Where: HI = heat index (°C); T = temperature (°F); H = relative humidity (%); c_1 = - 42,379; c_2 = 2,04901523; c_3 = 10,14333127; c_4 = - 0,22475541; c_5 = - 6,83783x10^{-3}; c_6 = - 5,481717x10^{-2}; c_7 = 1,22874x10^{-3}; c_8 = 8,5282x10^{-4}; and c_9 = - 1,99x10^{-6}.

Table 1. HI alert levels and their consequences to human health

Alert Levels	Heat Index	Symptoms
Extreme Danger	54,0°C or more	Heatstroke; risk of imminent cardiovascular accident (CVA).
Danger	41,1°C – 54,0°C	Cramps, heatstroke, physical exhaustion. Possibility of brain damage (CVA) for long exposures with physical activities.
Extreme Caution	32,1°C – 41,0°C	Possibility of cramps, of physical exhaustion, and heat stroke for long exposures and physical activities.
Caution	27,1°C – 32,0°C	Possible fatigue in case of long exposures and physical activities.
No Alert	Less than 27,0°C	No problems.

4.2 Humidity and Temperature Index (HTI)

The humidity and temperature index is indicated for open environments that allow quantifying the thermal "stress" in the urban environment. The calculation for the HTI values is given at Equation 2. The comfort levels for the HTI results are presented in Table 2 (NÓBREGA; LEMOS, 2011).

$$HTI = 0,8 * T + \frac{H * T}{500} \quad \text{(Eq. 2)}$$

Where: HTI = humidity and temperature index (°C); T = temperature (°C); and H= relative humidity (%).

Table 2. HTI classification criteria.

Comfort level	HTI
Comfortable	21°C < HTI < 24°C
Slightly uncomfortable	24°C < HTI < 26°C
Extremely uncomfortable	HTI > 26°C

4.3 Thermal Discomfort Index (TDI)

As determined by Thom (1959), the calculation of the thermal discomfort index is given in function of the temperature and the relative humidity. Its formula is represented by Equation 3. Table 3 presents the TDI levels (SANTOS et al., 2012).

$$TDI = T - (0,55 - 0,0055 * H) * (T - 14,5) \quad \text{(Eq. 3)}$$

Where: TDI = thermal discomfort index (°C); T = temperature (°C); and H = relative humidity (%).

Table 3. Thermal Discomfort level in function of the TDI.

Thermal Discomfort level	TDI
Uncomfortable	TDI < 14,9°C
Comfortable	15°C – 19,9°C
Partial Comfort	20°C – 26,4°C
Uncomfortable	TDI > 26,5°C

4.4 Effective Temperature Index (ETI)

The effective temperature index by Thom (1959) is calculated from Equation 04. The obtained results were interpreted according to Table 4 of effective temperature classification (LUCENA et al., 2020 *apud* SUPING et al., 1992).

$$\mathrm{ETI} = \mathrm{T} - 0{,}4 * (\mathrm{T} - 10) * \left(1 - \frac{\mathrm{H}}{100}\right) \qquad \text{(Eq. 04)}$$

Where: ETI = effective temperature index (°C); T = temperature (°C); and H = relative humidity (%).

Table 4. ETI values and their respective descriptions.

Human feeling description	ETI
Very hot	ETI > 30°C
Moderately hot	24°C < ETI < 29,9°C
Pleasant	12°C < ETI < 23,9°C
Cool	6°C < ETI < 11,9°C
Very cool	0°C < ETI < 5,9°C
Cold	-12°C < ETI < -0,1°C
Very cold	-24°C < ETI < -12,1°C
Danger of Frostbite (Beginning)	-30°C < ETI < -24,1°C
Danger of Frostbite (Increasing)	ETI < -30°C

5. Results and Discussion

The developed Datalogger was taken to the field on March 8th, 2020, between 11:00 and 14:00 (climate was partially cloudy during this interval) for on-site temperature and relative humidity measurements. It was possible to automatically perform 2160 measurements in this interval, as the system was programmed to collect with a 5000 milliseconds frequency.

Research results demonstrated that relative humidity values obtained averaged at approximately 87,40% for an urban environment with a maximum of 95,87% and a minimum of 83,17%. The temperature average was 29,72^{o}, with a standard deviation of ±0,17. Chase et al. (2016) indicate that these measurements can be used for "thermal comfort" monitoring, pointing that, after identifying the climate behavior of a given region, it is possible to measure the necessary parameters for human and animal survival and well-being through the data gathered by the environmental variables monitoring platform.

Table 5 presents a summary of thermal conditions and the obtained results after the calculations of thermal comfort indexes, based on the temperature and relative humidity averages gathered on site. Results pointed out that distinct thermal comfort classifications for each index were obtained for the same temperature and humidity data. However, it is possible to observe that all indexes provided classifications that were close to each other.

Table 5. Thermal comfort indexes calculation results.

Thermal comfort indexes	Temperature	Classification
Heat Index (HI)	38,89°C	Extreme caution
Humidity and Temperature Index (HTI)	28,97°C	Extremely uncomfortable
Thermal Discomfort Index (TDI)	28,66°C	Uncomfortable
Effective Temperature Index (ETI)	28,73°C	Moderately hot

The four studied methodologies regarding thermal comfort analysis resulted in classifications that varied from "Uncomfortable" to "Extreme caution". These results may relate to the landscape changes caused by urban development, such as paving, one factor responsible for heat transmission to the air, increasing temperature, and causing thermal discomfort (BARBOZA, 2020).

It is important to emphasize that the developed prototype presents satisfactory results regarding environmental monitoring, as it has a considerably low precision error as calculated by the sensor manufacturer, having a precision of 0,01ºC for temperature and 0,008% for relative humidity.

It is also worth mentioning Lucena et al. (2020), which informs that analyzing thermal comfort index factors is a complex task, for it involves not only physical factors but also a range of personal factors making its definition very subjective. Therefore, it is vital to understand each index limitation and its methodological differences to determine which one best represents a given location.

6. Conclusion

Analyses demonstrated that the indexes presented the influence of urban parameters on user comfort and reiterates the idea of using these parameters to classify areas, thus validating the usage of indexes as tools to comprehend the variations of thermal comfort levels in urban environments. It is recommended for future studies to analyze thermal comfort more systematically.

The study also presented Arduino-based monitoring systems as a good choice when measuring temperature and relative humidity, as the system presented stability in its operation and a satisfactory functioning on site, attending to the work expectations until this moment.

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