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IX Encontro Sul Brasileiro de Meteorologia

Analysis of meteorological conditions in the municipality of palhoça/sc by a low-cost station with data transmitted via public lighting telemanagement

Análise das condições meteorológicas no município de palhoça/sc por uma estação de baixo custo com dados transmitidos via telegestão da iluminação pública

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ABSTRACT

Smart cities have a remote management system capable of monitoring various information via the public lighting system. It should be noted that environmental data is already collected via this system in other countries, but this initiative has not yet been implemented in Brazil. Thus, this project proposed installing a low-cost station in Palhoça/SC, transmitting data continuously, through the public lighting telemanagement system, to a storage platform and comparing the information obtained with professional meteorological stations nearby. In this solution, temperature and atmospheric pressure data were analyzed over a short period, highlighting three distinct meteorological conditions. The proposal is to implement several stations throughout the municipality in the future, generating information for regional meteorological analyses.

Keywords: Data transmission; Weather station; Public lighting remote management

RESUMO

As cidades inteligentes contam com um sistema de telegestão capaz de monitorar diversas informações via sistema de iluminação pública. Ressalta-se que dados ambientais já são coletados via esse sistema em outros países, mas no Brasil ainda não foi implementada essa iniciativa. Assim, este projeto propôs a instalação de uma estação de baixo custo no município de Palhoça/SC, transmitindo os dados de forma contínua, através do sistema de telegestão da iluminação pública, para uma plataforma de armazenamento e comparar as informações obtidas com estações meteorológicas profissionais, próximas. Nesta solução foram analisados os dados de temperatura e pressão atmosférica, em um curto período, com destaque para três condições meteorológicas distintas. Fica a proposição de num futuro implementar várias estações pelo município, gerando informações para análises meteorológicas regionais.

Palavras-chave: Transmissão dados; Estação meteorológica; Telegestão de iluminação pública

1 INTRODUCTION

In recent years, cities have been undergoing a technological change process. Constant innovations directly influence people's behavior, contributing effectively to life improvement and, hence, to the sustainability processes of the cities (Tarsis, 2014). Over time, the concepts of smart cities and sustainable cities have merged. Smart cities must be sustainable and offer quality of life, while sustainable cities must use information and communication technologies to monitor the flow of resources. (Kobayashi *et al*., 2017).

A set of indicators has been used, accompanied by numerous benchmarking projects, to classify the performance of several cities. Recently, several cities have sought out their indicators through real-time data incorporation, captured predominantly through sensors, cameras, and social and locative media (frequently termed "big data"), often under the banner of smart-city initiatives (Kitchin; Lauriault; McArdle, 2015).

ABNT (2020), by NBR ISO 37.122, establishes the indicators to identify a smart city. This concept is highlighted as a research priority by the Ministry of Science, Technology, and Innovation (MCTI), according to Ordinance nº 1.122/2020/MCTI, on two sustainability topics: Smart Cities and Environment Control.

In a smart city, data enable managers to generate, capture, process, and analyze information using their technologies. This helps them develop various aspects of the urban environment, such as social, educational, economic, and ecological areas (Remedio and Silva, 2017).

For the success of a smart network, it is essential to have robust communication capabilities (Suhaimy, 2022). This means selecting the most effective communication technology to provide additional connectivity and data flow. So, the deployed algorithms can act on relevant information, thereby increasing the level of automation in operations. (Bhagavathy, 2022).

Additional capabilities, such as Electric Vehicle (EV) charging, air quality monitoring, and weather detection, provide citizens and city authorities unique economic and social benefits (Akindipe, 2022).

As indicated by Akindipe (2022) in his study on integrating additional capabilities into the smart street lighting system, participants of the public survey highlighted the meteorological data collection and air-quality monitoring through sensors as the second most relevant.

Mendes (2020) conducted a comparative analysis using the literature and ISO 37120:2018 and 37122:2019. The author emphasized the importance of environmental management of natural resources, covering both human processes, directly or indirectly impacting the environment, and adequately administrating these resources. These elements are essential to the development of Sustainable Cities. In addition, Mendes (2020) pointed out that the capacity to predict and understand urban atmospheric processes is vital in protecting people from weather events and short- and long-term impacts, such as heavy rainfall and heat islands formation.

Fonteles (2019) states that urban development is directly associated with climatological factors. For conducting climatological studies, specific technologies require investment, such as data collection, which is essential to scale the problem and take preventive measures. One way to enhance the knowledge of greenhouse gas (GHG) emissions is by investing in technology that tracks them using satellites, drones, as well as air and building sensors. This will help create a more reliable data network for identifying the source and quantity of emissions while trying to develop techniques to reverse GHG effects. (Fonteles, 2019).

The climate of a region is determined by relatively static factors, such as latitude, altitude, continentality (distance from the sea), surface type, and other dynamic factors like air mass influences. Climate study depends on analyzing the general circulation of the atmosphere since the variables' variations are associated with air mass displacements (Back, 2020). The city of Palhoça/SC, where this study takes place, presents varied topographic characteristics, from the sea level to the 1.269 m altitude. Its climatology will be discussed further.

Thus, the analysis of mesoclimate data becomes necessary for understanding a locality's climate conditions, benefiting the citizens in its geographical surroundings. Luz (2013) highlights that the mesoclimate data inform the modifications at global and synoptic scales by local topography, such as valleys, mountains, vegetation, water bodies, or land cover. The author also underlines that microclimate data consider the effects of human actions on the environment.

For a given short period, a mesoscale analysis is essential. In this sense, Bitencourt et al. (2016) present a study on the Mesoregion of Santa Catarina Island relying on high-frequency measurements at four strategic sites. After 30 days of observations, they found that the wind's behavior affected the temperature. The wind's behavior, in turn, is influenced by the variation in relief rather than the distance between the stations. According to these authors, it is possible to identify mesoscale meteorological systems through meteorological networks consisting of automatic stations named "mesonet." As a result, it is possible to point out the occurrences in a smaller area for a specific time.

Low-cost stations for measuring variables that collect data in micro-regions are presented as a solution. The availability of a station set enables the mesoclimate analysis of an area. Therefore, the climatological analysis of a region must consider local data for greater assertiveness instead of coarser data that generate macroclimate information.

With the Telemanagement network operating throughout the Municipality, we can deploy several stations and collect data using this existing and available telecommunication network.

Therefore, the objective is to evaluate the meteorological conditions of a locality in Palhoça Municipality via the transmission in the Public Lighting Telemanagement system, allowing the local analysis and intercomparison with data extracted from an official weather station.

2 METHODOLOGY

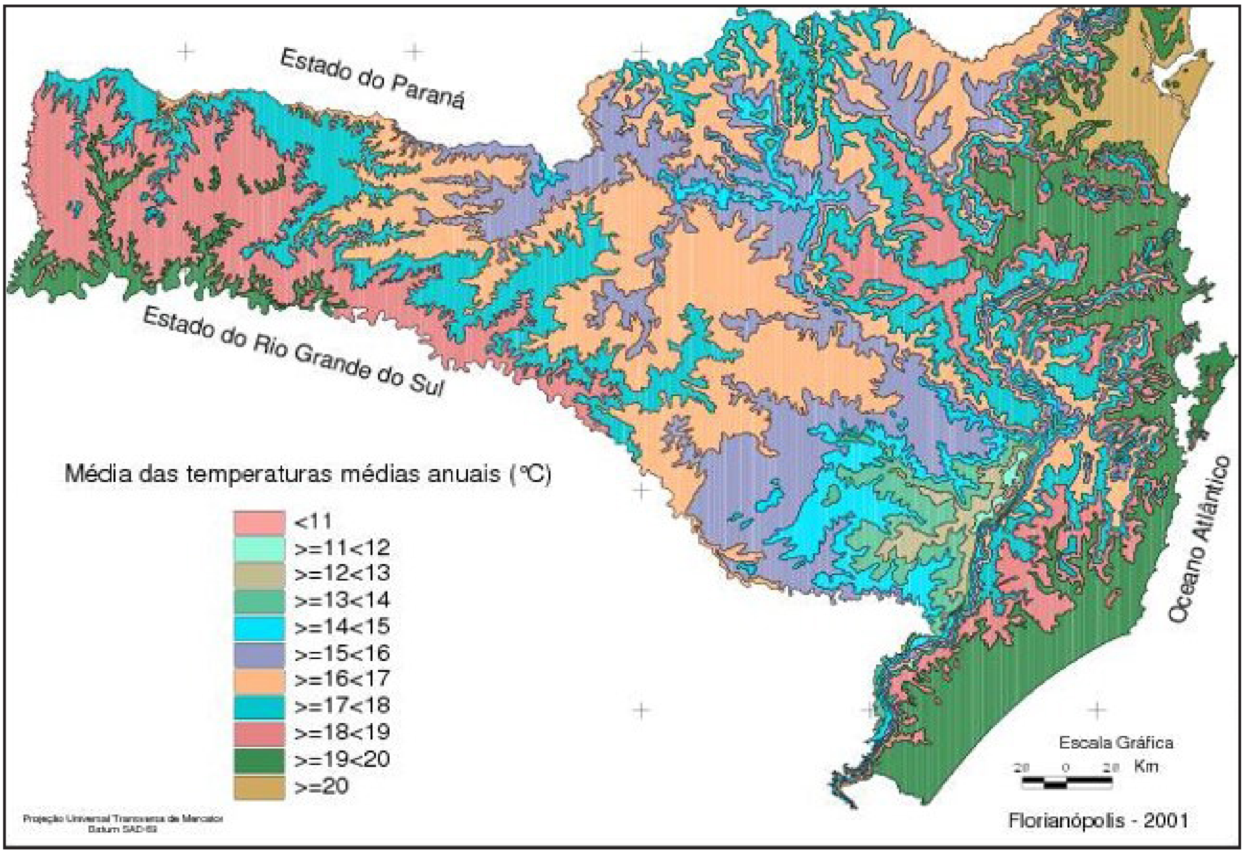
The method is based on installing a low-cost weather station connected to the Public Lighting Management System of Palhoça municipality for data transmission. The data obtained at this station were compared with data from INMET's automatic weather station A806/Florianópolis (27°36'09" S/48°37'11" W) located in the Campinas neighborhood, Municipality of São José, adopted as a reference station. Data treatment was based on basic and inferential statistics. Finally, data collected from the low-cost station was analyzed and compared with data from the automatic reference station under specific meteorological conditions. INPE's satellite images, the Brazilian Navy's synoptic charts, and analyses from a meteorological model were also examined.

2.1 Study location and climate

Palhoça Municipality is found within the Greater Florianópolis, where the climate resembles that of Santa Catarina's capital. It is predominantly warm and temperate, with 19,9ºC and 1810 mm on the annual average (Figure 1). Thus, with the information provided by INMET's automatic weather station A806/Florianópolis (27°36'09" S/48°37'11" W) located in the Campinas neighborhood, Municipality of São José (Figure 2), it is possible to compare the meteorological data from the experimental station in Palhoça (Wrege *et al*., 2012).

Palhoça and São José are neighboring cities, with the stations approximately 14 km apart. The project station is situated in a region with different relief characteristics from the INMET station.

Figure 1 – Santa Catarina´s Climate Classification



Source: PANDOLFO, C, *et al* (2002)

Adapted Climate Atlas of the Stade Santa Catarina

2.2 Weather station description and data transmission

This section discusses the type and operating module of the weather station, as well as how the data was transmitted by the Telemanagement system and how the measured data were processed.

Data were collected for the following variables to analyze the mesoclimate in this proposed region: wind speed and direction, atmospheric pressure, and air temperature.

2.2.1 Weather Station Features

The weather station used in this project was developed by Sanches (2020). It is a prototype intended for use with low-cost sensors based on an Arduino platform, enabling large-scale reproduction and generating information from various locations.

However, its use showed some need for improvement to withstand the atmospheric conditions since its low-cost proposal did not consider the resistance to weather. Some modifications were necessary on the initial version, where the leading outcome was a protective box (Figure 2) for the set and the sensors.

The mechanical constitution of the anemometer's and anemoscope's base was manufactured in an aluminum structural profile with a rectangular section, allowing alignment with the cardinal points. Its mobile components have been manufactured from Carbon Fiber Reinforced Plastic (CFRP).

The anemometer shells are semi-spherical with 80 mm of external diameter, fixed by a flange with a central bearing, and have two neodymium magnets installed diametrically opposite to associate the hall effect sensor (US1881, type CMOS) with its magnetic field. Each complete turn of the flange sends a signal to the electronic board.

In the anemoscope, also laminated in CFRP, a neodymium magnet was inserted for alignment with the magnetometer sensor (HMC5883L), from which the information comes out to define the angle of the wind direction. It sends the measured values to the electronic board by I2C communication.

The BME280 sensor was used to measure atmospheric pressure and air temperature. It was put in a box with a frontal inlet that allows air circulation, and its communication with the electronic board was also by I2C. This box was attached to the outside of the box where the electronic board and the transmission system are placed, preventing any temperature variation of the system from influencing the sensor.

The central assembly of the station consists of a printed circuit board powered through a 220Vac/12Vdc transformer/rectifier, with output for various functions.

The microcontroller is a 5Vdc-powered, programable ESP8266 with low-power and low-cost IoT development. Its functionality permits it to be used as a WI-FI module for the Arduino, enabling internet connection and on-board processing and storage of the station's sensors. The high level of integration implies a minimum occupation area of the board.

The system includes a real-time clock module with a micro-SD recorder and a liquid crystal display with I2C communication.

The programming was developed by Integrated Development Environment (IDE) in Arduino, considering the standards elaborated by the World Meteorological Organization. Temperature and atmospheric pressure are measured every minute. However, wind speed and direction, as they suffer more variations as a function of time, are measured at each turn of the anemometer.

The analysis of Sanches (2020) concerning the low-cost station shows the comparison of the same equipment of the study with the IFSC/Campus Florianópolis Campus station from the Meteorology Course. Temperature, atmospheric pressure, and relative humidity were measured by only one sensor (BME280), to the detriment of the IFSC station that used separate sensors. The author revealed that the temperature was used to compensate the sensors of the other quantities, generating differences between the stations compared. It was also noted that the prototype station measurements distorted from the IFSC station during high temperatures, only remaining closer in lower values. Overall, Sanches (2020) concludes that the prototype presented close values for temperature, atmospheric pressure, relative humidity, wind speed and direction, proving its effectiveness in measurement and transmission.

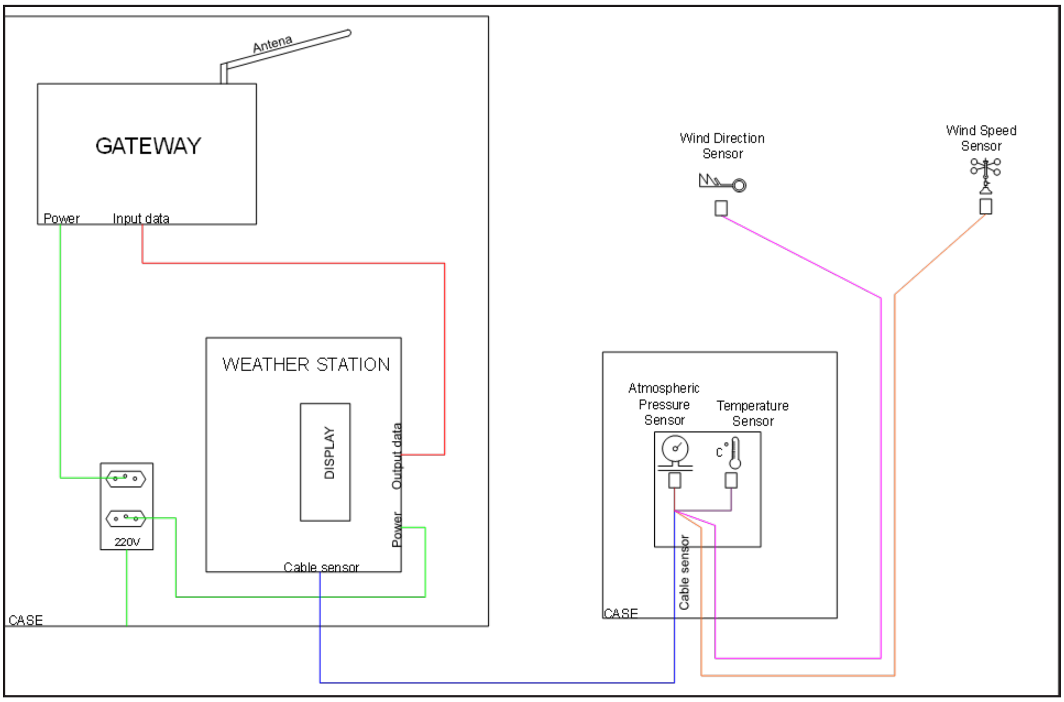
Torres (2015) presents a solution using this same low-cost model with similar hardware and software used here. After the testing period, the author showed that the station correlated with a conventional automatic weather station nearby. Torres (2015) also highlights the importance of a meteorological shelter for the station, protecting the sensors and minimizing interference, consequently obtaining more reliable data. These points were also improved in the station designed by Sanches (2020).

Figure 2 – Images of the project's meteorological station prototype installed on the field (wall facing South)

Source: The author (2023)

Author's private collection (April 2023)

Figure 3 – Weather station connection diagram



Source: Author (2023)

As illustrated in Figure 3, a communication system was incorporated during the assembly to provide convenient and centralized access to the set.

2.2.2 Data Transmission

At this stage, the station was installed in Ariru, within Palhoça Municipality (27°41’06” S / 48°40’09” W), to analyze the system’s behavior and data transmission in the region.

The Telemanagement solution used by the Street Lighting Concessionaire - QLUZ, is supplied by Smartgreen. It is implemented throughout the municipality, reaching the installation and connection location of the low-cost weather station. It should be noted that, according to the project proposal, the system will be able to transmit data anywhere in the municipality where there is public lighting with LED and Remote Management. For this reason, it is enough that the station is concentrated within a communication radius of the luminaire device signal range. Previous field tests found that the prototype could be installed 50 meters from the luminaire and the station without interference. This allowed for a safer and ampler location, away from the pole where the public lighting is located.

The communication solution adopted involves data transmission from the station through Radio Frequency (RF). During this process, analog or digital signals are converted into electromagnetic waves and transmitted through an antenna to a radio receiver. The receiving station is located on the pole where a street light controlled by Telemanagement is installed.

By this individual command, transmitted via an input port for communication with the radio receiver, a software will manage the information with a specific application for this solution.

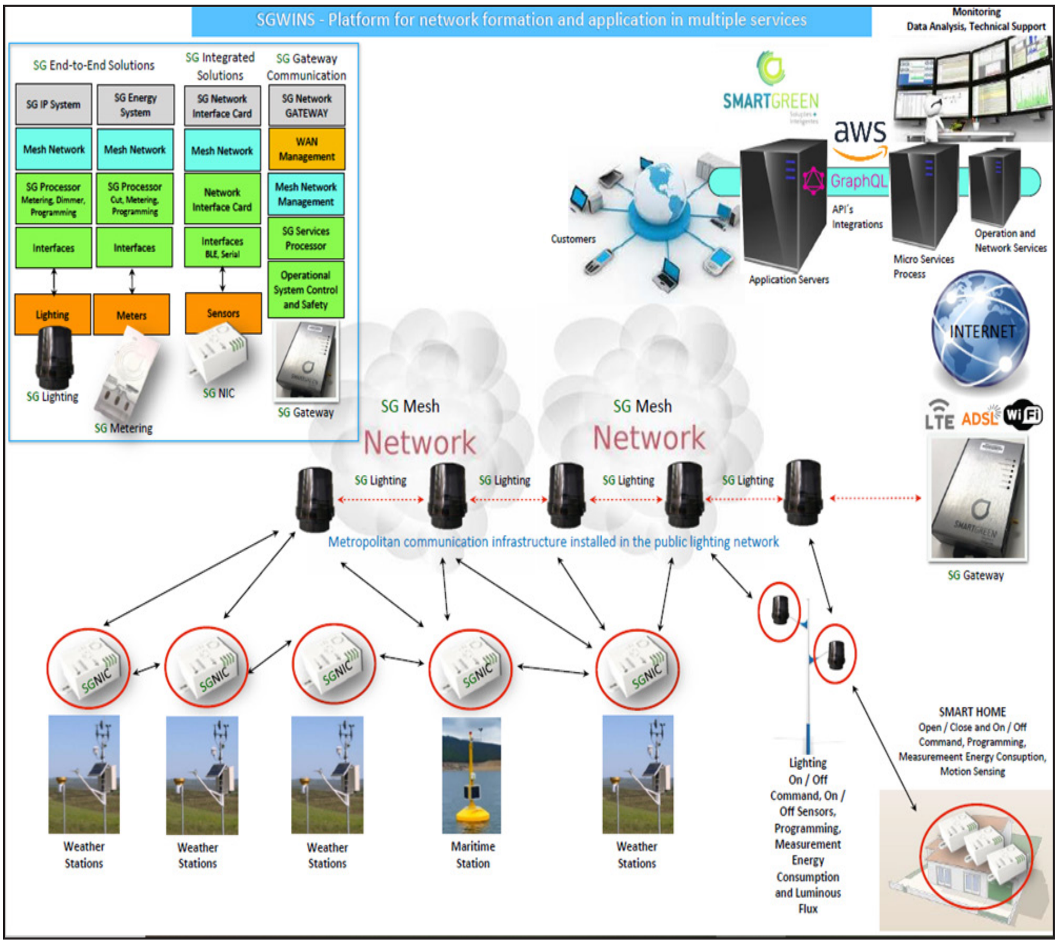
Every installed equipment serves two functions: a generic one, which is to form a network, and a specific one, which is determined by its intended use. This system was developed to monitor a street light; measure electric, gas, or water consumption;

monitor an environment; control equipment, track a vehicle; or even image monitor a person or an animal.

The solution is based on a platform whose concept is based on a set of equipment developed to provide information control and management in a vast field of action. It involves electronic equipment, management software solutions, embedded software, and communication architecture.

Figure 4 shows how each station, located in any area of the city, can connect to the Telemanagement system, which is deployed where there is a remote-controlled street light, providing an extensive network of meteorological data information. We have illustrated the platform's procedure, consisting of three separate action layers. These layers are described below.

Figure 4 – WEB Management Platform



Source: Smartgreen (2023)

The first layer involves the remote device (named controller), designed to be a versatile product incorporating intelligent embedded software. This software can automatically and autonomously execute the corresponding functions to each equipment connected to it, whether a device, vehicle, meteorological station or person. The devices are installed on the street lights.

From the devices installed in the luminaires, the communication with the station occurs in binary form in the American Standard Code for Information Interchange (ASCII) format through the RS232 protocol. It is known as asynchronous communication, where each word receives an identification. In this way, both the sender and the receiver know strictly what is being transmitted because the rules for decoding the information have already been established. Table 1 demonstrates how the station transmits and how the system receives the data.

Table 1 – Example of how the station transmits data and the system receives it

Data-hora	Velocidade de Vento (m/s)	Temperatura (°C)	Pressão Atmosférica (hPa)	Direção do Vento (graus)
05/05/2023 09:52	1,6392	25,27	1020,43	83

Source: Author (2023)

The second layer corresponds to the networks' formation, which enables the organic growth of the connectivity mesh through which the information from all services travels (mesh network). This layer comprises a wireless system installed inside each equipment on the street lights. These systems are responsible for selecting the information that travels through it, filtering the instructions received, and retransmitting them to the network. This process is carried out through a concentrator (gateway), which transmits the received data to a central by long-distance systems, such as cellular modules or optical fiber.

Its communication relies on an application protocol that sends commands to the controllers in each luminaire in a similar way that it receives information from them.

This process includes the information generated by the solutions interconnected to the system, such as the weather station.

The third layer comprises management and network management software that handles large computer databases. It is important to note that this layer has two distinct groups of systems. The first group monitors the network's state, including its connections, traffic capacity, authentications, velocity, and information security. Their primary objective is to ensure optimal network balancing and high availability. Meanwhile, the second group processes the information and makes it accessible to customers. These systems are accessible by internet access platforms that require secure passwords. It is crucial to emphasize that they are designed for real-time monitoring and provide access to historical data.

The receiving system ensures messages' large-volume processing of all functionalities operating in the system are monitored in real-time, alerting if there is a backlog of messages. Once the messages are received and validated for security, they undergo decryption and become accessible for further analysis.

In this environment, the information generated by the weather station is stored at the same time that it is recorded on the memory card inside the station.

After the customer receives the data, it is processed to analyze the weather conditions around the station's area.

2.3 Data processing and case studies

Statistical methods with Minitab and Matlab tools evaluated the consistency of the weather station's data. For data analysis, the INMET station - São José/Campinas (INMET Code: A806) was used as a reference, with hourly measurements taken for 38 days, from March 18 to April 24, 2023).

The information is sent in real-time to a central and made available in ASCII format (.txt) to confirm the accuracy of the data collected by the meteorological station's sensors. However, the data requires processing before it can be analyzed.

Once processed, basic statistical methods are used to present initial comprehension using the following methods:

Time series graphs to inspect the behavior of the locally measured variables and the same variables computed at reference stations.

Time series graphs of the locally measured variables' moving averages and their equivalents at reference stations to evaluate the behavior trend of the series.

Histograms and normality tests on the measured series and their equivalents at the reference stations to choose between parametric and nonparametric statistical methods in order to compare both series.

Lastly, inferential statistics were used to elaborate analyses supported by hypothesis tests. The following methods were used:

Comparison test between equivalent historical series to evaluate the compatibility and raise the statistical differences, when applicable.

Confidence interval calculation for the difference between corresponding variables measured at the reference stations and locally.

Correlation coefficient calculation by the Spearman method.

According to Wilks (2006) and Camparotto et al. (2013), the mean error (ME), the mean absolute error (MAE), and the mean squared error (MSE) are appropriate methods for verifying the estimated data accuracy concerning those observed.

The temperature behavior on three days with different meteorological conditions was analyzed to verify the influence of climatological factors on the difference between the stations' data. The analysis was based on satellite images from INPE, synoptic charts from the Brazilian Navy, and analyses from the Global Forecast System (GFS) model made available by the National Center for Environmental Prediction (NCEP).

Figures 7 to 9 (GOES) were generated using a PYHTON script, downloading the data file from the NOAA website, which selects the desired area (described in the top right corner), keeping the corresponding date and time in the top left corner.

3 RESULTS AND DISCUSSIONS

This section compares the collected data from the project's station and INMET's A806 meteorological station in São José/SC. It also evaluates three meteorological conditions in different periods of the time series analyzed.

It is noteworthy that the reports of the transmitted data allow a behavioral analysis of the variables during the studied period (from March 18 to April 24, 2023).

During the data collection period, two episodes occurred in which the project's station did not generate data, resulting in a lapse in the series.

3.1 Comparative analysis between the weather stations

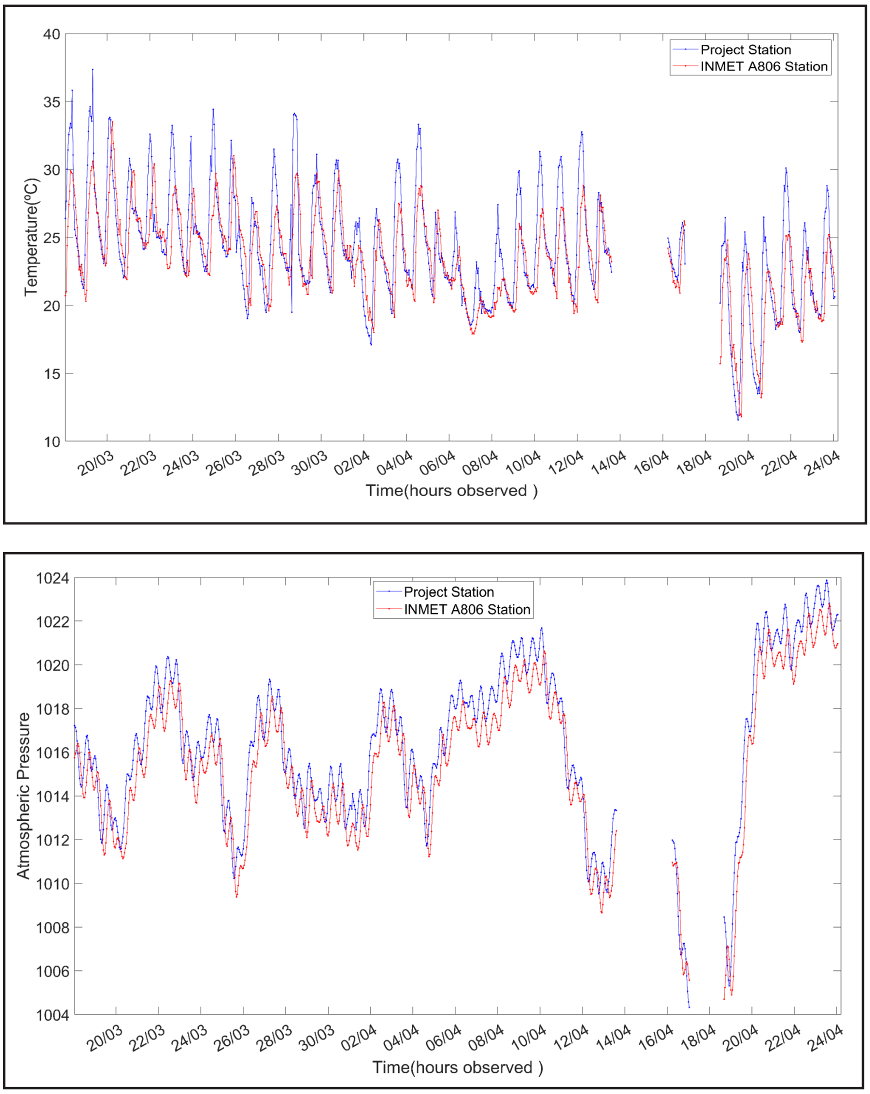
The analysis of Figure 5a presents the temperature time series from the two stations. It reveals a similarity in the valleys (associated with recording daily minimum temperatures). However, the differences accentuate in the peaks (daily maximum temperatures).

When analyzing the data, it is clear that the temperature readings from the stations show similar time series patterns and exhibit consistent behavior. Although discrepancies occur in the moments of most prominent thermal intensity, suggesting the influence of regional factors, the curves of the series preserve the simultaneous decreasing and increasing trend over time.

Another relevant factor in Figure 5a is the indication of seasonal migration, verified by the decreasing trend in temperature from the beginning to the end of the series at both stations.

The analysis of the atmospheric pressure time series (Figure 5b) concurs better between the stations. However, the project's station still presents a few divergent values, presenting a trend of higher pressures.

Figure 5 – Time series graphs of (a) Air Temperature (ºC) at 2m and (b) Atmospheric Pressure (hPa) at the surface recorded at the project's (blue line) and INMET's (red line) weather stations between March and April 2023



Source: Author (2023)

Figure 6 presents the histogram of the differences between the stations for temperature (Figure 6a) and atmospheric pressure (Figure 6b). It is observed that the distribution of the differences does not present the same behavior for both variables.

For the difference between the temperature data (Figure 6a), two different temperature distributions resemble two bell-shaped curves positioned next to each other, corresponding to low and high temperatures.

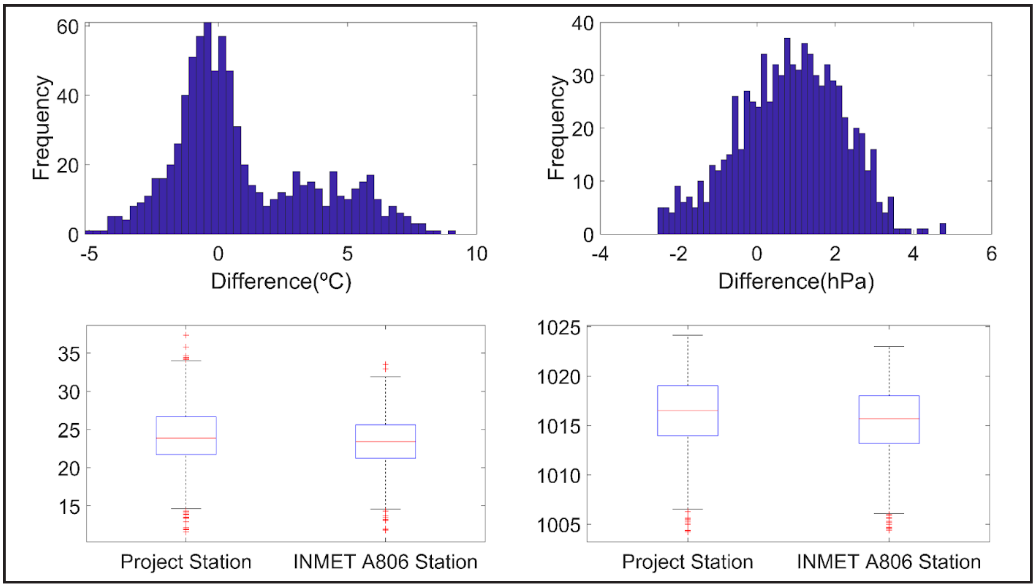
Based on the comparison of Figure 6a and Figure 5a, it can be interpreted that the project station generally moves no more than 4-5 degrees away from the INMET station, both during the minimum and maximum periods. The differences between the two stations are greater during the maximums and less during the minimums.

A well-defined distribution behavior is observed for the differences between the atmospheric pressure data (Figure 6b), suggesting that it corresponds to a normal distribution.

This variation of the differences between the variables measured by the stations indicate trends imposed by the components' precision class of the project. Due to the low cost, they may present less accuracy than the sensors of INMET's station.

It is essential to consider that professional weather stations, such as those from INMET, with sophisticated and calibrated equipment, can provide more accurate and reliable measurements. These professional stations follow strict quality standards and undergo regular verification and calibration.

Figure 6 – Histogram of the difference between the project's and INMET's weather stations for (a) Temperature (ºC) at 2m and (b) Atmospheric Pressure (hPa) and boxplot graphs for (c) temperature (ºC) at 2m and (d) Atmospheric Pressure (hPa) at the project's and INMET's weather stations



Source: Author (2023)

Figure 6 also illustrates the boxplots for temperature and atmospheric pressure (Figure 6c and 6d). When analyzing these graphs, it is possible to observe a higher occurrence of discrepant values in the local series compared to that of the INMET. This can be attributed to the distancing between the sets during the daily highs. However, this finding is more evident for temperature (Figure 6c). On the other hand, for pressure (Figure 6d), the discrepant data appears equally in both stations.

It is verified that the data dispersion is similar for both stations, with a slightly asymmetric distribution to the left for both variables, as shown in the graphs and validated by the asymmetry coefficients (Table 2).

Table 2 – Stations' asymmetry coefficients for temperature and atmospheric pressure

	Project Station		**INMET A806 Station**	
	Temperature	**Atmospheric Pressure**	**Temperature**	**Atmospheric Presure**
Asymmetry Coefficient	-2,39	-2,39	-0,04	-0,78

Source: Author (2023)

It was found that both the prototype and INMET stations were statistically significant when compared using a simple linear regression technique, as shown in Table 3. The p-value was 0.000 for both cases. The measured values were closer for atmospheric pressure (R^2 = 84.83) and less close but still accurate for temperature (R^2 = 52.35).

Linear regression analysis overestimates the difference between the monitored parameters concerning the histograms in Figure 6 because it assumes linearity in their relationship, which may not reflect reality. Even so, the two strategies suggest proximity between the data observed in both scenarios, ratifying the ability to transmit them via remote management.

Table 3 also presents the Spearman correlation for the quantities of the stations under analysis. Spearman's correlation is a statistical measure that evaluates the relationship between two variables, quantifying the strength and direction of this relationship and indicating whether the variables tend to vary similarly or inversely.

Table 3 – Data analysis between the project's and INMET's meteorological stations

Statistical Parameters Between the Stations	Temperature	Atmospheric Pressure
Spearman's Rho	O,737	0,931
p-value	0,000	0,000
R^2 (%)	52,35	84,83

Source: Author (2023)

Table 3 reveals that the data from both stations are correlated; higher values occur for atmospheric pressure. Thus, we can affirm that the variation in the atmospheric pressure is close, following the same trend. However, temperature presents some peaks that diverge between stations, although it mainly demonstrates a congruent variation.

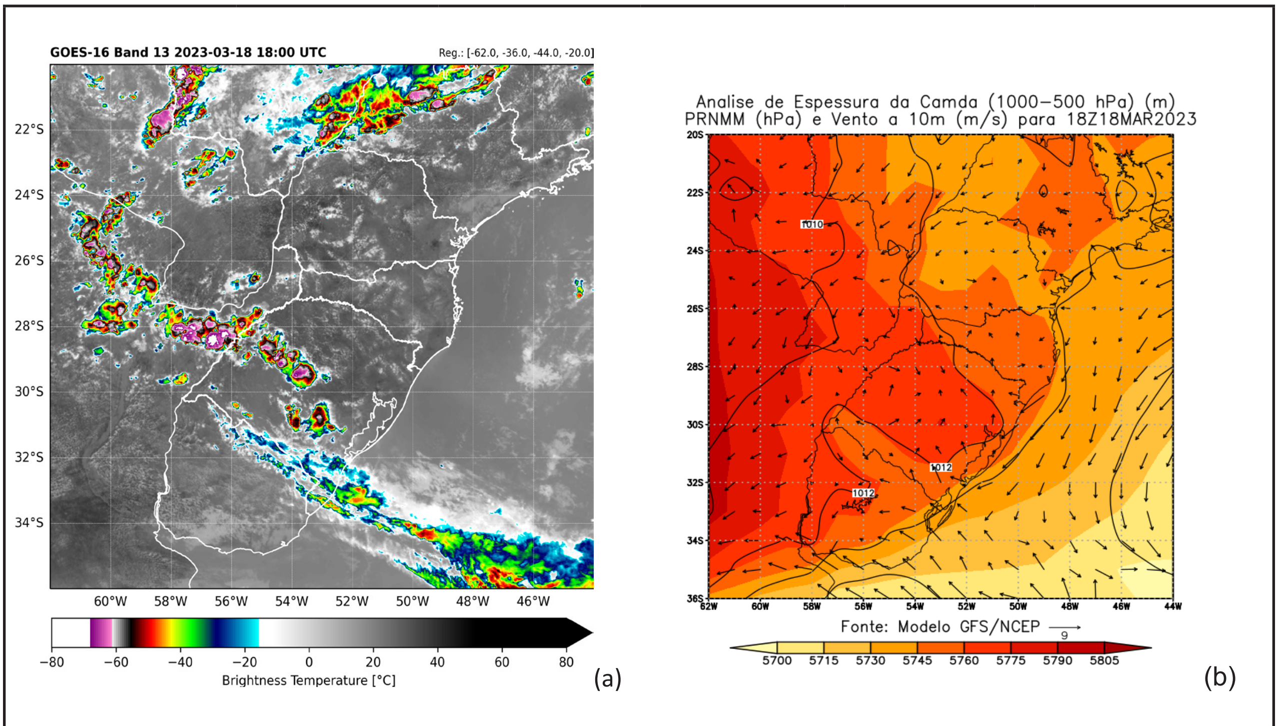
3.2 Analysis of different meteorological conditions

The behavior of temperature data, with distinct meteorological conditions, was analyzed to verify the influence of climatological factors on the difference between stations' data. The following conditions were investigated: one day characterized by high thermal amplitude and clear sky (MC1), one day denoted by low thermal amplitude and clear sky (MC2), and one day marked by low thermal amplitude and a cloudy condition (MC3).

3.2.1 Meteorological Condition 1 (MC1) - Clear sky and high thermal amplitude

This meteorological condition is characterized by a high thermal amplitude (difference between the minimum and maximum daily temperature) and cloud absence. This thermal variation occurs because of the interaction between solar radiation and the atmosphere, resulting in a daily heating and cooling cycle. On this day, due to the diurnal cycle, the temperature is expected to rise gradually throughout the morning, peak in the afternoon, and decrease at dusk. As shown in Figure 9a, cloud absence allows the maximum incidence of direct solar radiation.

Figure 7 – (a) GOES-16 geostationary satellite image from the Visible Channel (03) at 18 UTC, (b) Thickness fields (mgp) between 1000 and 500 hPa (shaded), isolines of mean sea level pressure (hPa) and horizontal wind vectors at 10m (m/s) (GFS model at 18 UTC). A table summarizing the meteorological condition during 03/18/2023 is also presented



Date-Time (Local)	Wind Direction (degrees)		Temperature (°C)		Global Radiation (W/m²) from INMET A806 station
	Project Station	INMET A806	Project Station	INMET A806	
03/18/2023 15:00	3	36	33,4	29,9	2823,8

Source: (a) INPE – (b) GFS/NCEP Model e Author (2023)

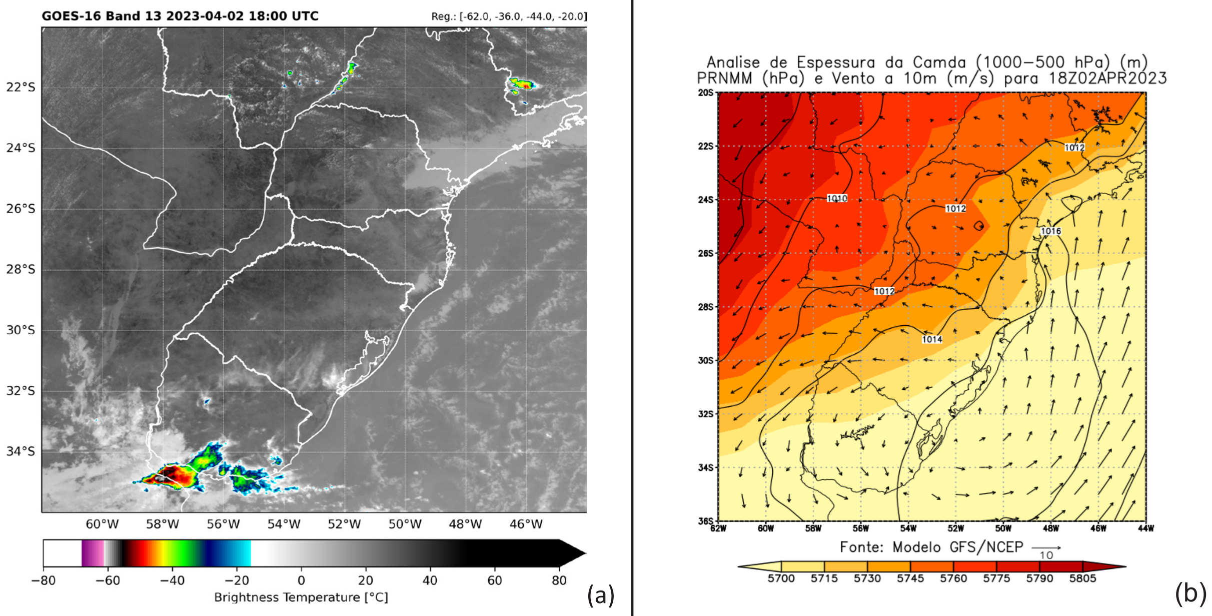
In MC1, the analysis of the Brazilian Navy's synoptic chart at 12 UTC (not shown) indicates northern wind associated with a prefrontal condition. Figures 7a and 7b corroborate this analysis, revealing a cold front on the border between Uruguay and the Rio Grande do Sul. The eastern part of Santa Catarina State experiences a clear sky (Figure 7a) and a warmer air mass, as shown by the thickness field (Figure 7b). Associated with this meteorological condition, the temperature data from the project's station (33,4ºC) presented the most significant difference concerning INMET's station data (29,9ºC), proving the distortion of the values for maximum temperatures. In this condition, persistent northern wind associated with a prefrontal condition (cold front approaching) was observed for several days (Figure 7b).

3.2.2 Meteorological Condition 2 (MC2) - Clear sky with an incoming cold air mass

Meteorological Condition 2 (MC2) was characterized by low thermal amplitude and cloud absence. This pattern occurs when, even with a clear sky, temperatures do not rise due to the cold air mass. In this condition, even with cloud absence (Figure 8a) in the afternoon, there is no significant temperature increase throughout the day. The GOES-16 satellite image presented in Figure 8a shows cloud absence corroborated by the high value of global radiation over practically the entire southern region of Brazil, associated with a high-pressure system over the area. On the coast of Santa Catarina, southern winds predominate (Figure 8b). It should be noted that, at this time, the low-cost station indicates wind from the north quadrant.

Associated with this tropospheric pattern, the maximum temperature of the project's station (26,2ºC) is close to INMET's station (25,9ºC), indicating a 0,3ºC difference. This condition was observed after the cold front's passage by Santa Catarina State. In these circumstances, persistent southern wind predominates, which is associated with this postfrontal condition.

Figure 8 – As in Figure 7, for 04/02/2023



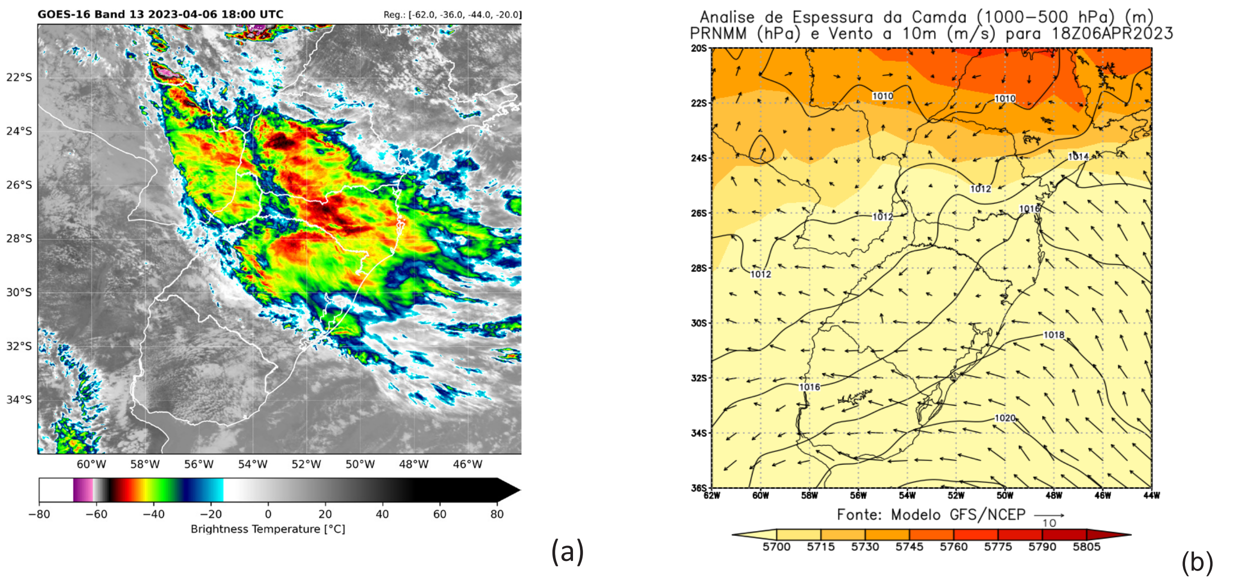
Date-Time (Local)	Wind Direction (degrees)		Temperature (°C)		Global Radiation (W/m²) from INMET A806 station
	Project Station	INMET A806	Project Station	INMET A806	
04/02/2023 15:00	58	152	26,2	25,9	2533,6

Source: (a) INPE – (b) GFS/NCEP Model e Author (2023)

3.2.3 Meteorological Condition 3 (MC3) - Cloudy

Meteorological Condition 3 (MC3) differs from previous MCs. This condition was also characterized by low thermal amplitude but with cloud presence in the afternoon over Palhoça/SC (Figure 9a). The analysis of the GFS/NCEP model (Figure 9b) indicates southeastern wind associated with maritime humid air incursion. In MC3, the temperatures do not rise due to the effects of a surface trough. The Brazilian Navy's synoptic chart (not shown) indicates an inverted through over Santa Catarina associated with a frontal system over the Atlantic Ocean. Winds of the south quadrant from both stations are observed, and global radiation from INMET's station shows low values associated with this pattern. Cloud presence configures a low thermal amplitude due to shortwave radiation incidence reduction. During MC3, the maximum temperature of the project's station (22,6ºC) is also close to the one from INMET's station (23,5ºC), indicating a 1,1ºC difference.

Figure 9 – As in Figure 8, for 04/06/2023



Date-Time (Local)	Wind Direction (degrees)		Temperature (°C)		Global Radiation (W/m²) from INMET A806 station
	Project Station	INMET A806	Project Station	INMET A806	
04/06/2023 15:00	95	157	22,6	23,5	394,2

Source: (a) INPE – (b) GFS/NCEP Model e Author (2023)

In summary, Table 4 compares the previously analyzed conditions.

Table 4 – Demonstration of the behavior of the analyzed meteorological conditions

OCCURRENCES TYPES	MC1	MC2	MC3
Occurrences Percentage	32,26%	41,94%	25,81%
Max. Temperature Difference	6,02°C	2,62°C	1,59°C
Max. Pressure Difference	2,48 hPa	2,29 hPa	1,40 hPa

Source: Author (2023)

4 FINAL REMARKS

The feasibility of integrating weather stations into the telemanagement infrastructure of public lighting was explored in this study, as demonstrated for Palhoça municipality. Although the data transmission system for functionalities such as weather stations is still under development in Brazil, the proposal presented in this work contributes to expanding this field.

Initial tests of the integrated weather station showed promising results, indicating the possibility of transmitting weather data effectively. However, the innovative nature of the solution requires continuous adjustments and improvements, given the constant technological evolution in this sector.

Analyses of the transmitted data revealed a correlation between the thermal variations recorded by the project's station and INMET's A806 station. Differences were observed in the measurement peaks, but the overall trends were similar, suggesting a reliable database. However, variations in data accuracy, especially concerning temperature, indicate the need to consider some factors, such as station location and mesoclimate conditions, when interpreting the results. In addition, as already mentioned, it should be borne in mind that the project's low-cost components may be less accurate than the INMET station's sensors.

The analysis of the meteorological patterns for three distinct conditions showed that, during the study period, days with slight temperature variations and no clouds predominated, followed by days of more significant thermal amplitude, also with clear skies. These analyses demonstrated how climatological factors impact the difference between station data, particularly for mesoclimate measurements in urban environments.

Finally, this study demonstrates that integrating weather stations with remote management systems for public lighting represents an opportunity for cities searching for smart and sustainable solutions. The ability to collect and manage environmental data from a network of stations spread across the city could improve the understanding of local weather patterns and support more efficient and responsive urban management.

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