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CONSTRUCTION OF A METEOROLOGICAL STATION FOR THE NEEDS OF SPORTS AVIATION

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Abstract

In this research, we are dedicated to the design and construction of our own meteorological station and its use in sports aviation. In the first part of the research, we deal with meteorological elements that occur in the atmosphere and their measurement by instruments. In the next part, we focus on the importance of observing and measuring weather in aviation and we point out situations that may arise due to adverse weather. Subsequently, we describe the devices that we use at our meteorological station. We mention the ranges in which they measure and the ways in which the devices work. Towards the end, we devote ourselves to the design of the prototype of our weather station and its construction and programming for proper functioning. Finally, we compare the measured results of our meteorological station and the meteorological station at the selected airport.

Keywords

meteorogical station, meteorogical senzors, programming

1. INTRODUCTION

Weather monitoring and forecasting is one of the most important activities in aviation. Its monitoring allows us to create an overview of the phenomena that occur in the given area. Especially at airports. Changes in the weather can lead to situations that can adversely affect the smooth running of air traffic at the airport. The information needed to create an overview of the current weather is obtained from professional weather stations located at airports. Weather reports in the form of METAR and TAF are further created from the measured values, which are used in flight planning or even during the flight to provide pilots with an overview of the weather in the given areas. These reports are generated at designated airports. Smaller airports located in the vicinity of designated airports use the METAR reports that were created for those airports.

Our goal is to create a prototype meteorological station using freely available sensors and devices. In the work, we will focus on the used sensors and devices, where we will discuss their characteristic features. We will discuss the ranges in which they provide the data, their connection to the Arduino microprocessor, and then their programming in the Arduino software.

During the acquisition of the necessary data, the station prototype will be located near the Žilina airport in the village of Kotešová for 14 days. With the use of sensors and their correct coding, we will be able to measure meteorological variables in the required formats. After the specified test period, we will subsequently compare and validate the obtained values in comparison with the values in the METAR reports issued at the given airport from the same period. By validating our values, we point out the overall accuracy of the devices and sensors used.

Finally, we will propose possible optimizations based on the information obtained during testing.

2. METEOROLOGICAL ELEMENTS AND HOW THEY FORM

2.1. Air pressure

The air around us has a certain weight and thus exerts a given pressure on everything it touches. The pressure it acts on is called atmospheric pressure or air pressure. Air pressure is the force exerted by the air from above on the surface due to gravity [1].

If the air reaches a high density, its weight also increases and, as a result, it exerts a greater force on the surface. It is also the fact that air pressure (mass by which air acts) decreases with increasing altitude, therefore the highest air pressure is observed at the earth's surface [1] [2].

Air pressure is one of the most important meteorological elements. Each of its changes causes a change in the atmosphere. Other meteorological elements such as temperature, solar radiation and wind are also associated with changes in air pressure. Changes in pressure occur constantly, so it is not possible to define a pressure standard for any area [2].

2.2. Wind

Winds are caused by different values of air pressure. The wind balances the pressure values by means of flow from high pressure to low pressure. Thanks to this, we observe cloudless and windless weather at the pressure level. On the other hand, in the pressure trough, we observe increased wind and accumulated clouds. In addition to equalizing pressure, wind generally moves energy, water, and the like in the atmosphere [2].

2.3. Sun radiation

In meteorology, an interesting part of solar radiation is electromagnetic radiation with wavelengths from 100 to 10,000 nm (nanometers).

- Ultraviolet radiation (UV) 100-400 nm
- Visible radiation (VIS) 400-700 nm
- Infrared radiation (IR) 700-1000 nm [3]

Solar radiation falling on the Earth warms the Earth's surface by absorbing the radiation and subsequently convection occurs. It is the conversion of solar radiation into heat, which causes the surrounding air to warm. Convection is the vertical upward movement of warm air. With its expansion, the warm air reaches a lower density than the surrounding colder air and begins to rise upwards, and the cooler air flows downwards and replaces its place, and the whole procedure is repeated. Such movement of warm air, gradually cooling through the atmosphere, creates clouds, which later contribute to precipitation [4].

2.4. Temperature

Air temperature or the overall temperature regime of the atmosphere is included among the meteorological elements, on the basis of which we are able to monitor temperature differences in a specific area or in the atmosphere as a whole. Using the average of the measured temperatures in a certain period and the amount of precipitation, we further determine the type of climate in the area. The device used to measure the temperature is a thermometer, located in the meteorological booth. We will discuss its exact location in the meteorological station later in the work [2].

2.5. Moisture/Precipitation

In the atmosphere, water occurs in all its states. The presence of water, humidity, in the atmosphere affects the weather to a very large extent. We observe water in the atmosphere in the form of clouds and precipitation that is produced from clouds (rain, frost, snow, fog, etc.) [2].

3. IMPORTANCE OF WEATHER FORECASTING IN AVIATION

Acquaintance with weather information is a basic duty of pilots before the flight, before departure and also during the flight. Adverse weather conditions can create situations where even experienced pilots have a problem with managing it during the flight. Safety always comes first, so it is very important to be familiar with weather information. In addition to the safety of the flight, great emphasis is also placed on the economy of the flight itself, which can also be adversely affected by the weather [6].

Aspects such as:

- Wind – Wind in general can cause major problems during flight. A headwind causes the aircraft to slow down in flight relative to the ground, but helps create a greater amount of lift during takeoff (a favorable aspect). In areas where there are mountains, it causes turbulence. Another adverse effect that the wind creates is crosswind. It causes difficulties especially when landing
- Precipitation – Heavy rain or other forms of precipitation affect the flight in ways such as aquaplaning, i.e. it lengthens the braking distance, the presence of clouds can reduce visibility
- Turbulence – Meteorological forecasts can indicate areas of turbulence so that pilots can safely avoid them
- Temperature – Low temperatures create dangerous situations at airports and airplanes (ice, frost, snow, etc.), but high temperatures also have an adverse effect (reduces the performance of airplanes).
- Visibility – Reduced visibility hinders the pilot's visual navigation. VFR flights are limited [6] [7].

3.1. Weather reports

On the ground, during planning, the briefing includes weather information, possible adverse conditions, current weather and conditions, in-flight weather, forecast and current weather at the destination, wind direction and speed at altitudes at which the flight will be carried out, airport forecasts (TAF) and meteorological reports (METAR) [6].

Efficiency and simplicity are some of the key factors that apply to aviation weather reporting. In aviation, we encounter weather reports mainly in the form of METARs and also TAFs. METAR is issued at designated airports of each country at an interval of 30 minutes. TAF is issued at airports with controlled air traffic at an interval of every 6 hours with a validity of 24 hours or 3 hours with a validity of 9 hours. The reports provide the flight crew with the most important information about the current weather at the airport and its surroundings [8] [9].

3.2. Impact of weather on air operations

We mentioned that weather changes or adverse weather conditions can create challenging situations for pilots. However, these conditions are equally demanding for employees who work at the airport, manage flight operations in the air or on the ground on airport areas, or even for the airport operators themselves [10].

3.2.1. Airport closure/diversion of flights

There may be a situation where very adverse weather conditions inevitably lead to the closure of the airport, as the safety of transportation would be greatly compromised. Flights are diverted to other airports and operations at a specific airport are suspended until the weather clears. Such situations also occur in our territory of Slovakia. For example, flight FR2366 from London Stansted Airport to Košice Airport on 13/11/2022 had to be diverted to Vienna Airport due to the fog created and accumulated at Košice Airport [10] [11].

3.2.2. Selection of take-off and landing runway

Wind speed and wind direction are the most important factors in deciding which take-off and landing runway will be used (if the airport has two or more such runways). It is also decided in which direction the planes will take off and land [10].

There is a wind that does not flow in the direction of the runways, but its direction is across the runways. We refer to such wind as cross wind or side wind. Airplanes can generally take off or land only when there is no or minimal crosswind. Usually up to 25 km/h. As soon as the crosswind reaches a higher value, the aircraft is forced to use another runway or divert to an alternate airport [10].

3.2.3. Wind shear

This is a sudden change in wind direction or wind speed. It usually occurs during thunderstorms. Wind shear can be in the horizontal direction, but also in the vertical direction, which can lead to considerable complications in controlling the aircraft during takeoff or landing [10].

4. METEOROLOGICAL INSTRUMENTS

4.1. Thermometer

A thermometer, as a meteorological instrument, is used to measure air temperature. It is placed in a meteorological booth approximately two meters from the earth's surface. A second thermometer is often placed at the meteorological station, which is placed closer to the earth's surface. The temperature at the earth's surface has a different value than the temperature two meters above the surface. A suitably placed thermometer near the earth's surface will make it possible to better measure these temperature deviations and thus create a temperature image in the measured area [12].

4.2. Hygrometer

A device for measuring air humidity gives us data such as the air humidity itself in percent and the dew point temperature. The measurement of air humidity is often combined with the measurement of temperature due to the recalculation of the dew point, where it is necessary to know the relative humidity and temperature of the surrounding air [13].

In our case, as mentioned, we equipped the weather station with a sensor that detects air temperature and air humidity. By merging the sensors into one, we gain an advantage in our favor. The basic code that the sensor uses allows us to directly calculate the dew point values by defining the calculation in the sensor code. This way we get the data we need exactly [14].

4.2.1. SHT31

The sensor for measuring temperature, which we used in the construction of the weather station, has the designation SHT31. It is made of polymer. The sensor itself has a digital output and allows customization according to the user's needs (we can adjust the changes when coding the sensor). In addition to measuring air temperature, the sensor also has a sensor for measuring air humidity [14].

The SHT31 sensor ranks among the highest quality and most accurate sensors available at an affordable price. Air humidity measurement measures in the full range from 0 to 100% with an accuracy of ±2% and in the range from 20% to 80% with an accuracy of 0.01%. Air temperature measurement measures in the range from -40 °C to 125 °C with an accuracy of ±0.3 °C at 25 °C [14].

4.3. Anemometer + wind direction

An anemometer is a meteorological instrument used to measure wind speed. This instrument is one of the most important instruments that every weather station must have. This device allows meteorologists to monitor the wind speed and its changes in real time. Changes in wind speed represent very important information at airports due to aircraft taking off and arriving [15] [16].

Wind direction is used to determine the direction of wind flow. A horizontal rod, with a vertical vane at one end and a balancing body at the other, is mounted on a freely rotating shaft that allows the compass to rotate against the direction of the wind [16].

4.3.1. WH-SP-WS01 and WH-SP-WD

For the needs of measuring wind speed, we have chosen a suitable device with the designation WH-SP-WS01, which enables such measurement. It is made of plastic. The principle of operation of the device is based on sensing the revolutions of the sensor using a magnetic reed contact. The device uses a specified constant for calculating the wind speed (1 pulse = 0.33 m/s) [17].

The instrument for determining the direction of the wind that we decided to use has the designation WH-SP-WD. Specifically, this type of device is capable of direct connection to the already mentioned anemometer, which enables simple communication between the devices. It also works on a mechanical principle. The sensor has 8 magnetic switches which are connected to a resistor of different value. The rotating part of the device can touch up to two switches at the same time, which enables the indication of up to 16 different positions [18].

4.4. Barometer

A barometer is an instrument used to measure air pressure. As mentioned, the air exerts a certain force on the earth's surface and on everything it touches. We call this force pressure.

Atmospheric pressure tells us what the weather is like in a given area. Atmospheric fluctuations, including changes in air pressure, have a direct effect on the current weather in the area. The device measures air pressure in bars/hectopascals [bar/hPa] or atmospheres [19].

4.4.1. BMP 180

In our meteorological station, we used the BMP 180 sensor for measuring air pressure. It is a digital barometer that, in addition to measuring air pressure, also provides measurements of air temperature. As we know, with increasing altitude, air pressure decreases. The sensor has this information written in the code, and the sensor thus recalculates the height of its location according to the air pressure. Thanks to this, it can be used as an altimeter for aircraft models. It can determine the calculated height with an accuracy of 17 cm to 50 cm according to the noise that arises between the communication of the airplane and the control device [20].

The range in which the sensor is able to measure air pressure values is from 300 hPa to 1,100 hPa, which actually represents 9,000 meters above sea level (300 hPa) and -500 meters converted from sea level (1,100 hPa) [20].

The sensor can measure the temperature in the range from -40 °C to 85 °C with a deviation of ±1 °C [20].

5. PROTOTYPE DESIGN OF OUR OWN METEOROLOGICAL STATION

5.1. Siting weather station

The correct location of the weather station is one of the most important things for the weather station to function properly and to provide the most accurate measurement results [21] [22].

5.1.1. Sunlight

Due to solar radiation, it is important to place the weather station in a place where there is no risk of shadow from surrounding obstacles (trees, buildings, etc.). It is also important to take into account the change of seasons, due to the change in the angle of incidence of solar radiation on the earth's surface, and thus the change in the lengths of the shadows of surrounding obstacles [21] [22].

5.1.2. Wind

An open space is also essential for the correct measurement of wind speed. A weather station that would be downwind of buildings or other obstacles will not provide relevant data on wind speed. To avoid adverse effects and deviations in measurements, it is recommended to place the weather station at a distance of 7-10 times the height of the highest obstacle in its vicinity [21] [22].

Example:

- Height of obstacle = 11 meters
- Station location = 77 – 110 meters

5.1.3. Temperature and humidity sensors

Sensors for measuring air temperature and humidity are largely influenced by the surface where they are located. Dark surfaces absorb more sunlight and emit more heat, which affects the accuracy of the measured values. Weather stations that are located over surfaces such as asphalt and gravel will measure significantly higher temperatures and lower air humidity values compared to weather stations located over grassy areas [21] [22].

Based on the above-mentioned information, it is important that the weather station is placed in the best possible conditions in order to prevent measurement errors [21] [22].

5.1.4. Standards

The installation of sensors at the weather station is also subject to established rules or certain standards, which must be followed in order to obtain the most adequate data [23] [24].

Sensor type	The height of the sensor	Sensor positioning
Air temperature Humidity	1,5 m ± 1 m (AASC) 1,25 m 2 m (WMO)	The sensors must be placed in a ventilated booth that will protect them from solar radiation. It is recommended that the sensors be placed at least 30 meters from concrete or asphalt surfaces.
Anemometer Wind direction	3 m ± 0,1 m (AASC) 2 m ± 0,1 m/10 m ± 0,5 m (AASC) 10 m (WMO)	The sensors must be at least 10 meters away from the highest obstacle

5.2. Designing and modeling and images from the design

For our prototype model, we need a device on which we will place individual sensors. We used a tripod whose height is approximately 200cm to meet the frame in which the sensors are to be placed. The device itself has a low weight and is foldable, which will allow it to be easily moved according to our needs during measurements. At the top, it has a shoulder on which an anemometer with a direction indicator can be attached, as well as an anti-radiation booth with sensors for measuring temperature, air humidity and air pressure.

The anti-radiation booth must be well ventilated for the accuracy of the readings and must above all protect the sensors from the heat radiated from the ground surface or obstacles. We modeled the anti-radiation booth in the Autodesk Inventor Professional program. We created the model of the anti-radiation booth so that it is easy to assemble. After modeling the booth in Inventor, we then printed it on a 3D printer [24].

5.3. Coding

The sensors we use need to be correctly coded in order to function. For coding, we used Arduino, which allows relatively easy coding of sensors using the libraries contained in its databases. Each sensor needs its own unique code, according to which it can perform its function. In the code, we can define what the given sensor should do, in what form we want the values to be displayed. With some sensors, we also add calculations from the values they measure to obtain the values we need.

6. TESTING OF THE METEOROLOGICAL STATION

Testing and subsequent validation of measured values from meteorological stations takes a long period of time. During this period, the data results of the tested meteorological station are compared with a station that has undergone this process in the past and is currently used as one of the main sources of weather data. The measurement accuracy of the devices, their deviations and also the reliability of the individual components are monitored in the specified time period. In our case, we tested the weather station over a short period of time, so the overall validation of our results is only informative. This means that the results measured by us cannot yet be used as the main sources of information, but only as possible supplementary information. The goal of testing is to achieve the highest possible accuracy of the values at our meteorological station in comparison with a professional meteorological station, according to which we compare the acquired results.

We decided to place our meteorological station for the given time period near the Žilina airport in the village of Kotešová. The location of the station was approximately 600 meters away from the extended axis of the runway. The aerial distance of the location of our station from Žilina airport was 1.7 km. We chose this location for our testing because METAR reports are issued at that airport. The regularity of these reports and their simple free availability allowed us to easily obtain correct information about the weather near the airport. METAR reports will serve us as data according to which we will evaluate deviations in the values measured by our meteorological station.

During the period when the weather station collected data, we accumulated METAR reports issued at a particular airport. We sorted the data according to the values needed for our comparisons.

For example:

- Wind direction [°]
- Wind speed [knots]
- Air temperature [°C]
- Air pressure at sea level [hPa]

7. DEVIATIONS OF MEASURED VALUES

In our results there were deviations of the values from the values of the METAR reports. Deviations can be observed for each measured element. We averaged the values we measured during the given interval and then rounded them to the nearest whole number. In order to better approximate the values of the individual deviations with which our devices measured, we created separate calculations. We calculated the differences in the given values for the entire test period and for all the elements we measured. We averaged the resulting differences in absolute values and thus calculated the average deviations for each measured element.

7.1. Wind direction

The average deviation measured by the wind direction indicator we used was 9.27 degrees. Due to the fact that the given instrument was able to measure wind direction angles from 16 different angles, and thus we point out the limited measurement range of the instrument, we can round the given deviation value to a value of 10 degrees. By using a more accurate instrument that would provide wind direction data in the entire angular range, such deviations could be avoided.

average value deviation	Wind direction
	9,27
average rounded value of deviation	10

7.2. 2Wind speed

The average deviation measured by the anemometer we used was 3.08 knots. The occurrence of the given deviation could be caused by the mechanical design of the device and its function of switching individual switches. In addition to the mechanical factor, the location of the weather station and the surrounding terrain also caused deviations. The anemometer we used was placed at a height of 2 meters, that is, at such a height the device provides data on the surface wind speed. The location of the anemometer of the professional station was according to WMO standards, which means its location at a height of 10 meters. Wind speed data at different altitudes will almost always vary due to the ruggedness of the terrain.

Average value deviation	Wind speed
	3,08
Average rounded value deviation	3

7.3. Temperature

The average value of the deviation measured by the SHT 31 sensor used by us was 0.23 degrees Celsius. According to the data measurement range specified by the manufacturer, the measurement accuracy range is up to 0.3 °C. During the testing period, we obtained values in decimal numbers and thus all air temperature data were rounded from these values. By real testing of this sensor, we proved that the stated measurement range data are real. We can eliminate the inaccuracy of the sensor based on the calculated deviation compared to the measurement deviation stated by the manufacturer. The resulting deviations could therefore be due to the use of insufficiently insulating material of the anti-radiation cover. By using a material with better characteristics, these deviations could be eliminated to a minimum.

Average value deviation	Temperature
	0,23

7.4. .Dew point temperature

The average value of the deviation in which our SHT 31 sensor provided dew point temperature data was 1.19 degrees Celsius. The accuracy of the measurement of the given value is not listed in any table, because we added this value to the sensor code based on the calculation from the obtained values provided by the sensor. The resulting deviations are therefore due to the inaccuracy of the data measured by the sensor. In the previous part concerning the air temperature, we used the obtained deviation to verify the accuracy of the sensor when measuring the air temperature. Based on this fact, we can claim that the cause of the deviations in this case may be the insufficient accuracy of the air humidity measurement. The manufacturer states that the accuracy of the air humidity measurement is up to 2%, but this value could be verified if the given sensor was compared with the air humidity values measured by the relevant meteorological station.

Average value deviation	Dew point temperature
	1,19

7.5. Air pressure at sea level

The average value of deviation in which our BMP 180 sensor provided air pressure data at sea level reached a value of 1.86 hPa. The manufacturer states that the measurement range of the BMP 180 sensor is up to 2 hPa. The values obtained by us were within the specified range when compared with the values from the METAR reports. As we have already mentioned, the value of air pressure at sea level is recalculated based on the input value of the altitude of the location of the meteorological station and the obtained value of air pressure in the given area. Since the data on the altitude of the location of the meteorological station is fixed and changed only in the event of a change in the location of the station, we can thus declare that the resulting deviations in values were caused by the sensor range of measuring air pressure values in the given area.

Priemerná hodnota odchýlky	Tlak vzduchu na hladine mora
	1,86

8. CONCLUSION

The goal of our work was to design, model, program and test our own meteorological station. During the design of the meteorological station, we selected individual sensors with an emphasis on their accuracy of measurements and on their range in which they can measure the given values. We designed parts such as the anti-radiation cover and the server box with a focus on their practicality of use. We also emphasized the requirements of proper ventilation and protection of the sensors of the anti-radiation cover. We chose to use a specific tripod, where the given components were attached, on the basis of its simple folding and carrying over longer distances.

The process of modeling the components of the anti-radiation cover and the server box took place in the Autodesk Inventor Professional program. We then printed the modeled components on a 3D printer.

We programmed the sensors using the Arduino software, where we programmed the individual components according to our needs. During programming, the sensors were connected to the PCB board, which allows easy connection and disconnection of sensors and devices. Such a connection makes it possible to easily add or remove the sensors that we want to be connected. By using a PCB board, we avoided the possible problematic removal of faulty sensor connections. By using it, we got easier handling of device pins. We then stored them in the assigned locations at the weather station and plugged them into the server box.

Testing of our meteorological station took place near the Žilina airport in Dolný Hričov in the village of Kotešová for 14 days. We compared the results measured by us with the METAR reports that were issued at the given airport. We obtained data for comparing measurements from freely available internet sources.

By comparing the results, we gained an overview of the accuracy of the data measurements of our weather station. The measured values related to wind direction, wind speed, air temperature, dew point temperature and air pressure at sea level. We compared our measured values with METAR report values. Later, we addressed the factors that could affect the accuracy of our measurements. For example, the inaccuracy of the sensors, the distance of the location from the airport, insufficient thermal insulation of the anti-radiation shield material and others. Subsequently, we paid attention to the resulting deviations of the measured values and calculated the average value of the deviations for each monitored element. In the case of deviations, we discussed their possible origins and by calculating the average values of deviations for individual elements, we verified the accuracy of the data provided by the sensors we used. By calculating the average values of our deviations, we verified and confirmed the accuracy ranges of the sensors given by the manufacturer.

Based on testing over a short period of time, our measured data can only be considered informative and cannot be considered an adequate source of weather information. All the data measured by us serve only to demonstrate the accuracy of the measurement and the reliability of the given components.

By building, testing and providing the results of our weather station measurements, we have created a weather station concept that has many options for expanding it with additional sensors for measurements.

We proposed a possible optimization of our weather station by mentioning additional devices, sensors and their functions. With the use of the given sensors, a simpler operation of the meteorological station could be achieved.

REFERENCES

[1] https://education.nationalgeographic.org/resource/atmospheric-pressure

[2] PROKOP, M., FÖRCHTGOTT, J., a kol.: *Meteorologie pro sportovní letce*. Praha: Naše vojsko, 2. vydanie, 1963. 268 s.

[3] https://www.shmu.sk/en/?page=2458#q1

[4] http://skhmet.ir/Library/meteorologytoday-pdf.pdf

[5] https://psl.noaa.gov/outreach/education/science/convection/Sky.html

[6] https://calaero.edu/importance-flight-weather-planning/

[7] https://www.dtn.com/the-importance-of-accurate-forecasting-for-aviation/

[8] https://www.shmu.sk/sk/?page=484

[9] https://www.shmu.sk/sk/?page=483

[10] https://www.airservicesaustralia.com/about-us/our-services/how-air-traffic-control-works/impact-of-weather/

[11] https://www.flightradar24.com/data/flights/fr2366

[12] https://education.nationalgeographic.org/resource/thermometer

[13] https://www.checkline.eu/cat/relative-humidity-meters

[14] https://wiki.seeedstudio.com/Grove-TempAndHumi_Sensor-SHT31/

[15] https://education.nationalgeographic.org/resource/anemometer

[16] https://windy.app/blog/wind-measurement-instruments.html

[17] https://www.laskakit.cz/wh-sp-ws01-cidlo-rychlosti-vetru-anemometr/

[18] https://www.laskakit.cz/wh-sp-wd-cidlo-smeru-vetru/

[19] https://education.nationalgeographic.org/resource/barometer

[20] https://lastminuteengineers.com/bmp180-arduino-tutorial/

[21] https://repository.arizona.edu/bitstream/handle/10150/147006/az1260-2010.pdf?sequence=1&isAllowed=y

[22] https://www.weather.gov/media/epz/mesonet/CWOP-Siting.pdf

[23] https://www.inmtn.com/docs/csi/b_weatherstation_IEI.pdf

[24] https://www.campbellsci.com/weather-station-siting