Investigating Altitudinal Variations in Indoor Temperature Using CubeSat Pressure Data

Skyler Wang, Yang He
Benjamin N. Cardozo High School, City College of New York of CUNY
Queensborough Community College of CUNY

Faculty Advisor: Paul Marchese
Physics Department
PMarchese@qcc.cuny.edu

ABSTRACT

Understanding indoor temperature variations with an altitude is crucial for optimizing HVAC (Heating, Ventilation, and Air Conditioning) systems and enhancing indoor climate control. This study uses a CubeSat equipped with an MPU6050 temperature sensor and an BMP280 barometric pressure sensor to investigate these variations in a multi-story building. The CubeSat records continuous pressure and temperature data at one-second intervals during vertical movement, recording5 minutes at each floor of the building. Using the recorded pressure data, the altitude in meters will be calculated with the barometric formula, then correlated with temperature readings.

INTRODUCTION

CubeSats, a type of nanosatellite, have revolutionized space missions by providing cost-effective platforms for scientific research and educational opportunities. These compact satellites, typically measuring 10x10x10 cm and weighing around 1.33 kg, are used in a variety of applications, ranging from Earth observation to deep space exploration. Their small size and modular design allow for rapid development and deployment, making them the ideal machinery for educational projects and smaller research missions that require flexibility and low costs.

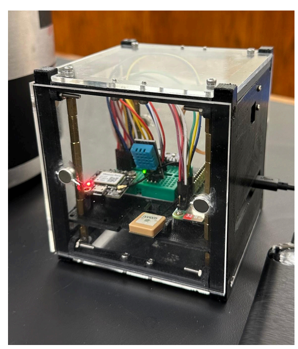
The CubeSat was equipped with a BMP280 barometric pressure sensor and an MPU6050 temperature sensor, both chosen for their accuracy and reliability in environmental monitoring. The BMP280 sensor, known for its precision in measuring atmospheric pressure, allows for the calculation of altitude using the barometric formula. The MPU6050 sensor provided continuous temperature data, essential for correlating temperature variations within changes of altitude.

The CubeSat was deployed inside the building and moves vertically from floor to floor, recording 5 minutes of data at each level. This approach provides a unique perspective on how temperature varies with altitude within a confined indoor environment, a factor that is critical for optimizing HVAC (Heating, Ventilation, and Air Conditioning) systems and enhancing indoor climate control. By correlating the calculated altitude data with temperature readings, this study aims to offer insights that could improve the efficiency of HVAC systems, leading to better energy management and increased indoor comfort.

METHODOLOGY

CubeSat Design

The CubeSat was custom-built and equipped with a BMP280 barometric pressure sensor and an MPU6050 temperature sensor. This setup allows for the precise measurement of both atmospheric pressure and temperature as the CubeSat moves vertically within the building.



(Figure 1a: Side-View of Fully Built CubeSat)

Deployment and Data Collection

The CubeSat is deployed inside a multistory building and moves vertically, spending 5 minutes on each floor to record pressure and temperature data at one-second intervals. The altitude in meters is calculated from the recorded pressure data using the barometric formula, and this altitude data is then correlated with the temperature readings.

Data Analysis

After the data collection phase, the recorded pressure values are processed using the barometric formula to calculate the corresponding altitude for each measurement. The temperature readings are then correlated with these altitude values to explore how temperature varies with height within the building. This analysis involves identifying any trends or anomalies in the data, which could be indicative of specific environmental factors or sensor performance issues.

Equations

To calculate the altitude from the recorded pressure data, the barometric formula is employed. The barometric formula relates atmospheric pressure to altitude and is given by:

$$h = \frac{T_0}{L}\left[1 - \left(\frac{P}{P_0}\right)^{\frac{R\times L}{g\times M}}\right] (1)$$

where:

h= altitude above sea level (meters)

T_0 = standard temperature at sea level (Kelvin)

L = standard temperature lapse rate (Kelvin per meter)

P = pressure at altitude (Pascals)

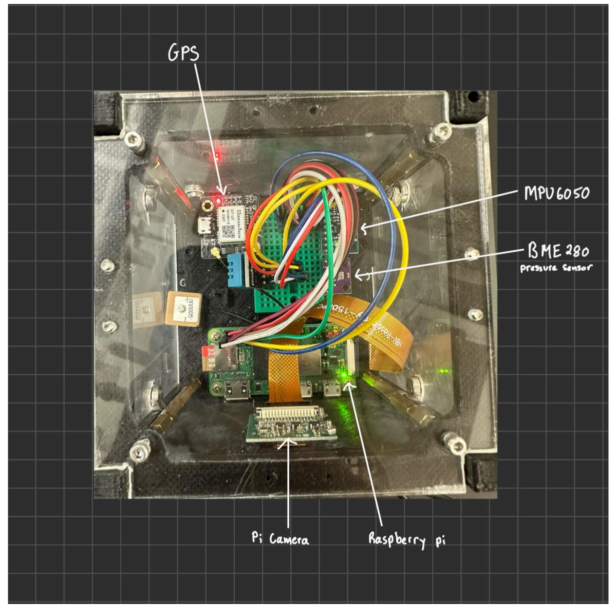
P_0 = standard atmospheric pressure at sea level (Pascals)

R = universal gas constant (8.31432 N·m / (mol·K))

g = acceleration due to gravity (9.80665 m/s²)

M = molar mass of Earth's air (0.0289644 kg/mol)

The BMP280 sensor provided the necessary pressure data (P), which then is used in the barometric formula to calculate the altitude for each recorded data point. The calculated altitude values are cross-referenced with the corresponding temperature data to identify patterns and relationships between altitude and temperature within the building.



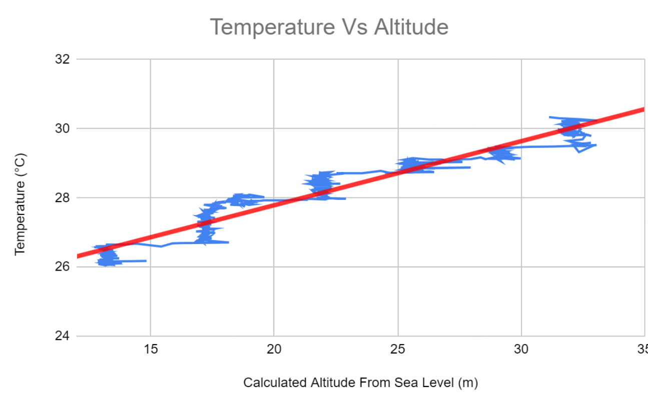
(Figure 1b: Top-Down View of Fully Built CubeSat)

DATA RESULTS

Table 1: Average Temperatures Across Different Floors

Floor	Average Temperature (°C)
Basement	26.26
Floor 1	27.58
Floor 2	27.31
Floor 3	25.68
Floor 4	28.66
Floor 5	29.39

(Figure 2: Average Temp On Different Floors)



(Figure 3: Temperature v. Altitude)

ANALYSIS

The data collected from the CubeSat revealed significant insights into the relationship between altitude and indoor temperature within the multistory building. The primary analysis of this study focuses on understanding how temperature varies as the CubeSat ascends through the building, with particular attention to any deviations from the expected patterns.

Positive Correlation Between Altitude and Temperature

The analysis revealed a generally positive correlation between altitude and temperature, with temperatures increasing as the CubeSat moved to higher floors. This trend aligns with the basic principle that heat rises, suggesting that upper floors tend to be warmer due to the accumulation of heat. The following key observations were made:

Basement to First Floor: A noticeable increase in temperature was observed as the CubeSat moved from the basement (26.26°C) to the first floor (27.58°C). This is consistent with the expectation that the basement, being underground, would be cooler due to limited exposure to external heat sources.

Upper Floors: As the CubeSat continued to ascend, the temperature further increased, reaching 29.39°C on the fifth floor. This steady rise in temperature suggests that the building's HVAC system may not be evenly distributing heat, leading to warmer conditions at higher altitudes.

Anomalies in Temperature Data

However, the analysis also identified an anomaly between the second and third floors, where the average temperature decreased from 27.31°C to 25.68°C, before rising again on the fourth and fifth floors. This deviation from the expected trend could be attributed to several factors:

Sensor Performance: The slight decrease in temperature could be due to sensor inaccuracies or potential overload from continuous data collection. The BMP280 and MPU6050 sensors, while generally reliable, may have experienced fluctuations in readings due to rapid environmental changes or interference.

Environmental Factors: The decrease in temperature could also be a result of localized cooling effects on the third floor, such as increased ventilation, proximity to cooling systems, or structural features that enhance heat dissipation. Further investigation into the building's design and HVAC configuration on this floor may be necessary to fully understand this anomaly.

Impact of HVAC System Design

The variations in temperature observed across different floors suggest that the building's HVAC system may not be optimally configured to maintain consistent temperatures throughout the building. The positive correlation between altitude and temperature, along with the identified anomalies, highlights potential inefficiencies in the system's heat distribution. Specifically:

Heat Accumulation: The increasing temperatures on higher floors may indicate that the HVAC system is struggling to effectively manage heat, leading to a buildup on the upper levels. This could result from inadequate ventilation, insufficient cooling capacity, or poor insulation.

CONCLUSION

This study successfully demonstrated the use of a custom-built CubeSat to investigate indoor temperature variations with respect to altitude within a multistory building. The key findings of the study include:

Positive Correlation Between Altitude and Temperature: The data showed a general increase in temperature as the CubeSat moved to higher floors, confirming the expectation that heat tends to rise within indoor environments.

Anomalous Temperature Drop: An unexpected decrease in temperature was observed between the second and third floors, suggesting potential localized factors or sensor-related issues that warrant further investigation.

Implications for HVAC Systems: The study highlighted possible inefficiencies in the building's HVAC system, particularly in its ability to evenly distribute heat across all floors. The positive correlation between altitude and temperature, coupled with the identified anomalies, indicates areas where HVAC operations could be optimized.

DISCUSSION

Optimizing HVAC System Performance:

Heat Distribution: The consistent increase in temperature with altitude suggests that the building’s HVAC system may be allowing heat to accumulate on higher floors, potentially due to inadequate ventilation or cooling capacity. Adjustments to the HVAC system, such as improving airflow or increasing cooling on upper floors, could help achieve a more balanced temperature distribution.

Energy Efficiency: By addressing the inefficiencies identified in this study, the building's HVAC system could operate more efficiently, reducing energy consumption and lowering operational costs. Implementing targeted improvements based on these findings could lead to significant energy savings, particularly in large, multistory buildings.

In conclusion, this research demonstrates the potential of CubeSat technology to provide valuable insights into indoor temperature variations with altitude. By identifying key trends and anomalies in temperature distribution, the study offers practical recommendations for optimizing HVAC system performance and improving energy efficiency. The findings of this research contribute to a growing body of knowledge on indoor climate control and highlight the innovative use of CubeSats in addressing everyday challenges in building management.

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