Will I fry my datalogger mounted outdoors?

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Author's note: I performed this study while working as an intern for Digital Sensing and Control. I was mentored by Harry Davitian, PhD, CEO of DSC. The concept for the study was given to me by my mentor and he provided guidance regarding the content and style of a technical report. We worked together on defining the scope of the study and how the results should be presented. I performed the computational analyses.

Summary

The purpose of this study is to understand the likelihood of a datalogger ("field node" or "node") having its electronics fail due to extreme heat. Specifically, this report focuses on the maximum temperatures likely to be experienced inside the node. We collected over one year of data from a working node mounted in the field. We examined the effects of various environmental conditions on the difference between the ambient temperature and the internal temperature of the node ("Temperature Differential" or "TD"): ambient temperature, ambient humidity, and exposure to sunlight. Sunlight radiation had a strong effect on TD. The highest TD observed was just shy of 21°F, indicating that the internal temperature of the nodes could reach 140°F if the ambient temperature rose above 120°F, the maximum ambient temperature expected to be experienced in a real-world setting. In general, electronics can tolerate temperatures up to 158 °F: it is unlikely that the nodes will fail due to their exposure to high temperatures.

Purpose

Cormit is a cloud-based sensing and control system developed by Digital Sensing and Control LLC. Cormit's dataloggers ("field nodes") are typically deployed outdoors and often experience high summer ambient temperatures simultaneously with exposure to direct sunshine. Under these conditions, internal temperatures will rise to high levels. Modern electronic equipment is designed to withstand high temperatures but, at some point, the equipment will be damaged.

Multiple factors affect the internal temperature of the node: ambient temperature, exposure to direct sunlight, and internal heat generated by the electronics. The prime purpose of this study was to understand the potential for a field node to become overheated to the point of failure when exposed to extreme conditions that might be experienced in an outdoor setting. However, the study went beyond that narrow purpose: it also differentiated the effects of ambient temperature and direct sunlight on the internal temperature.

Study method

Equipment and software tools

Cormit

Cormit is an integrated hardware-software system. Its field nodes collect data from a variety of sensors and communicate the data to the cloud. Cormit's computational engine (hosted on AWS) is composed of a database containing the data from the field nodes and a computational engine which organizes and analyzes the data for presentation in a variety of graphs and tables on a browser-based dashboard. While key features of Cormit are associated with water flow, water depth, and well/aquifer performance, the node also connects to environmental sensors: LUX (sunlight intensity), ambient temperature and humidity, etc.

Field node

This study is based on data from one node which has been reported data from July 1, 2023 until August of 2024.

Tableau

Data collected by the field node has been analyzed using Tableau, a data visualization program. Tableau makes data visualizations easy which otherwise would be time-consuming given the voluminous measurements Cormit collects.

DATA PURGING

Infrequently, a glitch in a sensor or communication with the cloud results in spurious data being recorded to the Cormit database. Such spurious data compromises the computation of metrics and the presentation of results.

Two forms of spurious data were identified and removed as follows:

- A review of the data showed that no valid data points had TDs greater than 21°F.
- The same review revealed that no data points with temperature differentials below 0 F were valid.

ANALYTICAL APPROACH

This study examines the effect of certain variables on the internal temperature of a Cormit field node and the level that internal temperature will reach under adverse conditions. In this study, we focused on TD instead of internal temperature. By studying the temperature difference rather than the temperature, we disassociate our results from the particular conditions at the location where this test node was deployed. In other words, we developed a general result that could be applied to any location.

High internal temperatures are much more likely to occur when sunlight shines directly on the node. It is important to note that the node used for this study is partially shaded towards the afternoon and is often under cloud cover, and so high temperatures experienced by this node would be less extreme than in a node located where it received constant sunlight and was oriented such that its largest side was approximately perpendicular to incoming sunlight at mid-day. We partially accounted for this by filtering the data to create a sub-set that only included data points when sunlight was shining on the node: "Sunlight Hours TD."

In the graphs in the results section, the vertical axis shows the TD in °F. The horizontal axis shows time in months. Note that the data set used for this analysis begins August 1, 2023 and ends August 1, 2024. That is, January was not the first month of recording.

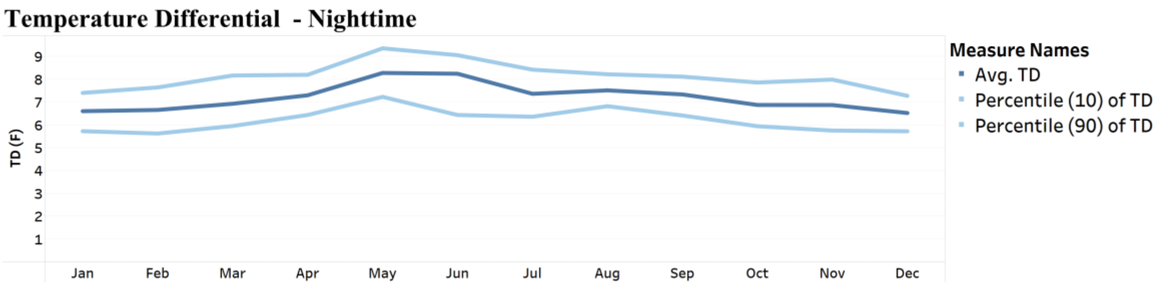
For the purposes of this study, the following definitions were applied for filtered data sets:

- Nighttime Hours: Midnight – 4 AM.
- Daytime Hours: Any hour not defined as Nighttime Hour above.
- Sunlight Hours: hours for which LUX reading > 10,000,000
- Cloudy Hours: Daytime Hours for which LUX reading < 10,000,000

Results

Nighttime TD

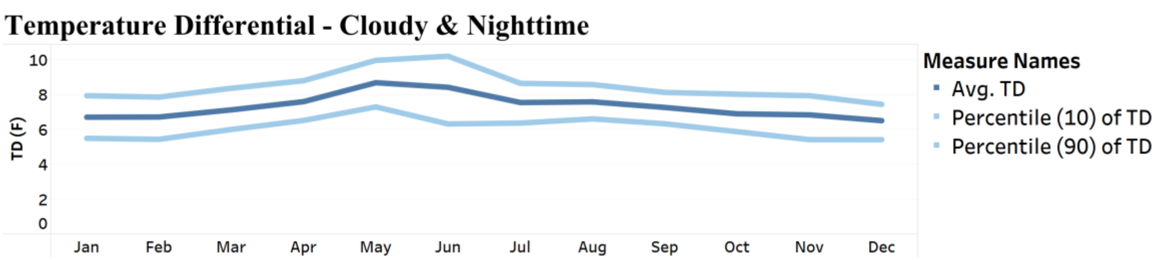
To understand how the internal heat generated by the electronics in the node, acting alone, affects the internal temperature, we need to eliminate the impact of sunlight on the node. Sunlight cannot affect the node in the middle of the night, so we created a data sub-set consisting only of nighttime hours. Specifically, this dataset included readings only for the hours from midnight to 4am. Most or all residual effects of sunlight should be well gone by midnight.



The average TD at night ranges from 6.5°F in the winter to 8.25°F in the summer. In the winter months the standard deviation is less than 0.75°F; in general, the summer months have higher deviations from the average than winter months. The standard deviation is anomalously high in June, likely due to a data error.

Cloudy & Nighttime TD

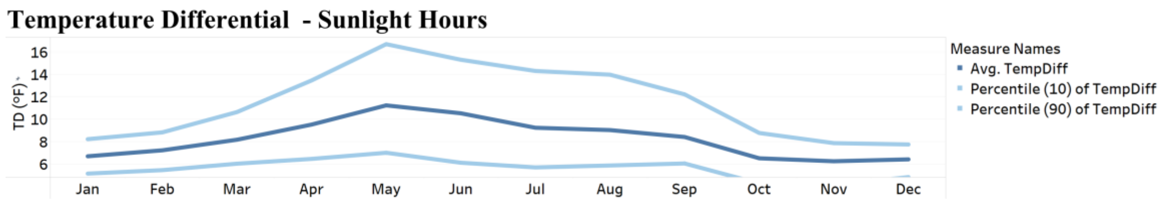
An alternative to looking solely at the nighttime TDs is to include any data point when the sun is not shining directly on the node. This dataset will include not only nighttime values, but also times when the node is shaded or when the sky is cloudy.



With this filter, TDs are overall higher than those in the middle of the night, but not significantly. Average TDs range from 6.5°F in the winter to 8.5°F in the summer, which is similar to the results seen in the Nighttime Hours, but the standard deviation in the Cloudy and Nighttime Hours is much higher than in just the Nighttime Hours.

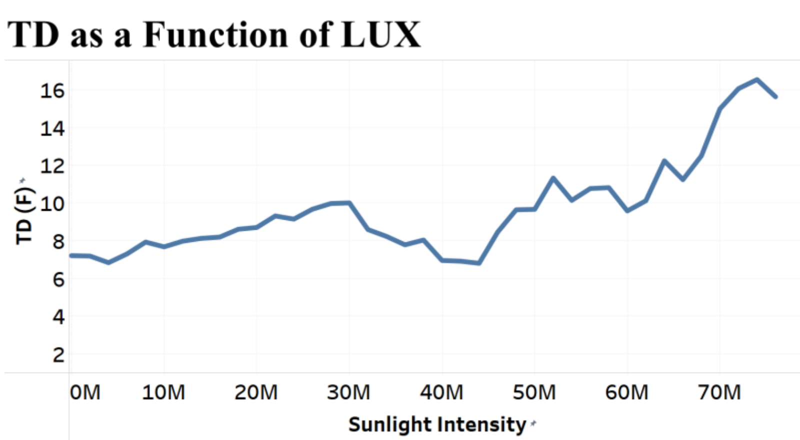
Sunlight Hours TD

To investigate the effect sunlight has on TD, we compared TD during Sunlight Hours to TD during Nighttime Hours or Cloudy Hours. The data shows higher TDs during Sunlight Hours. In general, differences in TD between the Sunlight Hours and the Nighttime Hours are much more pronounced in the summer than in the winter. Specifically, Sunlight Hours TDs range from 6.75°F in the winter months to 12.25°F in the summer. The lowest Sunlight Hours TD – 6°F – is in November, which is the only month which has a Sunlight Hours TD lower than its Nighttime TD. (See further discussion in section *Effect of Sunlight* below).



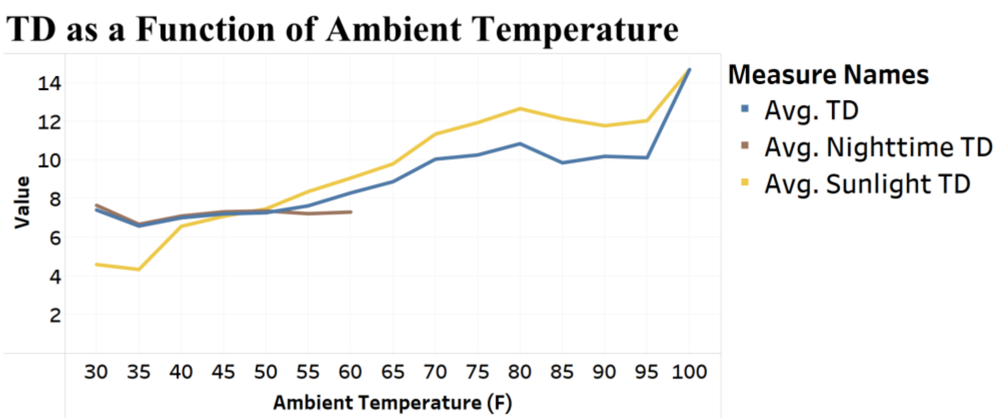
Effect of Sunlight

This section explores the effect of radiation, specifically sunlight, directly striking the node's exterior. To do this, we needed to isolate the causative effects of sunlight. To eliminate the correlative effect between sunlight and ambient temperature, we filtered data points to those with an ambient temperature reading between 60 and 70°F, a relatively narrow range of ambient temperature. However, the results were not significantly different from looking at the data as a whole. In the graph below, TD is plotted as a function of the intensity of sunlight (measured with the LUX sensor). As LUX levels increase, TD increases. At low LUX levels, the TD is around 8°F. At high LUX levels, the TD reaches 16°F. This clearly demonstrates the effect of sunlight radiation on the internal temperature of the node.



Effect of Ambient Temperature on TD (all hours—*i.e., no filter)*

The chart below shows the effect of ambient temperature on TD. The blue line includes all hours and shows an increase in TD as a function of ambient temperature. During Daytime Hours, shown on the yellow line, this same effect is seen, but it is less pronounced. When filtering for nighttime hours (on the brown line), there is no effect: an increase in ambient temperature corresponds to neither an increase nor decrease in TD.



We have previously noted that Sunlight Hours generally have a higher TD than Nighttime or Cloudy Hours. In both the blue and green lines, higher ambient temperatures correspond to Sunlight Hours, which is why an increase in ambient temperature coincides with a rise in TD. For the Nighttime Hours line, the effect of sunlight radiation on the node is eliminated. Therefore, the same positive correlation is not relevant, and a negative correlation appears; the TD drops as ambient temperature increases. We believe this effect is due to an increase in thermal radiation emanating from the node (which has a cooling effect on the node) at higher temperatures because thermal radiation is proportional to the fourth power of temperature.

As a note, the spike in temperature differentials above 100°F is probably due to low sample size: the ambient temperature only ever broke 100°F for 3.3 hours during the entire year.

Conclusions

The key findings of this study are:

- Effect of Sunlight on TD.
    - Sunlight Hour TDs generally average around 9°F, but they have a wide range. Nighttime Hour TDs, on the other hand, commonly average around 7°F, and have a much tighter range of TDs. Sunlight Hours can encompass a wider range of conditions – Sunlight Hours encompass both morning hours, when ambient temperature is rising, and evening hours, when temperature is falling – this can be compared to Nighttime Hours, which only include the period from midnight through 4 am, and when ambient temperatures vary less.
    - TDs in the sunnier summer months are significantly higher than TDs in winter months. This difference is most pronounced in the Sunlight Hours TD averages. The spread (standard deviation) of TD averages during the summer months is higher than the spread in the winter months. This is related to the effect described in the previous bullet point: summer Sunlight Hour TDs generally include a wider range of conditions when compared to winter Sunlight Hour TDs.
    - To explain why TD increases with LUX level, we note that in equilibrium (i.e the internal temperature is not changing) the total radiation hitting the node and emanating from the node are equal. During Sunlight Hours, radiation from the sun (at a very high effective "surface" temperature) adds to the natural heat radiation from the local

environment. Therefore, in order to balance radiation levels during Sunlight Hours, TD must be higher.

- Effect of Ambient Temperature on TD.
  - In general, an increase in ambient temperature correlates with an increase in TD because ambient temperatures are associated with Sunlight Hours.
  - During Nighttime Hours, an increase in ambient temperature corresponds to a slight decrease in TD. We note that heat radiation from a surface varies as the fourth power of the surface temperature. Therefore, this TD decrease may be due to a disproportionate increase in the thermal energy radiated away from the node to its surroundings as the ambient temperature increases (there is more thermal energy emanating from the surface of the node than radiation impinging on the surface from the surroundings).

Some of these findings are represented in the graph below. The graph shows the effect of various measured parameters on TD. For this purpose, we binned the TD values for each explanatory variable as follows:

- For ambient temperature, the bin size was 10°F.
- For humidity, the bin size was 10% relative humidity.
- For LUX, the bin size was 5M.
- For hour of day, each hour was binned separately.

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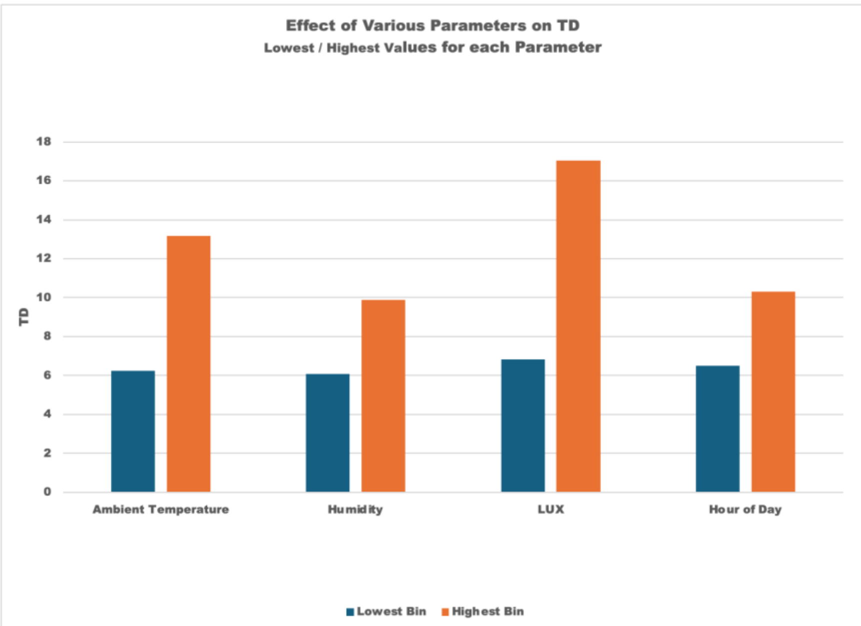

- Maximum internal temperature
  - Most important to this study is the maximum internal temperature that might be experienced. In most of the United States, ambient temperatures never rise above 125 °F. In the data studied, the TD never exceeded 21°F. If the TD were to reach that level under the highest ambient temperatures likely to be experienced, the internal temperature would be 146 °F. However, at high ambient temperatures over 120°F, the results of

this study show that TDs would not reach 21°F. A more realistic maximum internal temperature would slightly exceed 140°F. In general, electronics can tolerate temperatures up to 158°F: it is unlikely that the nodes will fail due to their exposure to high temperatures.