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AGRICULTURE SENSOR

APPLICATION NOTE FOR AMBIENT LIGHT SENSOR

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1 Introduction

Light plays a vital role in agriculture, especially in regions with limited light and water resources. Different crops need different amount of sunlight exposure and water for photosynthesis. It is therefore important to understand what the expected light readings are for different light and environmental conditions to make informed decisions.

The KIWI and CLOVER sensors are variants of the Kona Agriculture Sensor and are LoRaWAN IoT(Internet of Thing) Sensors intended for Agricultural uses. They are powered by a C-cell LTC battery and utilize a small IP67 casing. Both variants feature operating temperature of -40°C to 85°C, an ambient temperature and relative humidity transducer, a microcontroller temperature transducer, an ambient light sensor (henceforth referred to as ALS), and an accelerometer. For the purpose of this document, both variants will be collectively referred to as the Agricultural Sensor henceforth.

Product Code	Description
T0005982	Module, Agriculture Sensor, Clover, LoRa, All Regions
T0005986	Module, Agriculture Sensor, Kiwi, LoRa, All Regions

Table 1: Agricultural Sensor Variants

The purpose of this document is to describe the natural light sources the ALS is designed to capture, and describe the different light conditions and the typical light intensity readings of these conditions. The ALS is an integrated light transducer used by the Agricultural Sensor to measure illuminance in units of Lux. Illuminance is defined as total luminous flux incident on a surface, per unit area [1].

$$1\ lux = 1\ cd * sr/m^2$$

where cd is luminous flux in candela, sr (steradian) is the unit solid angle, and m^2 is the area of the surface.

2 Illuminance Measurement

The Agriculture Sensor is intended to be used in both indoor and outdoor applications. When used in indoor applications such as in greenhouses or indoor gardens, the illuminance readings from different ALS have higher consistencies and lower variance between them because they are taken in controlled lighting environments. Section 3 present examples of illuminance readings taken in varying indoor light conditions and environments.

When used in outdoor applications such as in direct sunlight, the illuminance readings may have lower consistencies and higher variance compared to indoor measurements as seen in the example in Section 4. This is because readings taken outdoor can be influenced by several biological and environmental factors [2]. This implies that even when outdoor light conditions may seem consistent or stable to the naked eye, the illuminance reading may vary from one Agricultural sensor to another during the daytime.

The preferred method of visualizing the reported illuminance is by plotting the readings on a logarithm scale (order of magnitude) to reflect the varying conditions. Although the lux values may vary from one device to another for reasons this document will expand on in subsequent sections, illuminance measurements taken by different agricultural sensors in the same lighting and environmental conditions and at the same time will always fall within the same logarithm range, as we will see in the examples in subsequent sections.

The following lists some of the factors that may influence the illuminance levels measured by the Ambient light sensor.

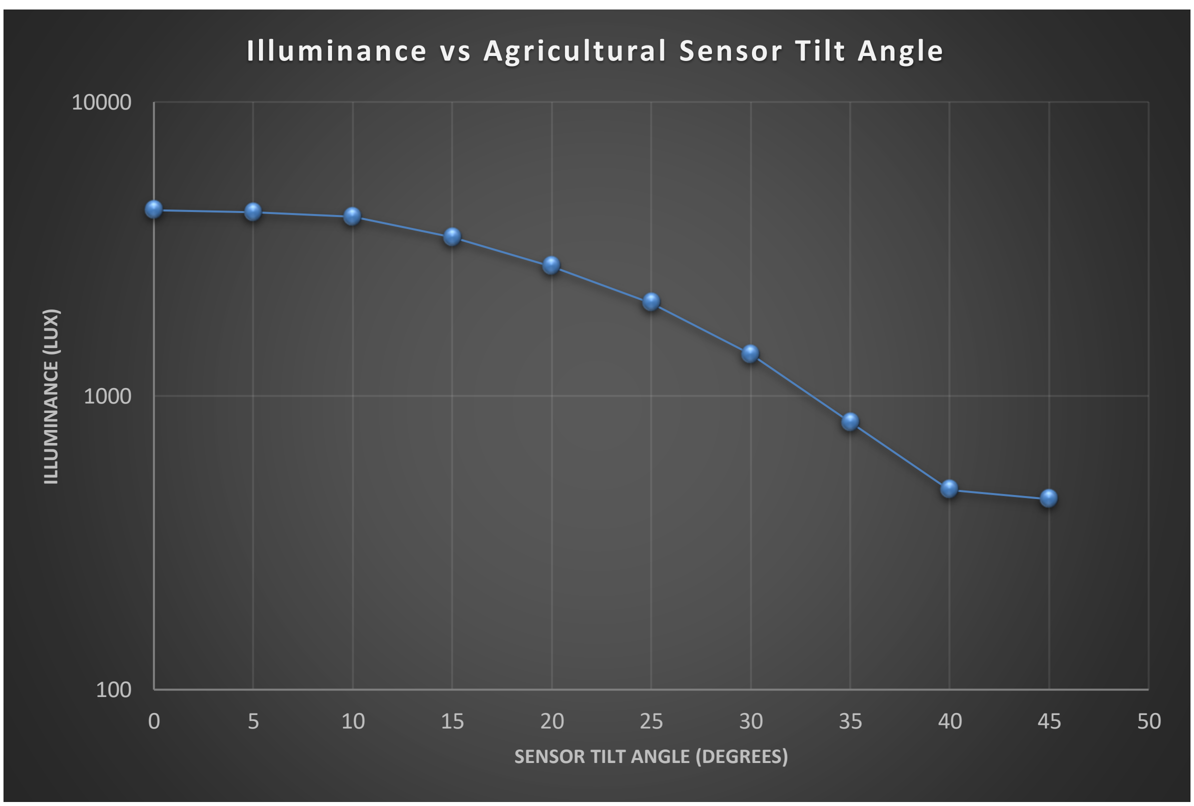
1. Variation in Sensor's Orientation or incident angle of light

   The level of illuminance reported by the Agricultural sensor is dependent on the amount of ambient light captured by the ALS. The amount of light reaching the ALS is in turn dependent on the incident angle of the light. It is therefore important to install the agriculture sensor at an angle of 0^o to the light source to ensure the ALS is capturing as much ambient light as possible.

   For example, the plot in Figure 2 below shows the effect of tilting the agricultural sensor from 0^o to 45^o on the illuminance measured by an agricultural sensor. The test conditions were kept constant for all tilt angles. The illuminance level reported by the agriculture sensor reduced by order of 1 magnitude from the 0^o orientation to the 45^o orientation with respect to the incoming light beam.

Figure 1: Test Setup – Left picture: Sensor at 0°, Right Picture: Sensor at 45°

Figure 2: Effect of Incident Angle on Illuminance Level



A second test was conducted to investigate the effect of rotating the test setup horizontally while keeping the vertical tilt at 0°. A second agricultural sensor was added to the test set up described above and the illuminance levels reported by both test devices were recorded at rotation angles 0°, 90°, 180°, and 270°.

The test conditions were kept constant at all rotation angles. Ten measurements were taken per test unit (one measurement per minute) and the average illuminance level per rotation is tabulated in Table 2 below. These averages are plotted in Figure 3 below.

Table 2: Average Illuminance Reported per Rotation Angle

Rotation Angle(°)	Average Illuminance for Test unit T0028 (lux)	Average Illuminance for Test unit T0033 (lux)
0	1804	1931
90	1745	2173
180	1865	2054
270	1757	2217

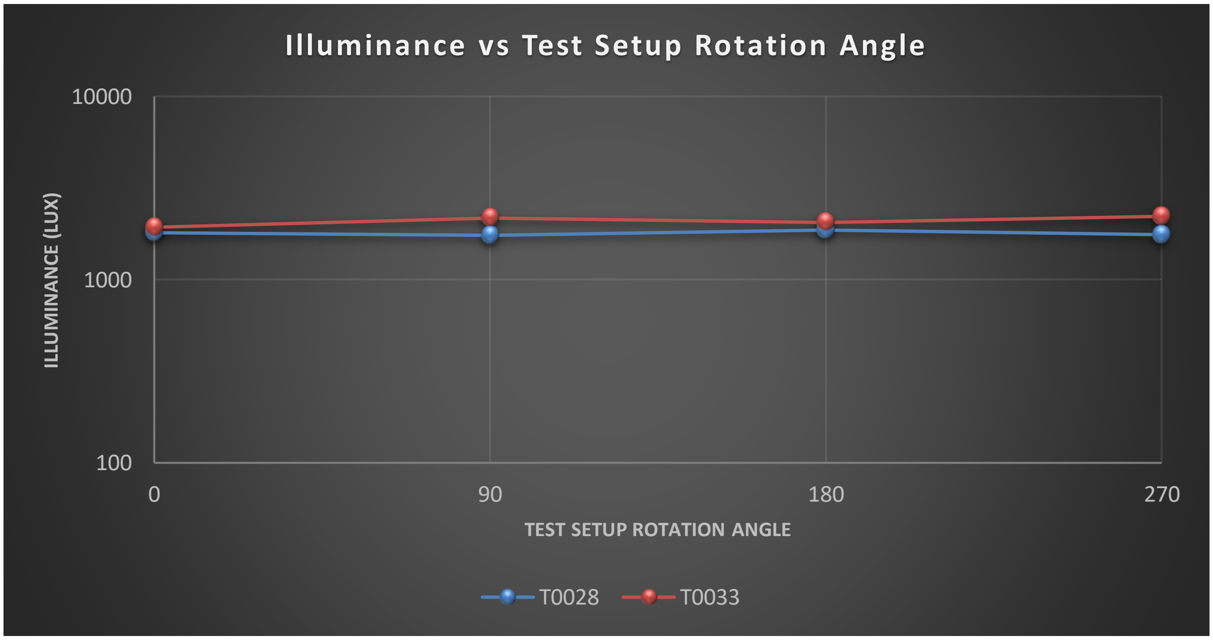


Figure 3: Effect of Rotating the Test Setup around the x-axis on Illuminance level.

Comparing the results from the test sensors at opposite rotation angles (0 and 180, 90 and 270), there are small variations in the reported illuminance levels that are due to the component-to-component differences but when viewed on a logarithmic scale as seen in Figure 3, these variations become less significant.

2. Shadows cast on the Sensor.

   When a shadow is cast over the Agricultural Sensor, the reported illuminance is that of the shadowed area and not the light source such as sunlight or grow light. Shadows can be cast by neighboring trees or plants, animals, buildings, or even humans. Ideally, the Agricultural sensor should therefore be installed in a spot free of shadows.

   To show the effect of shadows on illuminance readings form the ALS, illuminance readings from two Agricultural Sensors were recorded over a period of about 7 hours, with one of the sensors placed under in a tree shade and the other in an open and shadow-free location. During the peak sunlight hours for this day, the shaded sensor reported ambient illuminance about 1 order of magnitude less than that of the unshaded sensor, thereby misrepresenting what the actual ambient illuminance is for the day.

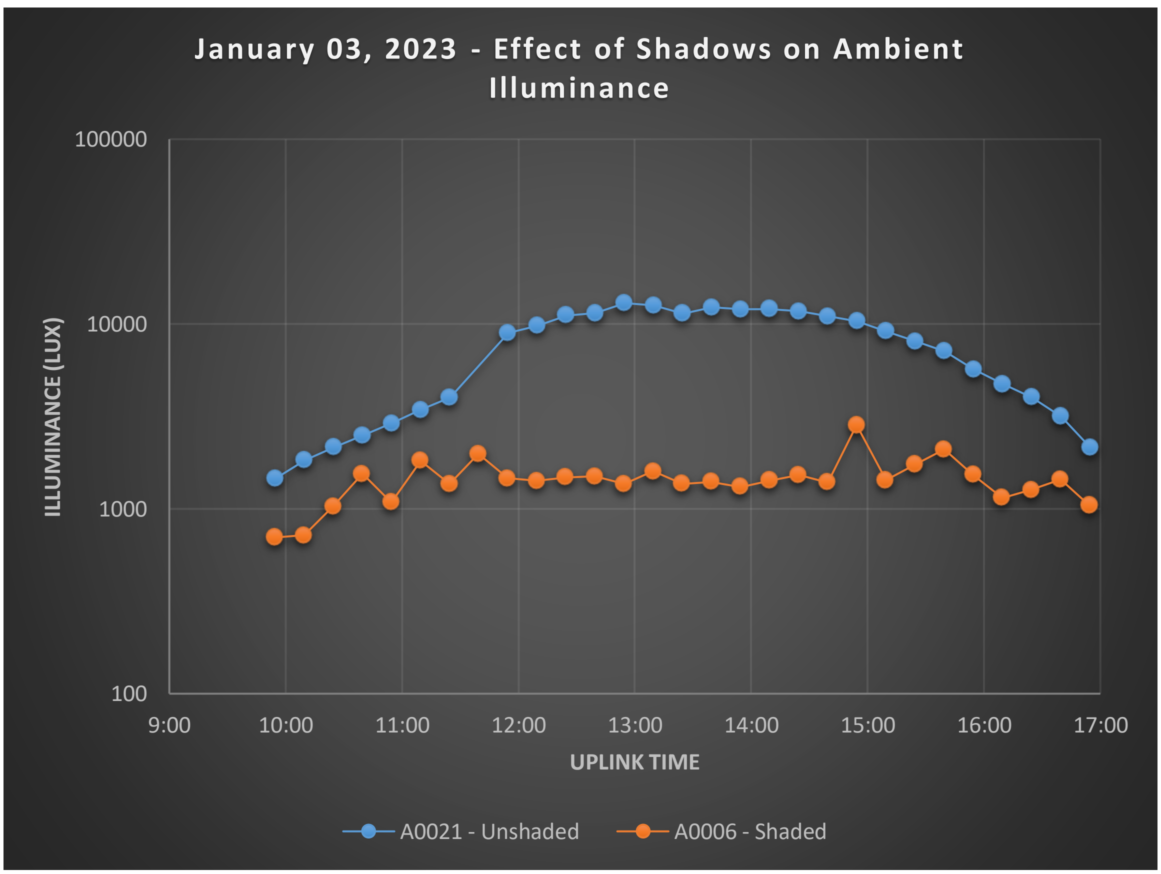


Figure 4: Effect of Shadows cast on the Illuminance Measurement

3 Indoor Lighting Conditions

The following table lists some common indoor light conditions and their typical illuminance levels.

Table 3: Common Indoor Light Conditions and their typical illuminance levels, adapted from [3] and [4]

Indoor Environments	Illuminance (lux)
Living Room	30
Dining Room	200
Kitchen	100
Bathroom	300
Bedroom	50
Hallway	30
Workshop/Laboratory	1000
Office Space	150 – 500

3.1 Indoor Light Sensing Examples

Multiple agricultural sensors were set up to collect illuminance measurements in different indoor locations and under different light conditions and intensity levels. It can be observed on the plots that although the illuminance readings vary slightly between the test units for each test case, the measured illuminance level all fall within the same illuminance logarithm range. This indicates that the sensors are in the same lighting condition and light intensity for each test case.

Note: The lighting conditions in these indoor examples are controlled i.e., there is minimal variation in ambient illuminance over time for any lighting condition (e.g., per office space location). Synchronization in the reporting period of the test devices is therefore not an important factor in showing the device-to-device variations in these indoor examples.

The plots below show the sensor-to-sensor variations in the illuminance readings in the following indoor light environments.

- Ten (10) measurements per test device in one open office location.
- One (1) measurement per test device in ten (10) different office locations.
- Grow light[1] with six (6) different light intensity settings.

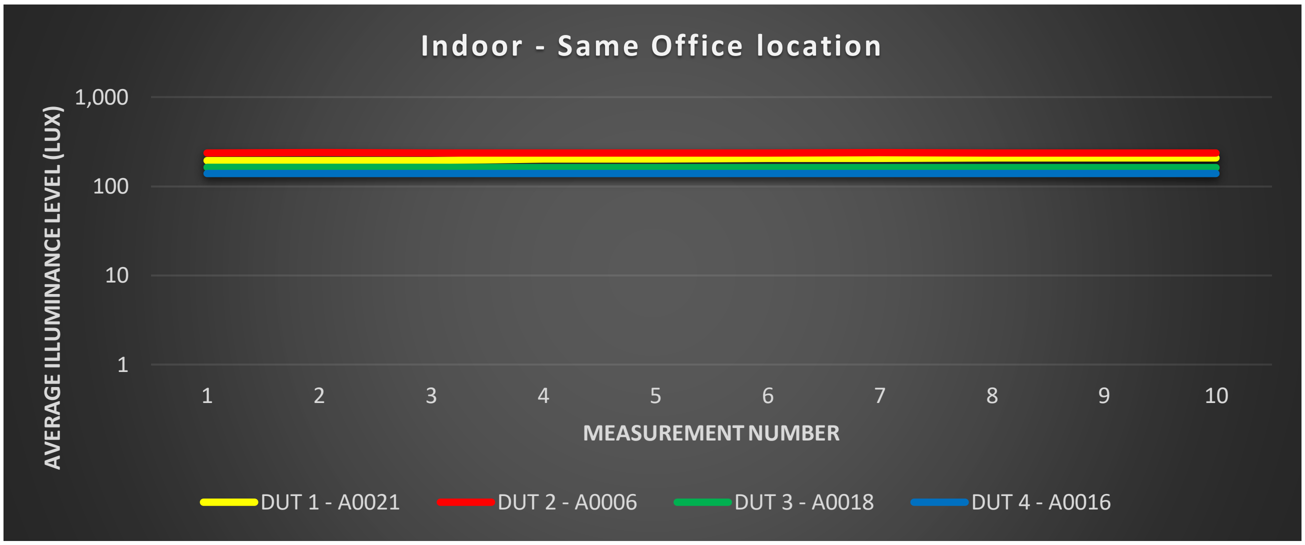


Figure 5: Ten (10) measurements per test device in one open office location

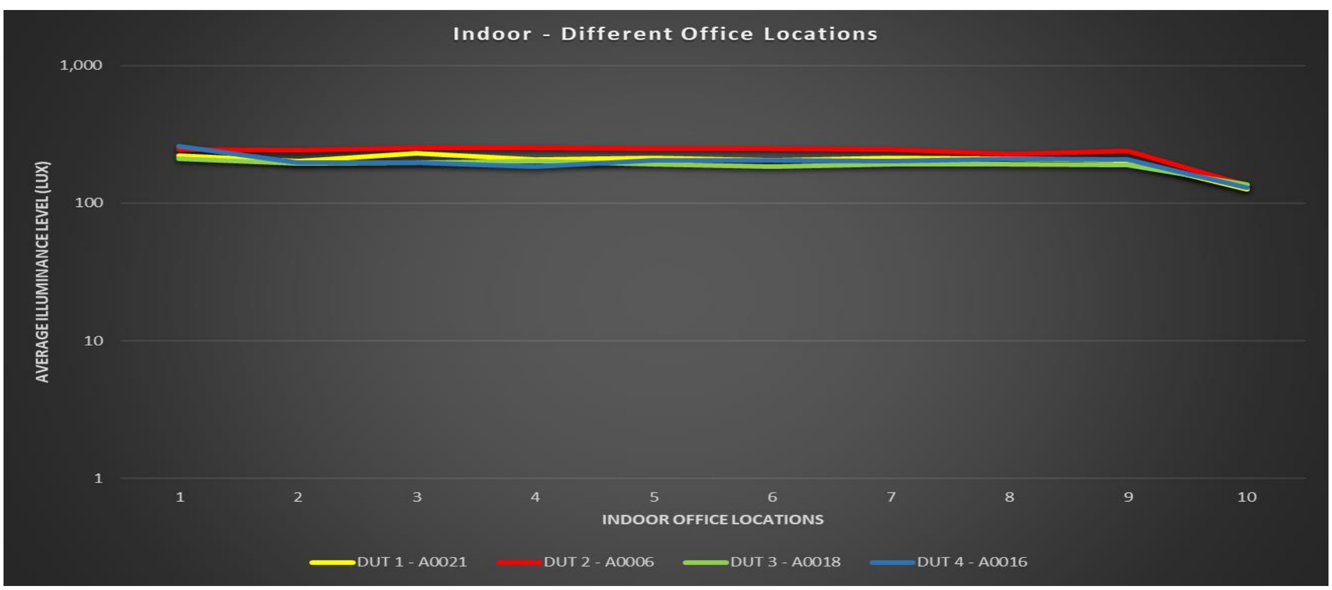


Figure 6: One (1) measurement per test device in ten (10) different open office locations.

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[1] More information on the grow light used here

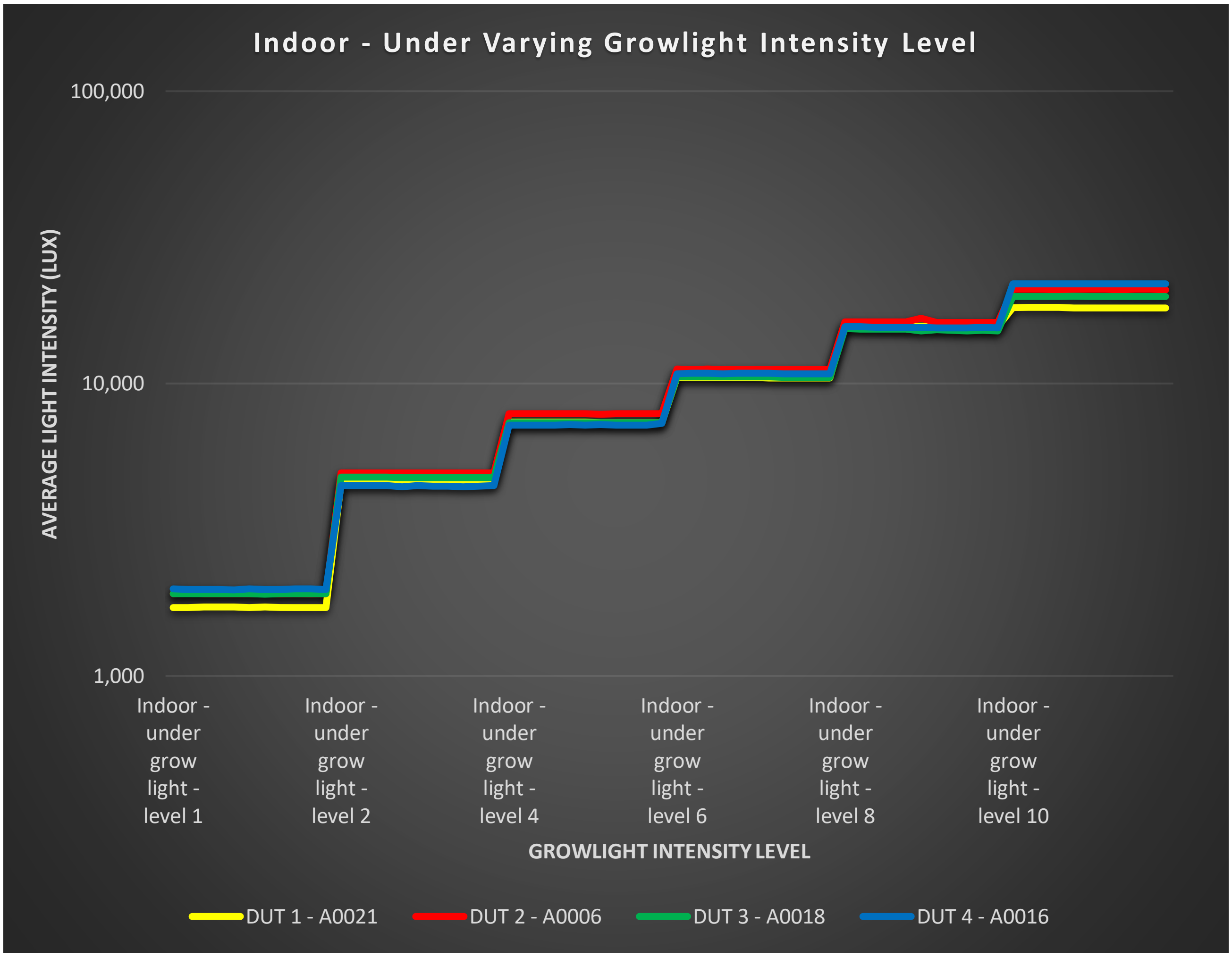


Figure 7: Indoor light measurement under grow light

4 Outdoor Lighting Conditions

The following table lists common outdoor light conditions and their typical illuminance levels.

Table 4: Common Outdoor Light Conditions and their typical Illuminance levels, adapted from [3]

Outdoor Light Conditions	Illuminance (lux)
Sun Overhead	>100000
Full Daylight	10000 - 25000
Overcast Day	1000
Dark Overcast Day	100
Sunrise, Sunset	10 - 400
Night	<1

Two Agricultural Sensors were set up to collect light measurement outdoors to demonstrate some of the outdoor light conditions in the table above.

4.1 Outdoor Light Sensing Example – November 23, 2022

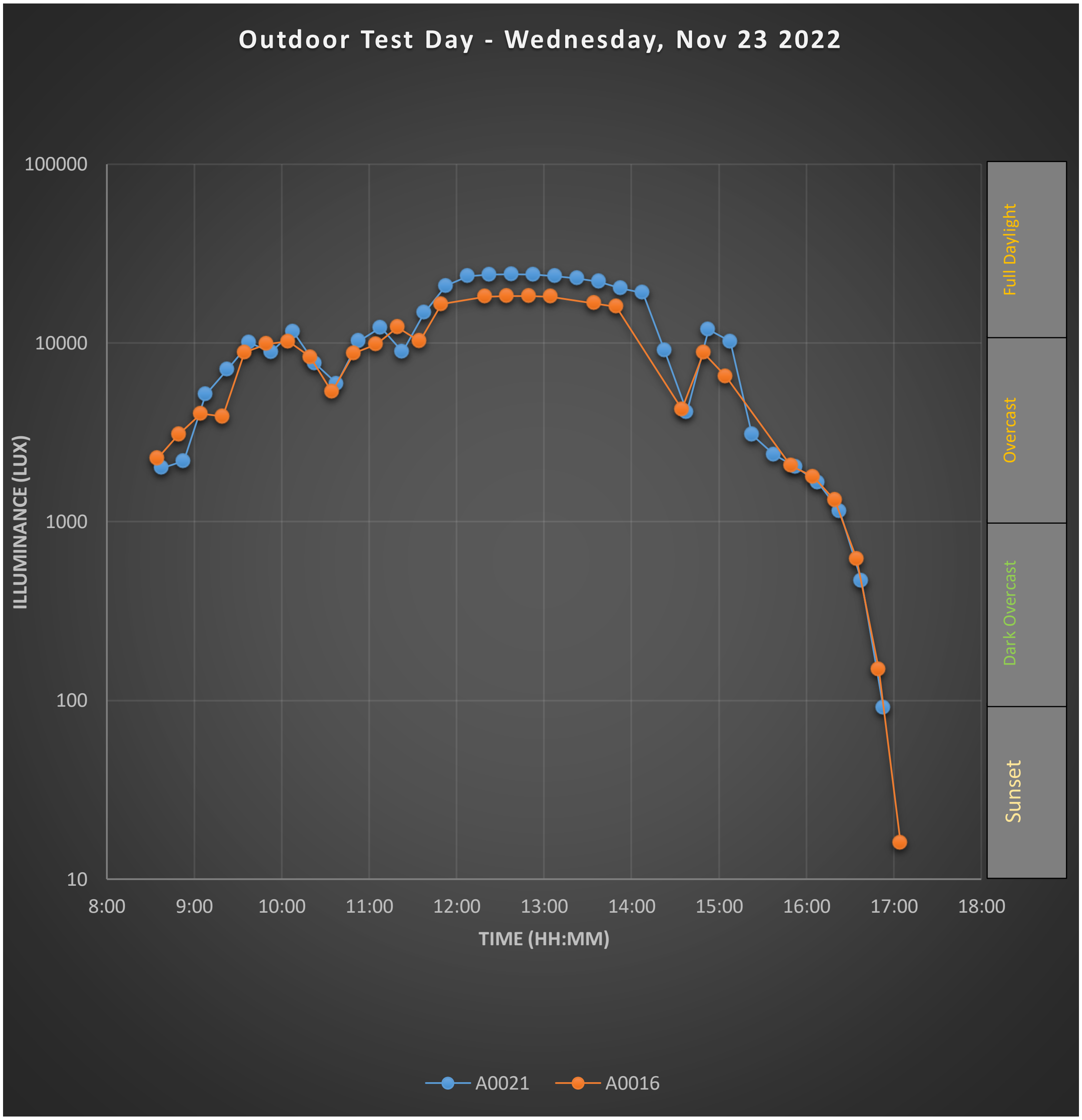
The plot in Figure 8 below shows the illuminance readings from the two test sensors over a period of about 8 hours on the outdoor test day in Calgary, Alberta, Canada. The sensors were configured to report ambient illuminance once every 15 minutes, with the sensor A0016 leading sensor A0021 by about three and a half minutes.

Table 5 below gives a brief overview of the solar conditions for this day.

Table 5: Solar Information for Wednesday November 23, 2022. [5]

Solar Information	Time
Sunrise	08:06
Solar noon	12:22
Sunset	16:39

Figure 8: Outdoor Light Condition - Test Day



To validate these results, Table 6 compares the data from the test sensors with the hourly weather reports for the test day from weatherspark.com, a website that collects and records weather information from multiple weather stations (from airports, environmental monitoring stations etc.) for different cities of the world.

Table 6: Validation of the Test Results

Time	Tektelic Test Sensors	Weatherspark.com [5]
08:06	N/A[2]	Sunrise, mostly cloudy
09:00	Overcast	Partly cloudy
10:00	Overcast	Mostly cloudy
11:00 to just before 14:00	Full Daylight	Mostly clear
14:00	Overcast	Partly cloudy
After 14:00 to 17:00	Overcast	Partly cloudy
17:00	Sunset	Sunset

Starting from the first applicable comparison point in time, data from the Tektelic test sensors show that the cloud gradually got clearer between the start of the test at 8:30am to around 10:00am. According to the test data, this period was immediately followed by a short period of the sky being cloudier between 10:00am and 10:30am. When compared to the reference data, these results are validated by the reference cloud clover report which shows the cloud went from being partly cloudy at 9:00am to mostly cloudy at 10:00am. However, the duration of the cloud cover being mostly cloudy could not be validated as the website only collects information right on the hour mark.

By 11:00am, both test data and reference data agree that the cloud cover had shifted to being mostly clear or full daylight, and stayed this way till around 2:00pm, where there is a slight drop in the measured illuminance level for both test sensors for about 30 minutes. The reference data shows that the cloud cover shifted from being mostly clear to being partly cloudy at around 2:00pm, explaining the drop seen on the test result plot. There was no significant change in the cloud cover between 3:00pm and 5:00pm for both the reference and test data.

The reference data shows that the sunset time for this day was 16:39pm while the first test unit to report illuminance levels in the sunset range was 13 minutes later at 4:52pm – within one measurement cycle. The other test unit reported illuminance level in the sunset range 25 minutes later than the reference time at 5:04pm – within two measurement cycle.

[2] The test data was collected after sunrise, so there are no test data on sunrise from the test units for this day.

5 Summary

The illuminance readings from the ALS transducer of the Agricultural sensors may vary from one device to another due to rapidly changing environmental and lighting conditions coupled with different reporting times to minimize the variation, we recommend installing the sensor at the spot with minimal angle of incidence to the light source and free of shadow. When visualizing data, it is recommended to use a log scale on the Illuminance axis to avoid over-emphasizing these expected small variations.

6 References

[1] B. L. J. H. Pingping Xin, "Optimization and Control of Light Environment for Greenhouse Crop Productions," *Scientific Reports,* 2019.

[2] B. Bareja, "CropsReview," 05 05 2022. [Online]. Available: https://www.cropsreview.com/light-intensity/#:~:text=Factors%20Affecting%20Light%20Intensity%20The%20intensity%20of%20light,geographic%20location%2C%20distance%20from%20the%20equator%2C%20and%20weather.. [Accessed 26 01 2023].

[3] P. Schlyter, "Radiometry and Photometry in Astronomy," 05 03 2017. [Online]. Available: http://stjarnhimlen.se/comp/radfaq.html#10. [Accessed 2022 12 21].

[4] "Recommended Lighting Levels in Buildings," Archtoolbox, 7 03 2021. [Online]. Available: https://www.archtoolbox.com/recommended-lighting-levels/#:~:text=Recommended%20Light%20Levels%20by%20Space%20%20%20,%20%200.59%20%2023%20more%20rows%20. [Accessed 24 01 2023].

[5] Weatherspark.com, "Historical Weather on Wednesday November 23 2022 in Calgary," 23 11 2022. [Online]. Available: https://weatherspark.com/h/d/2349/2022/11/23/Historical-Weather-on-Wednesday-November-23-2022-in-Calgary-Canada#metar-07-00. [Accessed 24 01 2023].