

Data Collection & Analysis Result

24 December 2024

PROJECT Heat Load Studies at The Grand Outlet, East Jakarta Karawang	CLIENT Mitsubishi Jisho Design Asia Pte. Ltd. Singapore
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Project:	Environmental Measurement Survey of Grand Outlet Karawang, West Java, Indonesia
Client:	Mitsubishi Jisho Design Asia Pte. Ltd.

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Glossary

Key Monitoring Points (Semi-Outdoor)

1. **Green Hub (GH)**
 - Central Semi-Outdoor location featuring vegetation and water elements.
 - Evaluates the environmental influence of greenery on thermal comfort.
2. **Under Canopy (Ground Level)**
 - Shaded area on the ground level.
 - Focuses on thermal comfort in partially enclosed spaces.
3. **Under Canopy (2F)**
 - Shaded area on the second floor near void spaces.
 - Analyzes elevated Semi-Outdoor temperature patterns and airflow.
4. **Promenade**
 - Open Semi-Outdoor pedestrian area with partial sunlight exposure.
 - Used to analyze pedestrian thermal comfort.
5. **Front Command Center (FCC)**
 - Positioned at the facility entrance without thermal controls.
 - Serves as a semi-outdoor transition area for environmental monitoring.

Key Monitoring Points (Outdoor)

1. **Rooftop 1**
 - Outdoor rooftop point equipped with **Ambient Weather WS-2000** station.
 - Measures various environmental parameters.
2. **Rooftop 2**
 - Another outdoor rooftop point with identical equipment.
 - Switched with Rooftop 1 for improved data transmission.

Instruments Used in Research

1. **Ambient Weather WS-2000 (AWS)**
 - Air Temperature (°C)
 - Wind Speed (m/s)
 - Wind Direction (°)

- Humidity (%)
- Solar Radiation (W/m²)
- Ultraviolet Index
- Daily Rainfall (mm)

2. **Lutron WBGT-2010SD (WBGT Meter)**

- Wet Bulb Globe Temperature (WBGT, °C)
- Black Globe Temperature (BGT, °C)
- Air Temperature (°C)
- Humidity (%)

3. **Lutron AM-4234SD Hotwire Anemometer (Anemometer)**

- Wind Speed (m/s)
- Air Temperature (°C)
- Humidity (%)

4. **T&D TR-74Ui Data Logger (Data Logger)**

- Air Temperature (°C)
- Humidity (%)
- Illuminance (Lux)

Data Collection

The environmental measurement instruments at The Grand Outlet, East Jakarta Karawang are strategically positioned to collect detailed data on both Semi-Outdoor and outdoor conditions, operated from 26/11 to 5/12 . Two weather stations are installed on rooftops to monitor key parameters such as temperature, humidity, wind speed, solar radiation, and rainfall, ensuring accurate weather data for the facility. Semi-Outdoors, measurements are taken at five key points: the entrance (open-air) captures data for the transition zone; shaded areas under canopies on Levels 1 and 2 are assessed for thermal comfort; the green hub evaluates the environmental effects of vegetation; and the promenade focuses on pedestrian comfort in direct sunlight. Instruments such as anemometers, WBGT meters, illuminance sensors, solar meters, and cameras provide comprehensive data on temperature, humidity, air movement, solar radiation, and visual activity, contributing to enhanced environmental performance and user comfort.

Inside Facility's Set of Instruments (Semi-Outdoor)

The Grand Outlet features five strategically selected Inside facility or Semi-Outdoor locations for environmental monitoring, each representing unique aspects of the facility's design and functionality. These include the open-air entrance, which captures transitional environmental conditions; the canopy areas on Levels 1 and 2, designed to assess shaded thermal comfort; the green hub, which highlights the influence of vegetation and water elements on Semi-Outdoor climate; and the promenade, focusing on pedestrian comfort under direct sunlight. Together, these key points provide insights into the facility's environmental performance and user experience.



Figure.1 Ground Floor plan
The Grand Outlet, East
Jakarta Karawang Karawang,
Bekasi, West Java (Source:
Mitsubishi, 2024)

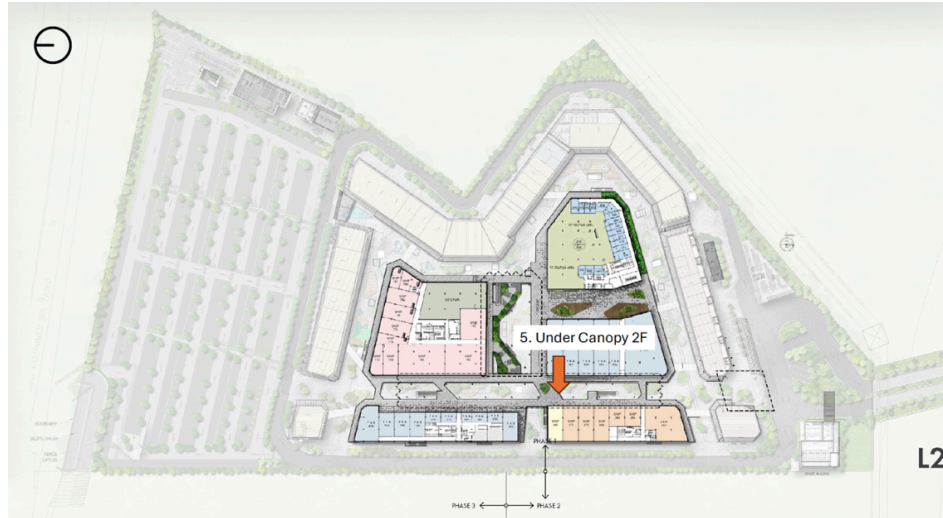


Figure.2 Second Floor Plan The Grand Outlet, East Jakarta Karawang Karawang, Bekasi, West Java (Source: Mitsubishi, 2024)

To optimize efficiency and ensure accurate data collection, we decided to assemble all environmental monitoring equipment onto a single tripod. This setup includes a Lutron WBGT meter, anemometer, and T&D data logger, strategically positioned to measure key parameters such as temperature, humidity, air velocity, and WBGT from a single point. The tripod ensures stability and maintains consistent height and orientation for reliable readings. Aluminum foil was added to specific sensors to minimize interference from direct radiation, enhancing data accuracy. This compact configuration simplifies deployment while enabling simultaneous

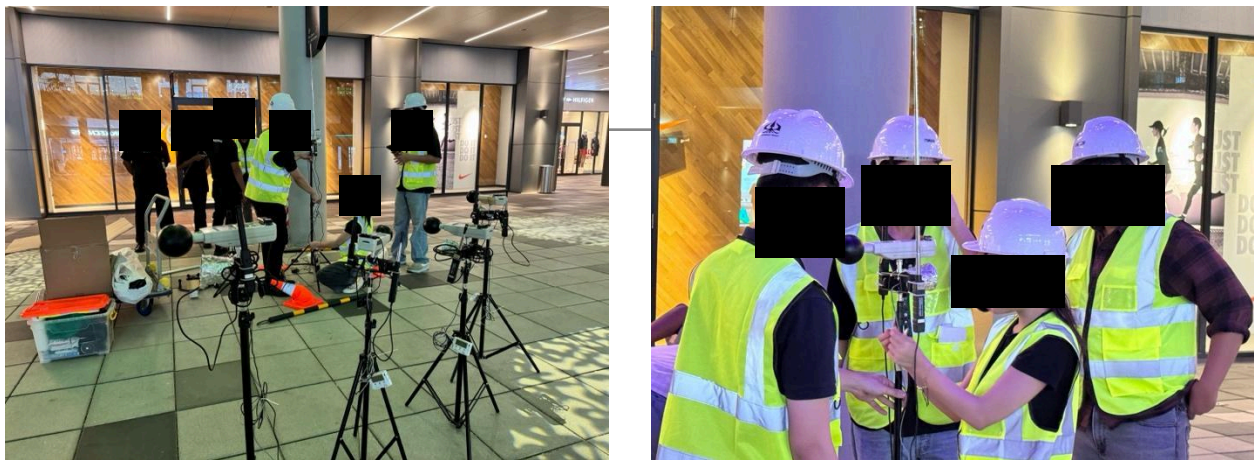


Figure.3 Data Collection Tool Assembly by Research Team (Source: Research Team, 2024)

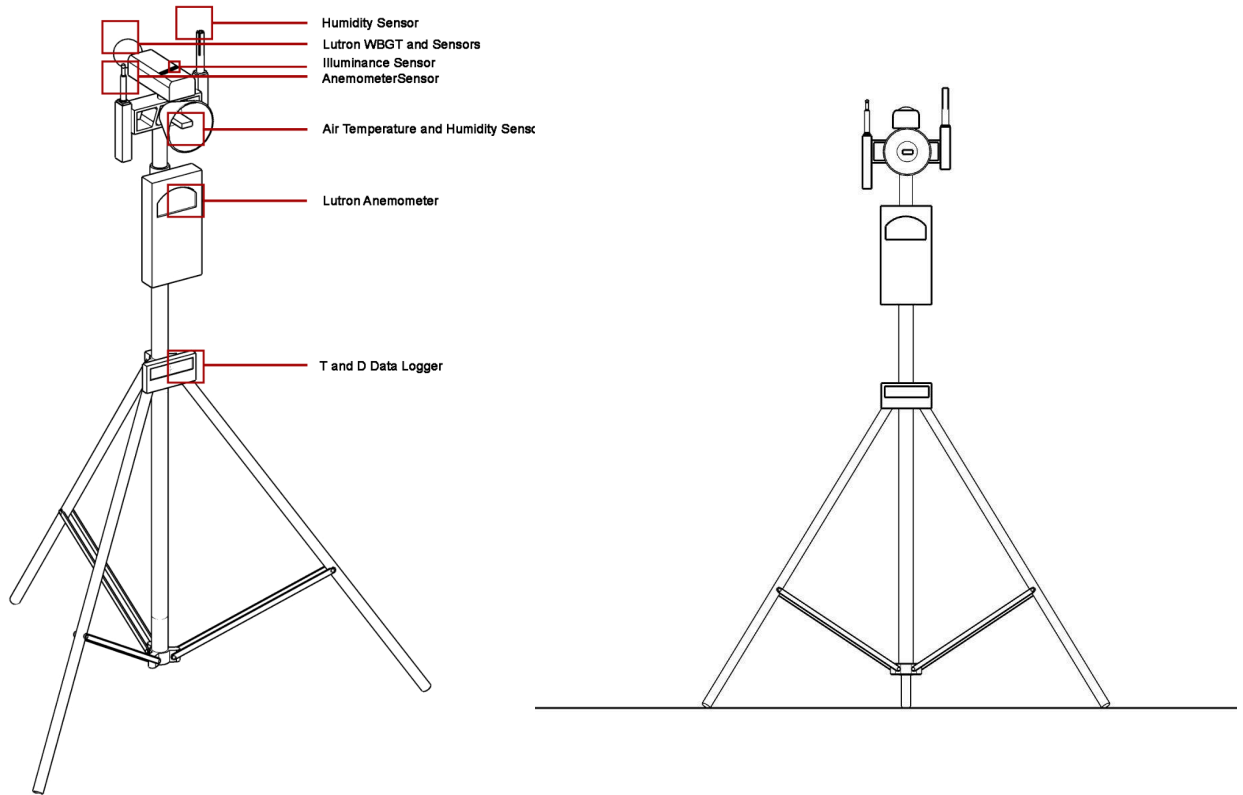


Figure. 4 Instruments installed on tripod (Source: Research Team, 2024)

Lutron AM-4234SD Hotwire Anemometer:

Wind Speed (m/s), Air Temperature (TA, °C), Humidity (%), Dew Point (°C)



Figure. 5 Anemometer (Source: lutroninstruments.eu, 2024)

Lutron WBGT-2010SD:

WBGT ($^{\circ}\text{C}$), Black Globe Temperature (BGT, $^{\circ}\text{C}$), Air Temperature (TA, $^{\circ}\text{C}$), Humidity (%), Dew Point Temperature ($^{\circ}\text{C}$)



Figure. 6 Lutron WBGT (Source: *lutroninstruments.eu*, 2024)

T AND D TR-74Ui:

Air Temperature (TA, $^{\circ}\text{C}$), Humidity (%), Illuminance (Lux)



Figure. 7 T and D TR-74Ui (Source: *tandd.com*, 2024)

The TR-74Ui data logger was programmed to automatically record temperature and humidity at fixed intervals throughout the day. After completing the recording phase, the data was retrieved by

connecting the device to a computer via its USB port. This process enabled efficient data extraction and ensured that all recorded information was securely stored for subsequent analysis.

This method allows for high-resolution temporal data collection, facilitating the identification of trends and patterns in the Semi-Outdoor environment before any interventions are applied. The data serves as a baseline for evaluating the effectiveness of heat mitigation strategies implemented in the house.

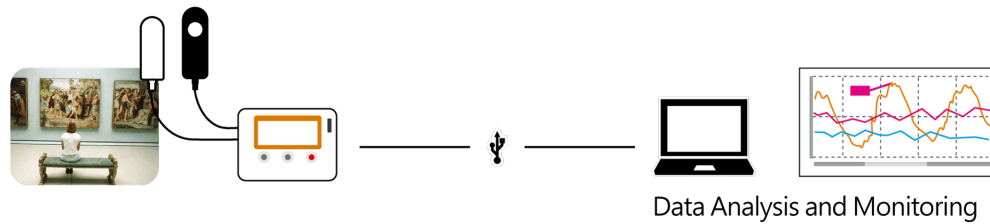


Figure. 8 Data Recording Programming System (Source: *tandd.com*, 2024)

Outside Facility's Set of Instruments (Outdoor)

To ensure a comprehensive and organized approach to environmental monitoring at the Grand Karawang Outlet, we created a detailed log table for each monitor **Outside Facility's Set of Instruments**;

The environmental monitoring setup at the Grand Karawang Outlet includes two strategically positioned points on the rooftop to capture detailed outdoor conditions. These points, as shown in the below image, are located at 01. *Outdoor rooftop* and 02. *Outdoor rooftop*, ensuring comprehensive coverage of the facility's external environment. Using Ambient Weather WS-2000 weather stations, these locations allow for precise measurement of parameters such as temperature, humidity, wind speed, solar radiation, and rainfall, providing valuable data to assess and optimize the facility's environmental performance in response to the surrounding tropical climate.



Figure. 9 Top View The Grand Outlet, East Jakarta Karawang Karawang, Bekasi, West Java (Source: Mitsubishi, 2024)

At each rooftop location, we have installed Ambient Weather WS-2000 weather stations, known for their high precision and multi-parameter measurement capabilities. These weather stations are equipped to monitor key outdoor conditions, including temperature, humidity, wind speed, wind direction, solar radiation, and rainfall intensity. The WS-2000's advanced sensors and real-time data logging features allow us to continuously gather critical environmental data, which is then analyzed to support the facility's thermal performance and user comfort optimization efforts



Figure. 10 Research Team is Preparing The Equipment on The Rooftop (Source: Research Team, 2024)

The data obtained from these weather stations will play a crucial role in analyzing the environmental load that may influence the microclimate within the facility. Factors such as solar heat gain, wind patterns, and humidity levels can significantly impact the Semi-Outdoor and outdoor thermal comfort conditions. Statistical methods will be employed to analyze and compare the data effectively. Techniques such as descriptive statistics, correlation analysis, and regression modeling will be used to identify trends and relationships between environmental parameters. For instance, correlation analysis will help us understand how external conditions like solar radiation and wind speed correlate with changes in temperature and humidity levels inside the facility.

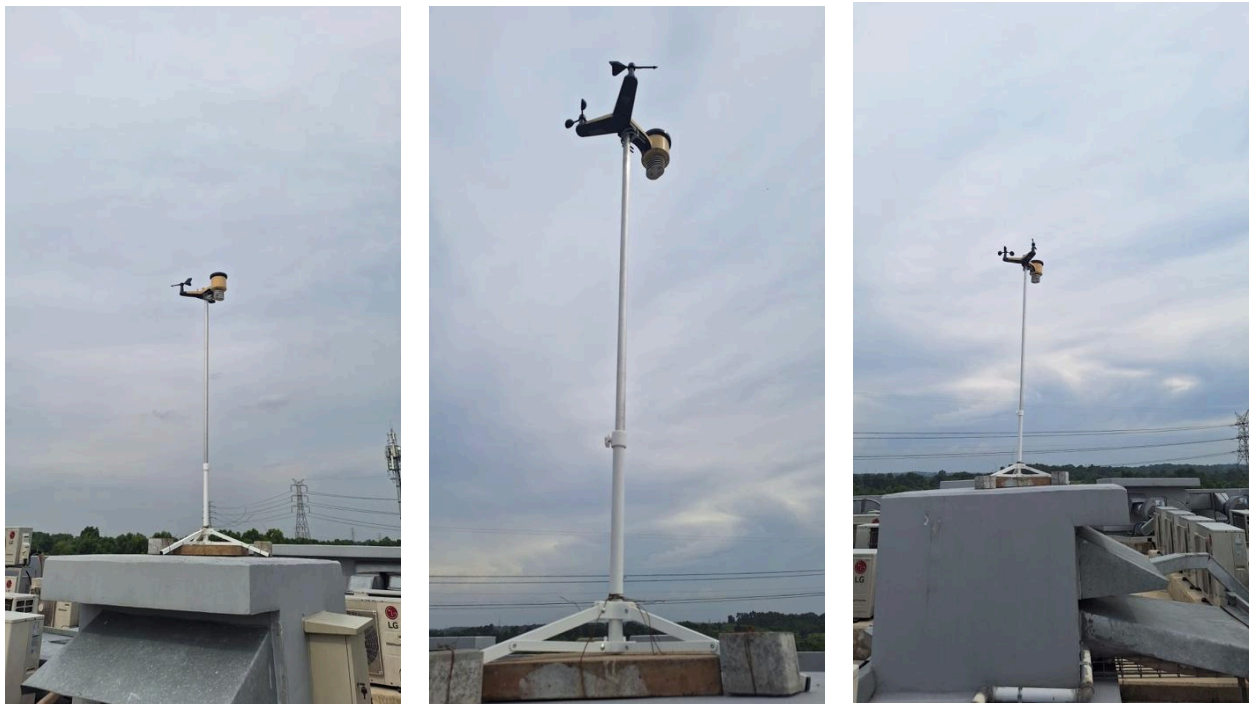


Figure.11 Weather Station installed on rooftop (*Source: Research Team, 2024*)

Additionally, Analysis of Variance (ANOVA) will be applied to compare environmental to assess their variability over time. This will help determine whether significant differences exist between the conditions measured at Point 01 and Point 02, offering deeper insights into the microclimatic variations across the facility. The data will also be integrated into predictive modeling to simulate the potential impact of environmental loads on the facility's microclimate, enabling proactive design strategies to mitigate adverse effects. By combining advanced statistical methods with precise environmental data, this setup provides a robust framework for understanding and optimizing the Grand Karawang Outlet's microclimate.

Data Collection Log

To ensure a comprehensive and organized approach to environmental monitoring at the Grand Outlet Karawang , we created a detailed log table for each monitoring point and the associated equipment (Green Hub, Under Canopy, 2F Under Canopy, FCC, Promenade, Rooftops, and Pictures Documentation). This table serves as a structured record of the parameters measured, including air temperature, humidity, air velocity, WBGT, solar radiation, and illumination levels, at both Semi-Outdoor and outdoor locations. By documenting the performance and functionality, the table provides a clear overview of data collection activities based on the date of operation. Additionally, this log allows for tracking any operational issues, interruptions, or environmental factors that may affect the equipment.

Table 1. (a,b) Data Log

(a)

[illegible]

(b)

No	Date	Promenade										Rooftop Outdoor 1						Rooftop Outdoor 1						Photos				
		TnD			WBGIT				Anemometer			Weather Station 2						Weather Station 2						Flir Camera		Surrounds		SVI
		Air Temperature (°C)	Humidity (%)	Illuminance (lx)	WBGIT (°C)	Globe Temperature (°C)	Wet Temperature (°C)	Dew Points (°C)	Air Velocity (m/s)	Air Temperature (°C)	Wind Direction (°)	Event Rain (mm)	Humidity (%)	Ultra-Violet Radiation Index	Solar Radiation (W/m²)	Avg Wind Direction (°)	Wind Direction (°)	Event Rain (mm)	Humidity (%)	Ultra-Violet Radiation Index	Solar Radiation (W/m²)	Wet Temp (°C)	Dew Point (°C)	Day	Night	Day	Night	
1	11/26/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
2	11/27/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
3	11/28/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
4	11/29/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
5	11/30/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
6	12/1/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
7	12/2/2024	☑	☑	☐	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
8	12/3/2024	☑	☐	☐	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
9	12/4/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	
10	12/5/2024	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☐	☐	☐	☐	☐	

During the data collection process at the Grand Karawang Outlet, various environmental monitoring instruments were strategically placed across key Semi-Outdoor and outdoor locations. These instruments, including T&D data loggers, anemometers, and Ambient Weather WS-2000 weather stations, were used to record critical parameters such as air temperature, humidity, air velocity, WBGT (Wet Bulb Globe Temperature), solar radiation, and illumination levels. The goal was to assess thermal comfort and environmental loads impacting the facility's microclimate.

However, the data collection faced several challenges. One of the main issues was an electrical shortage caused by the high demand for power during December's festival-related activities at the outlet. This disrupted the operation of monitoring equipment at certain points, leading to temporary data gaps. Additionally, a thunderstorm during the monitoring period required the evacuation of equipment from one rooftop location to prevent damage. This precaution temporarily halted data collection at that point but ensured the safety of both the instruments and the personnel.



Figure. 11 Research team is retrieving data everyday (Source: Research Team, 2024)

Another challenge involved equipment performance, as some instruments, such as Lutron WBGT and Lutron Anemometer, experienced issues due to prolonged operation. These devices occasionally needed recalibration or downtime to restore functionality, which briefly impacted data consistency.

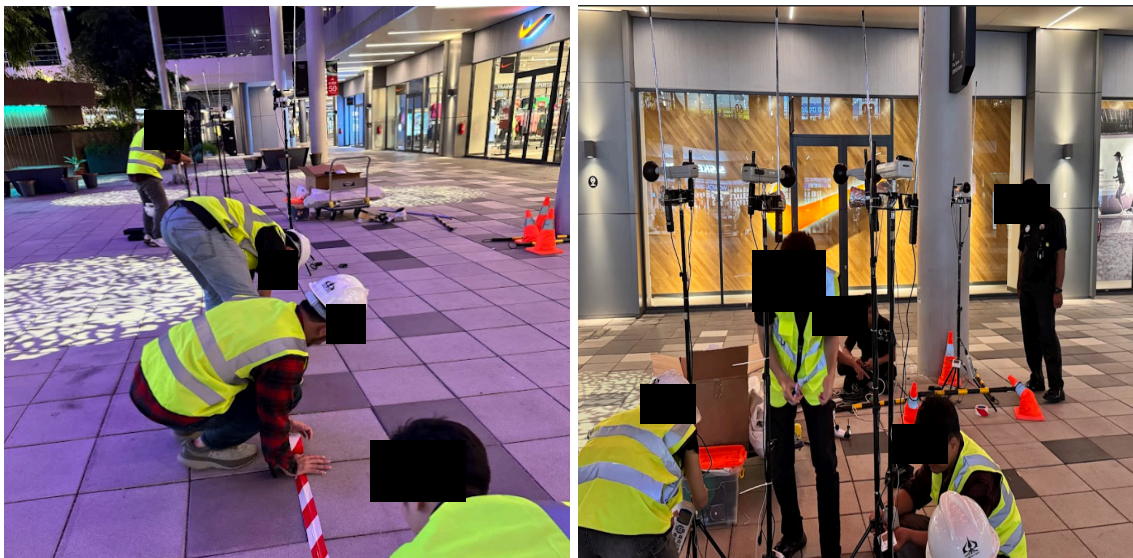
Despite these challenges, the data collected between 11/26/2024 and 12/5/2024 covered both Semi-Outdoor locations, such as the Green Hub, Canopy (2F), and FCC, and outdoor points like the Promenade and two rooftop stations. Rooftop weather stations provided valuable insights into external conditions, including solar radiation and wind patterns, while Semi-Outdoor monitoring focused on thermal comfort influenced by microclimatic variations.

Overall, the collected data forms a solid basis for analyzing environmental loads and their impact on thermal comfort within the facility. Addressing challenges such as power reliability and weatherproofing equipment in future efforts will further enhance the accuracy and consistency of data collection.

Green Hub

Beneficiary			
Name	Green Hub	Google Maps Location	https://maps.app.goo.gl/fMTzia1HRiBYeLLz6
Under Canopy	Yes		
Environmental Instruments			
Installation Status	Installed	Retrieved	
All instruments were successfully installed; however, An electrical issue originating from the Green hub impacted the performance of the anemometer and Luxtron WBGT, which influenced the reliability of the data collected.	✓	✓	
Point's Surrounding			
North	South	West	East
Outlet Shops	Outlet Shops	Vegetation, Water Elements, and Fan	Vegetation, Water Elements, and Fan
Parameters Measured			
Air Temperature, Humidity, Illuminance, Wet Bulb Globe Temperature, Air Velocity,			
Descriptive of The Points			
Existing			
The Green Hub area is designed with two large fans positioned on the east and west sides to enhance airflow and maintain a comfortable environment. Additionally, the area features two water elements: a pond and a fountain, which contribute to a cooler and more humid microclimate. Vegetation is placed at a distance of 15 meters from the Green Hub point. Whereas Outlets were on the front and back of the equipment.			

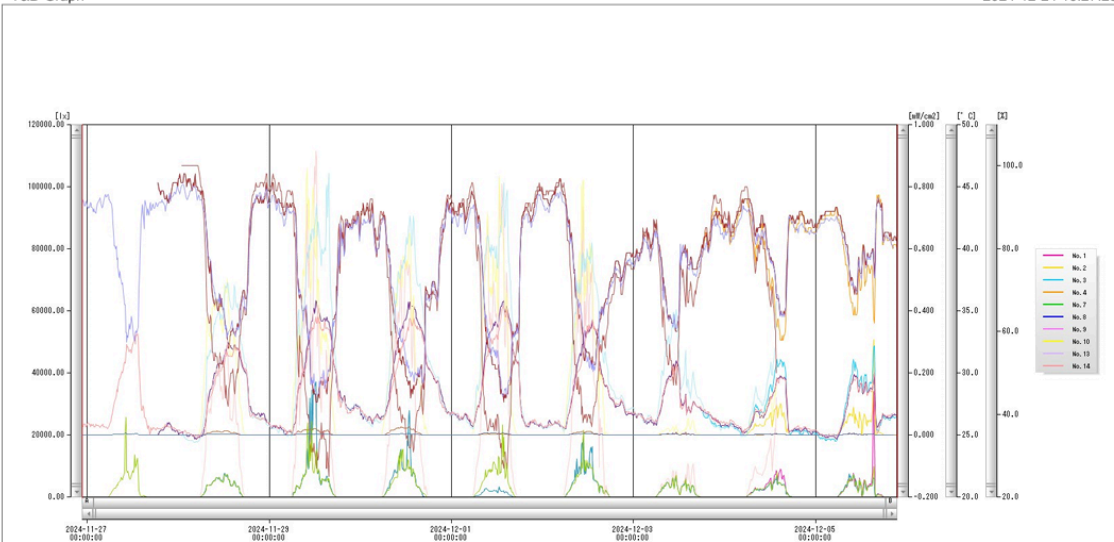
Fish Eye Surrounding Photos**Flir Photos****Flir By Day Green Hub****Flir By Night Green Hub****Installation Photos**



TnD Overall Result

T&D Graph

2024-12-24 16:27:23

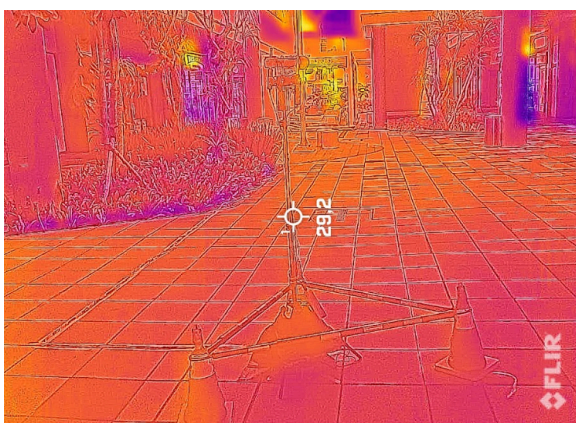
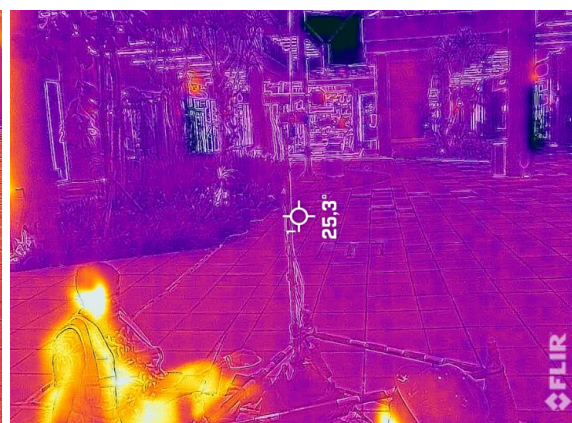


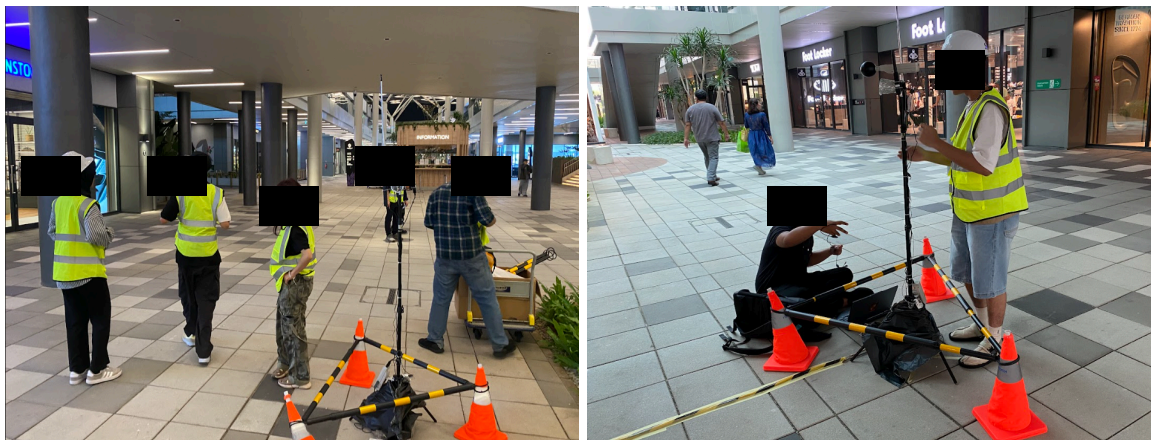
Display Range 2024-11-26 22:35:00 - 2024-12-05 21:30:00
 Calculation Range 2024-11-26 22:35:00 - 2024-12-05 21:30:00

No.	Channel Name	Interval	No. of Readings	Unit	Highest Value	Lowest Value	Average Value
No.1	ch1	10 min.	308	lx	34060.00	10.57	1868.72
No.2	ch2	10 min.	308	mW/cm2	0.307	0.000	0.020
No.3	ch3	10 min.	308	°C	32.2	24.5	26.7
No.4	ch4	10 min.	308	%	93.0	58.0	81.2
No.7	ch1	10 min.	1169	lx	37110.00	1.20	2244.47
No.8	ch2	10 min.	1169	mW/cm2	0.026	0.000	0.003
No.9	ch3	10 min.	1169	°C	35.8	24.7	28.1
No.10	ch4	10 min.	1169	%	98.0	43.0	77.8
No.13	ch1	10 min.	1169	lx	37110.00	1.20	2244.47
No.14	ch2	10 min.	1169	mW/cm2	0.026	0.000	0.003

Under Canopy

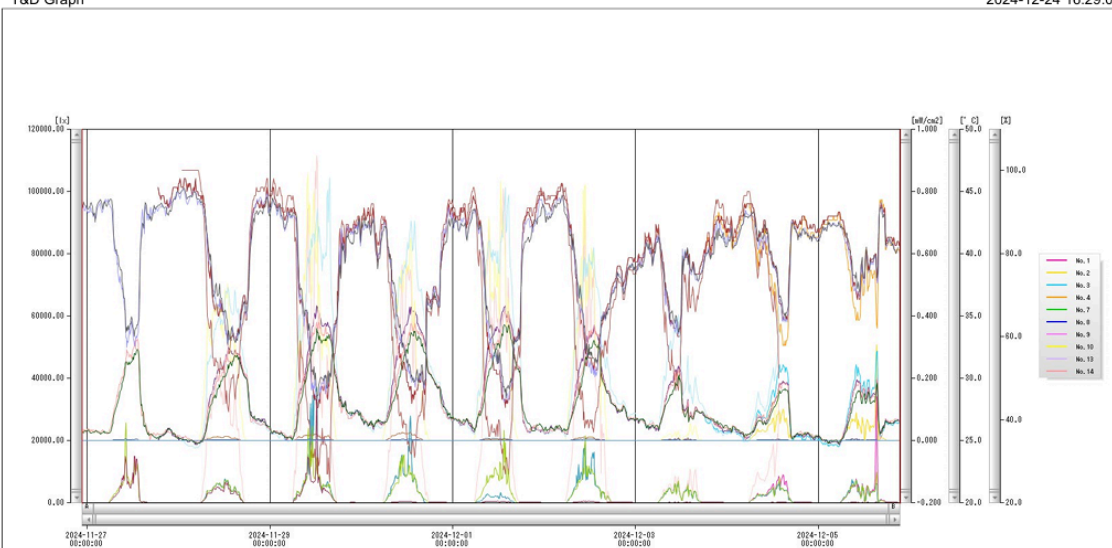
Beneficiary			
Name	Under Canopy	Google Maps Location	https://maps.app.goo.gl/fMTzia1HRiBYeLLz6
Under Canopy	Yes		
Environmental Instruments			
Installation Status	Installed	Retrieved	
All equipment has been installed in good condition; however, adjustments are required due to changes in electrical systems and the proximity of the equipment to vegetation. The close distance necessitates relocation to ensure optimal functionality and safety.	✓	✓	
Point's Surrounding			
North	South	West	East
Vegetation	Information center	Vegetation	Outlet Shops
Parameters Measured			
Air Temperature, Humidity, Illuminance, Wet Bulb Globe Temperature, Air Velocity,			
Descriptive of The Points			
Existing			
The equipment is positioned in the corridor, maintaining a distance of 3 meters from the vegetation and 4 meters from the outlet shop. Additionally, the placement is near the fans, which may affect the data collection process due to potential air circulation interference. Adjustments are necessary to align with the mall's conditions while considering visitor circulation and ensuring accurate data collection.			

Fish Eye Surrounding Photos**Flir Photos*****Flir By Day Green Hub******Flir By Night Green Hub*****Installation Photos**



TnD Overall Result

T&D Graph 2024-12-24 16:29:08



Display Range 2024-11-26 22:35:00 - 2024-12-05 21:30:00
Calculation Range 2024-11-26 22:35:00 - 2024-12-05 21:30:00

No.	Channel Name	Interval	No. of Readings	Unit	Highest Value	Lowest Value	Average Value
No.1	ch1	10 min.	308	lx	34060.00	10.57	1868.72
No.2	ch2	10 min.	308	mW/cm2	0.307	0.000	0.020
No.3	ch3	10 min.	308	°C	32.2	24.5	26.7
No.4	ch4	10 min.	308	%	93.0	58.0	81.2
No.7	ch1	10 min.	1169	lx	37110.00	1.20	2244.47
No.8	ch2	10 min.	1169	mW/cm2	0.026	0.000	0.003
No.9	ch3	10 min.	1169	°C	35.8	24.7	28.1
No.10	ch4	10 min.	1169	%	98.0	43.0	77.8
No.13	ch1	10 min.	1169	lx	37110.00	1.20	2244.47
No.14	ch2	10 min.	1169	mW/cm2	0.026	0.000	0.003

2F Under Canopy

Beneficiary			
Name	Under Canopy 2f	Google Maps Location	https://maps.app.goo.gl/fMTzia1HRiBYeLLz6
Under Canopy	Yes		
Environmental Instruments			
Installation Status	Installed	Retrieved	
The installed measuring instrument encounters several issues, including disruptions in the power supply due to human circulation within the mall. Additionally, the instrument experiences freezing, necessitating periodic maintenance.	✓	✓	
Point's Surrounding			
North	South	West	East
Void	Void	Corridor, Outlet shop	Corridor, Outlet shop
Parameters Measured			
Air Temperature, Humidity, Illuminance, Wet Bulb Globe Temperature, Air Velocity,			
Descriptive of The Points			
Existing			
The measuring instrument is located in the connecting area between outlets and close to the mall's void. The fan is positioned far from the instrument, and the instrument is placed relatively close to an open area. It is installed on the second floor, where no vegetation is present. The distance from the outlet to the instrument is 6 meters.			
Fish Eye Surrounding Photos			



Flir Photos



Flir By Night Under Canopy 2F

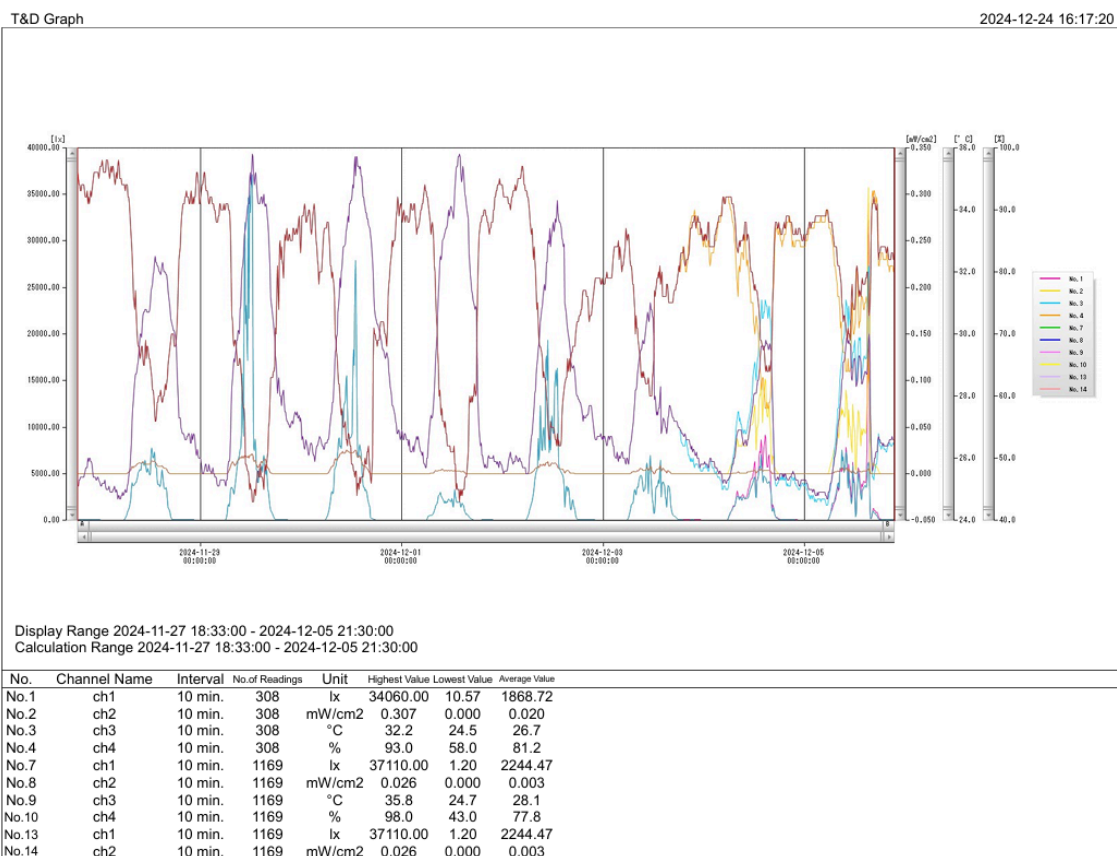


Flir By Day Under Canopy 2F

Installation Photos

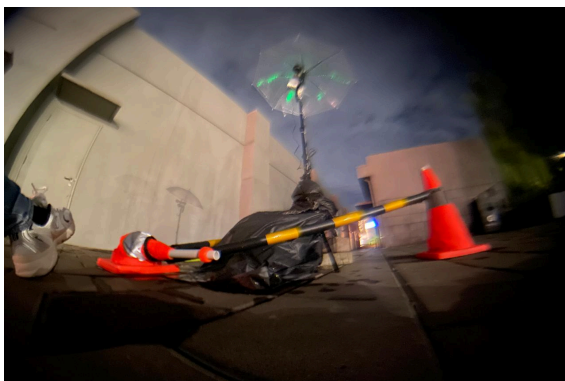
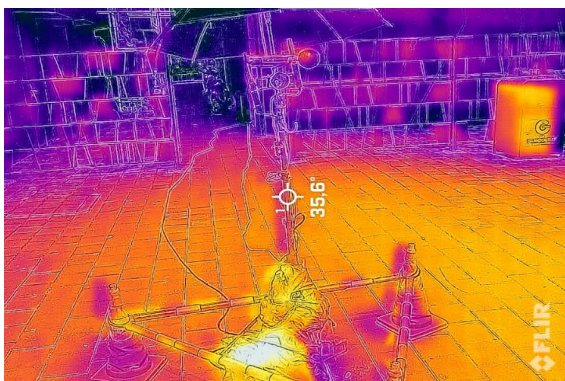
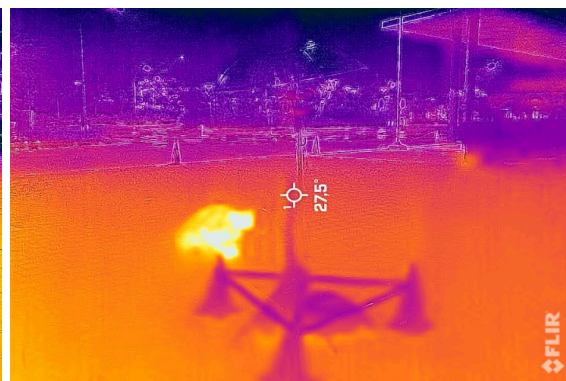


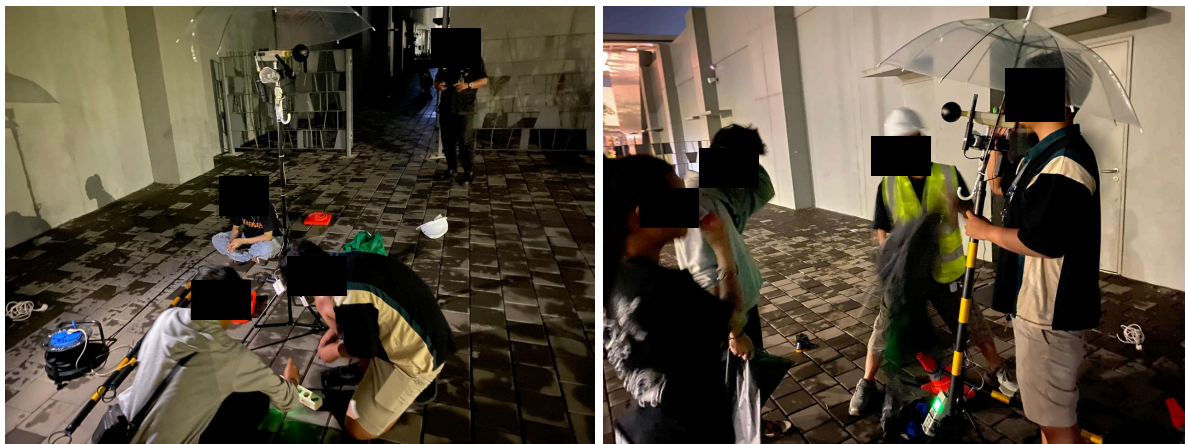
TnD Overall Result



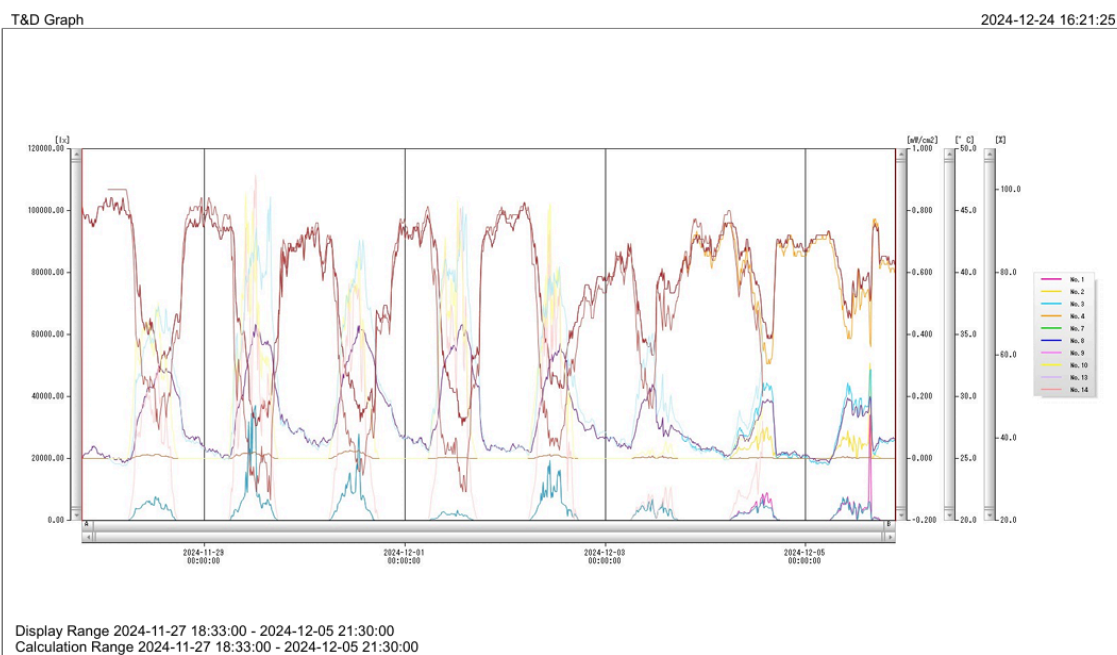
FCC (Front Command Center)

Beneficiary			
Name	Fire Command Center	Google Maps Location	https://maps.app.goo.gl/fMTzia1HRiBYeLLz6
Under Canopy	Yes		
Environmental Instruments			
Installation Status	Installed	Retrieved	
The measuring instrument was successfully installed despite electrical issues in the FCC area, which delayed its installation to the 27th. As the installation site was not covered by a canopy, additional preparation was required to address these conditions.	✓	✓	
Point's Surrounding			
North	South	West	East
Car Circulation	Storage Shimizu	Fire Command Center	Main Entrance Canopy
Parameters Measured			
Air Temperature, Humidity, Illuminance, Wet Bulb Globe Temperature, Air Velocity,			
Descriptive of The Points			
Existing			
The instrument is located in an open area without a canopy, positioned 10 meters from the FCC and 15 meters from the entrance. It is 7 meters away from vegetation situated in front of the FCC and faces vehicular circulation. To adapt to rainy conditions without a canopy, a transparent umbrella is used to ensure that data collection can proceed effectively.			
Fish Eye Surrounding Photos			

**Flir Photos*****Flir Fire Command Center By Day******Flir Fire Command Center By Night*****Installation Photos**



TnD Overall Result



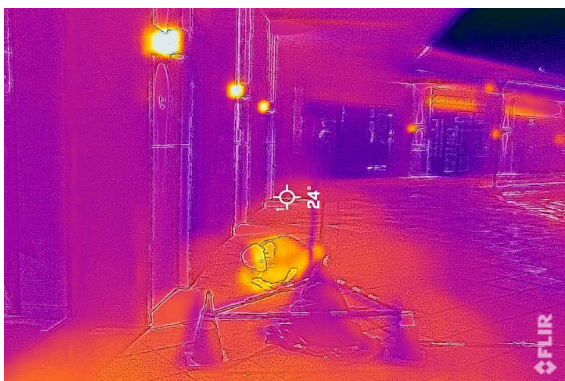
No.	Channel Name	Interval	No of Readings	Unit	Highest Value	Lowest Value	Average Value
No.1	ch1	10 min.	308	lx	34060.00	10.57	1868.72
No.2	ch2	10 min.	308	mW/cm2	0.307	0.000	0.020
No.3	ch3	10 min.	308	°C	32.2	24.5	26.7
No.4	ch4	10 min.	308	%	93.0	58.0	81.2
No.7	ch1	10 min.	1169	lx	37110.00	1.20	2244.47
No.8	ch2	10 min.	1169	mW/cm2	0.026	0.000	0.003
No.9	ch3	10 min.	1169	°C	35.8	24.7	28.1
No.10	ch4	10 min.	1169	%	98.0	43.0	77.8
No.13	ch1	10 min.	1169	lx	37110.00	1.20	2244.47
No.14	ch2	10 min.	1169	mW/cm2	0.026	0.000	0.003

Promenade

Beneficiary			
Name	Promenade	Google Maps Location	https://maps.app.goo.gl/fMTzia1HRiBYeLLz6
Under Canopy	Yes		
Environmental Instruments			
Installation Status	Installed	Retrieved	
The measuring instrument initially placed in the promenade was not covered by a canopy. Due to concerns about rain, wind, and the instrument's condition, it was relocated to a safer and more protected area.	✓	✓	
Point's Surrounding			
North	South	West	East
Outlet Shops	Promenade Plaza	Corridor	Outlet Shop
Parameters Measured			
Air Temperature, Humidity, Illuminance, Wet Bulb Globe Temperature, Air Velocity,			
Descriptive of The Points			
Existing			
The measuring instrument is located 2 meters from the shopping outlet, near the corridor leading to the restroom. It is positioned 1 meter from the plaza, which features numerous umbrellas. The placement is in an open area.			
Fish Eye Surrounding Photos			



Flir Photos

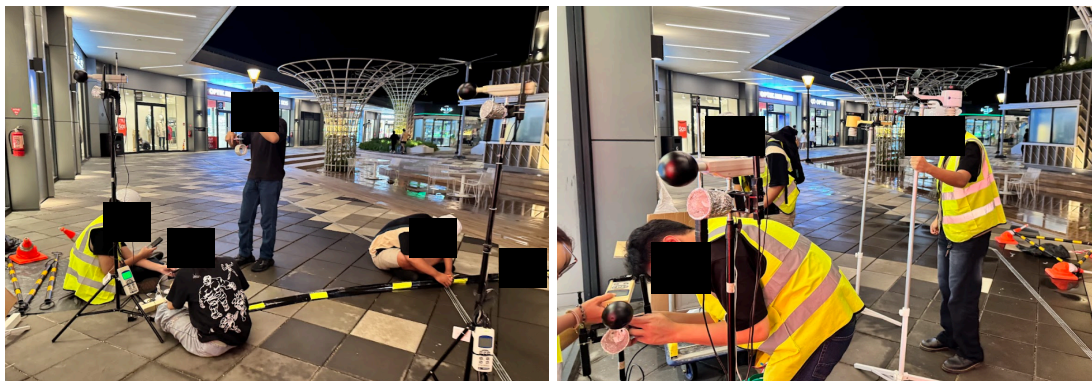


Flir Promenade By Night

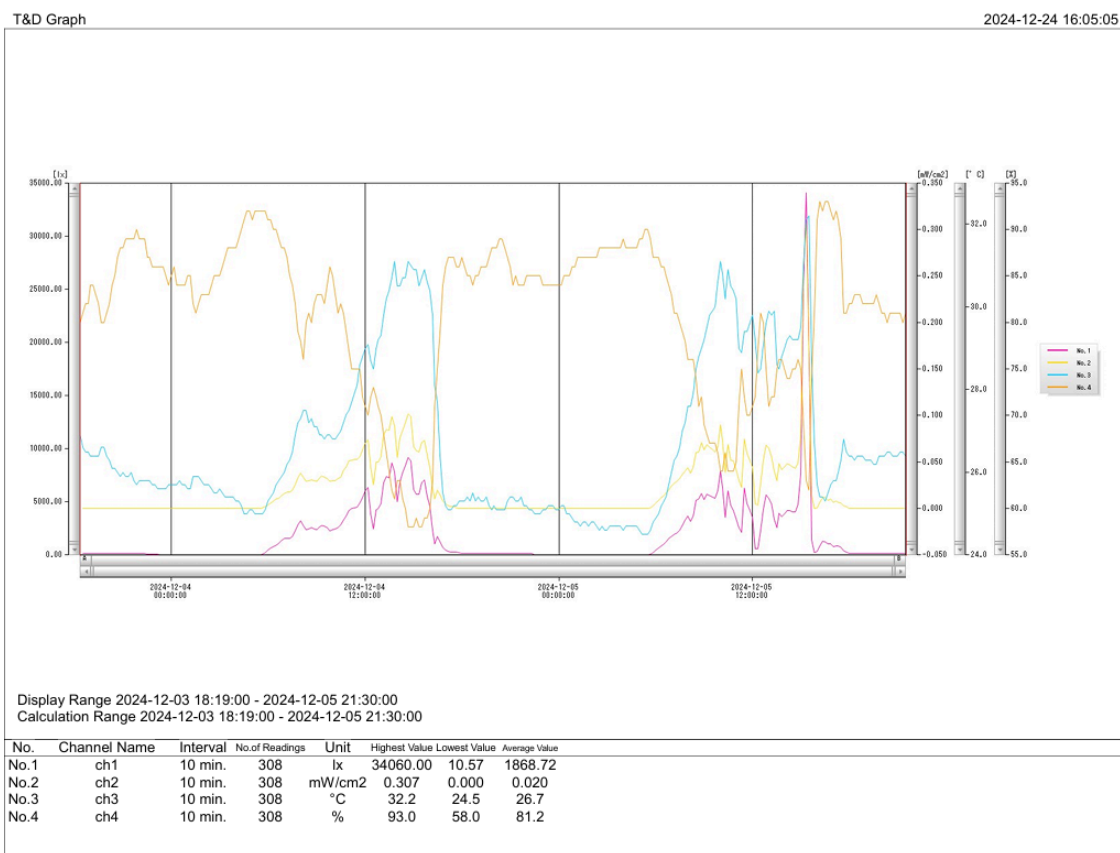


Flir Promenade By Day

Installation Photos



TnD Overall Result



Rooftops 1

Beneficiary			
Name	Rooftop 1	Google Maps Location	6° 21' 24.9552" S 107° 14' 34.5804" E
Under Canopy	No		
Environmental Instruments			
Installation Status	Installed	Retrieved	
The installation of Ambient Weather Stations at the The Grand Outlet, East Jakarta Karawang Karawang involved two units positioned on the facility's rooftops, coded as Rooftop 1 and Rooftop 2. Each weather station was initially assigned to its corresponding rooftop (Ambient Weather 1 on Rooftop 1 and Ambient Weather 2 on Rooftop 2). However, due to signal issues affecting data transmission, the stations were switched, with Ambient Weather 1 relocated to Rooftop 2 and Ambient Weather 2 moved to Rooftop 1, ensuring optimal functionality and reliable data collection for both monitoring points.	✓	✓	
Point's Surrounding			
North	South	West	East
-	-	-	-
Parameters Measured			
Outdoor Temperature, Wind Speed, Wind Direction, Daily Rain, Humidity, Ultra-Violet Radiation Index, Solar Radiation.			

Descriptive of The Points**Existing**

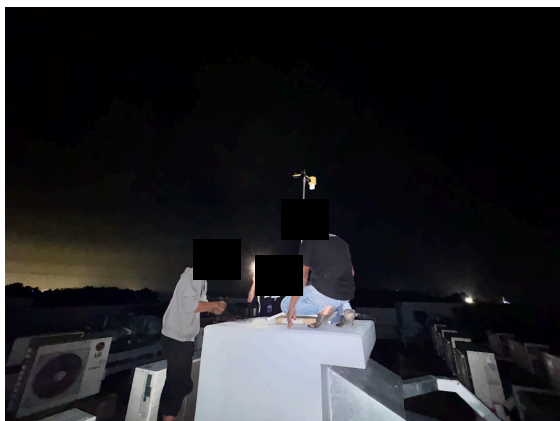
The equipment will be installed on the 3rd floor of a utility building, at a height of 9 meters above ground level. The installation area is open and unobstructed, ensuring the device can accurately collect data from the surrounding environment. It will be placed adjacent to the existing green hub area and accessed via an emergency staircase. The monitoring range is approximately 15-30 meters in radius.

Installation Photos

Rooftops 2

Beneficiary			
Name	Rooftop 2	Google Maps Location	📍 6° 21' 24.9552" S 10...
Under Canopy	No		
Environmental Instruments			
Installation Status	Installed	Retrieved	
Same as the previous condition, the installation of Ambient Weather Stations at the The Grand Outlet, East Jakarta Karawang Karawang involved two units placed on Rooftop 1 and Rooftop 2, coded respectively. Due to signal issues, the stations were switched, with Ambient Weather 1 moved to Rooftop 2 and Ambient Weather 2 relocated to Rooftop 1, ensuring reliable data transmission for both monitoring points.	✓	✓	
Point's Surrounding			
North	South	West	East
-	-	-	-
Parameters Measured			
Outdoor Temperature, Wind Speed, Wind Direction, Daily Rain, Humidity, Ultra-Violet Radiation Index, Solar Radiation.			
Descriptive of The Points			
Existing			
The equipment will be installed on the 3rd floor of a utility building, positioned 9 meters above ground level. The installation site is open and unobstructed, allowing the device to effectively collect environmental data. Due to exposure to high wind speeds, a stabilizing weight, such as stones, will be required to secure the equipment in place. The device will be located adjacent to the existing green hub area and accessed via an emergency staircase. The monitoring range is designed to cover a radius of approximately 20-35 meters.			

Installation Photos



Data Analyses

Key environmental parameters, including air temperature, humidity, air velocity, WBGT, and solar radiation, were recorded using instruments such as T&D data loggers, WBGT meter, anemometers, and Ambient Weather WS-2000 weather stations at selected Semi-Outdoor and outdoor points. Despite challenges like electrical shortages, thunderstorms, and equipment recalibration, the dataset provides a robust foundation for analyzing environmental loads and their impact on thermal comfort and microclimate conditions within the facility.

The analyses are conducted using JMP 18.0 Academic Version, employing statistical methods such as descriptive statistics, regression analysis, and ANOVA through graphs to interpret the dataset comprehensively.

Overall Condition

To summarize the overall condition during the operation period (26 November to 5 December), average values for each parameter, grouped by monitoring points (5 points inside facility and 2 points outside facility) and equipment, were conducted. This approach provides a concise representation of key environmental metrics, including air temperature, humidity, air velocity, WBGT, and solar radiation, ensuring a comprehensive overview for further analysis. Additionally, average value also conducted for Ambient Weather Stations that were placed at two points outside the facility to monitor parameters including air temperature, wind speed, wind direction, humidity, ultraviolet index, solar radiation, and daily rainfall. These outdoor measurements complement the previously stated parameters recorded inside the facility, providing a holistic understanding of the environmental conditions during the study.

Outside Facility Overall Conditions

The outside facility's overall conditions during the operation period are summarized by average values of key environmental parameters recorded using Ambient Weather Station WS2000 placed at two rooftop points (AWS1 placed on Rooftops 2, AWS2 placed on Rooftops 1). These parameters include air temperature, wind speed, wind direction, humidity, ultraviolet index, solar radiation, and daily rainfall. This summary provides a comprehensive overview of the external environmental conditions, which will

be analyzed further to understand their impact on the facility's microclimate and performance.

Air Temperature

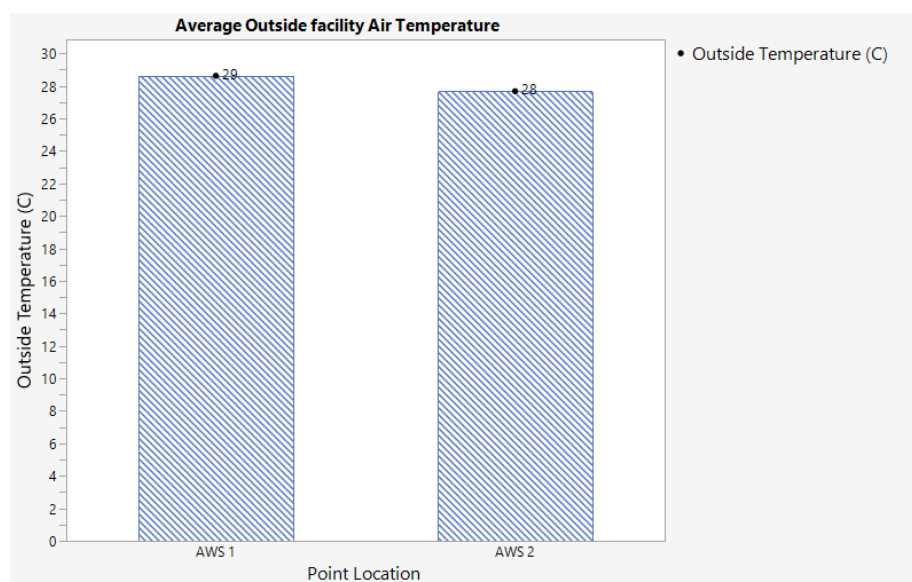


Figure 12. Comparison Average Temperature at Outside Facility (Source: Research Team, 2024)

Wind Speed

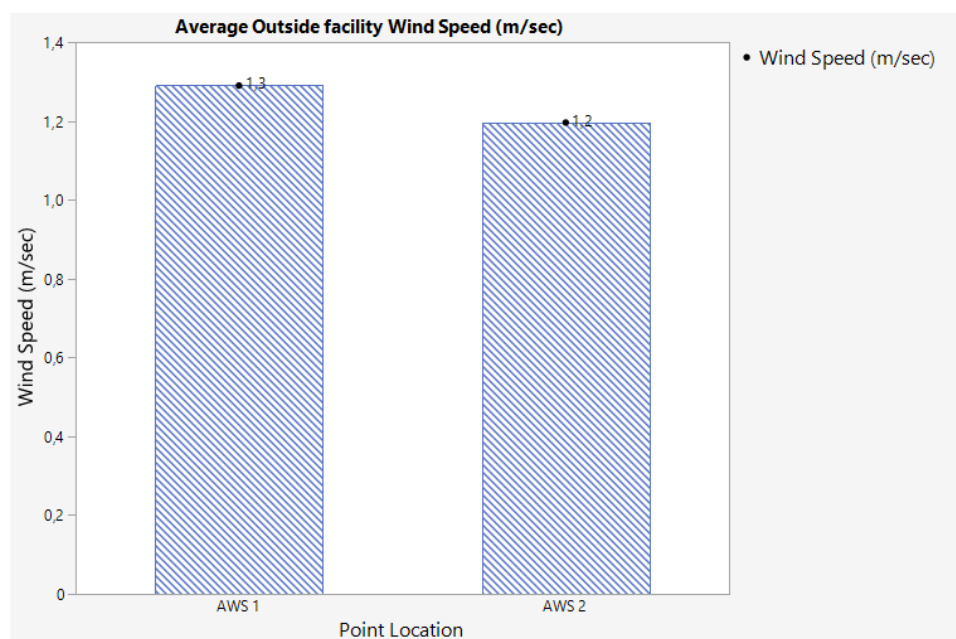


Figure 13. Comparison Average Wind Speed at Outside Facility (Source: Research Team, 2024)

Wind Direction

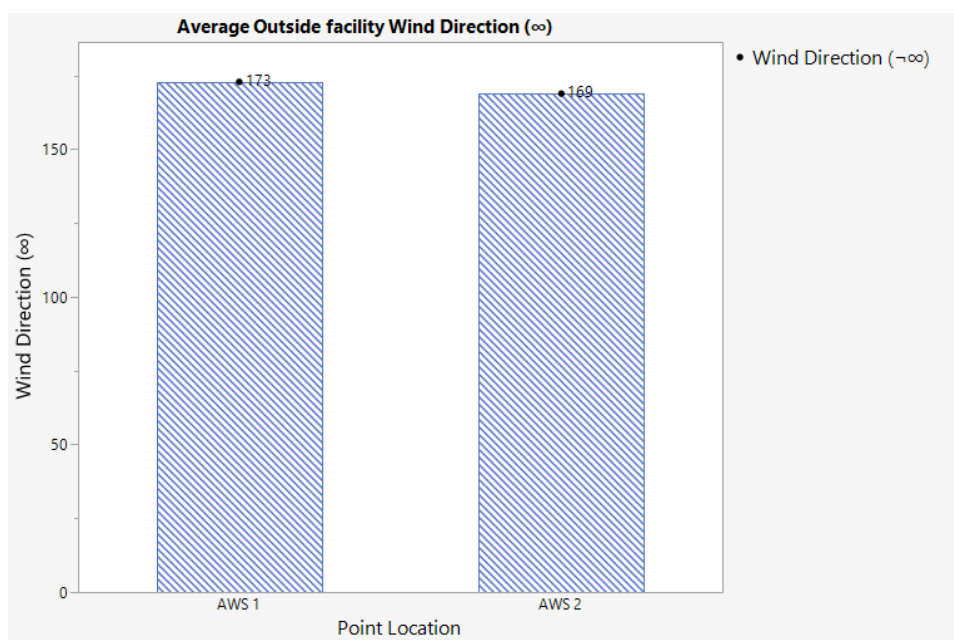


Figure 14. Comparison Average Wind Direction at Outside Facility (Source: Research Team, 2024)

Humidity

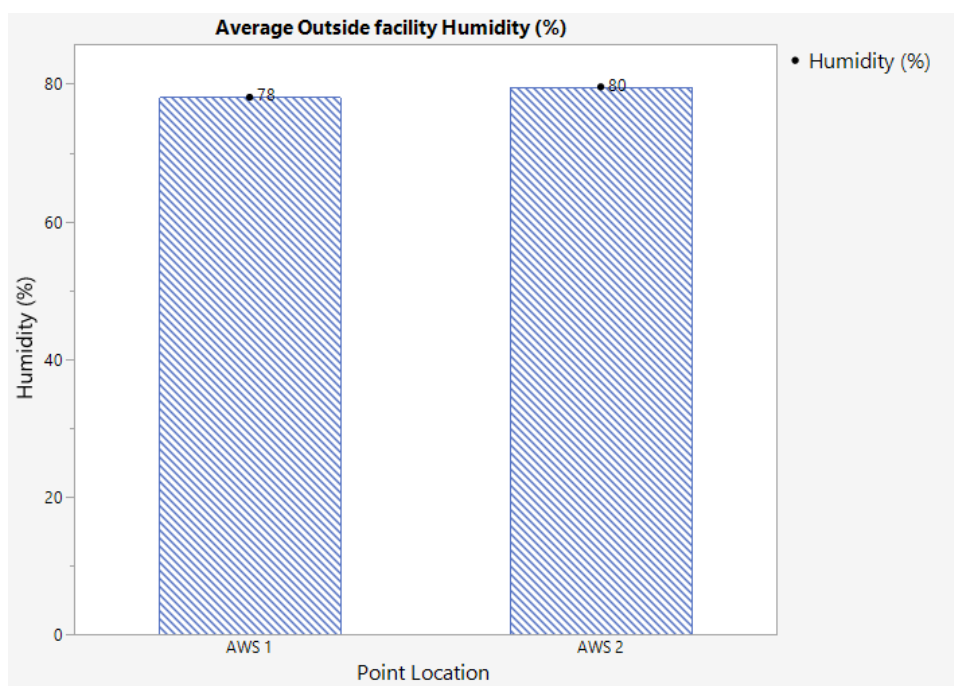


Figure 15. Comparison Average Humidity at Outside Facility (Source: Research Team, 2024)

Ultraviolet Radiation Index

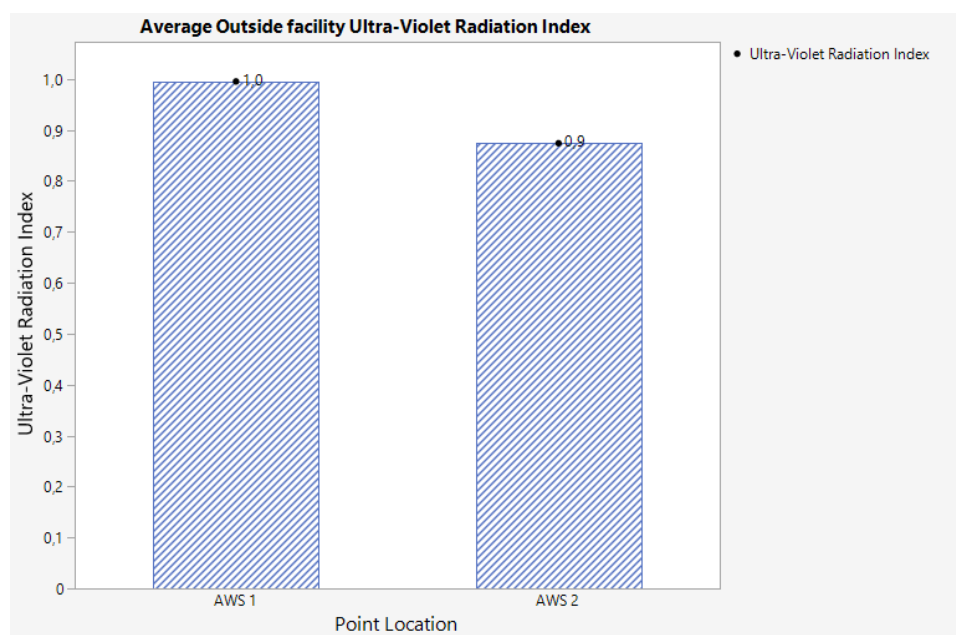


Figure 16. Comparison Average Ultra-Violet Radiation index at Outside Facility (Source: Research Team, 2024)

Solar Radiation

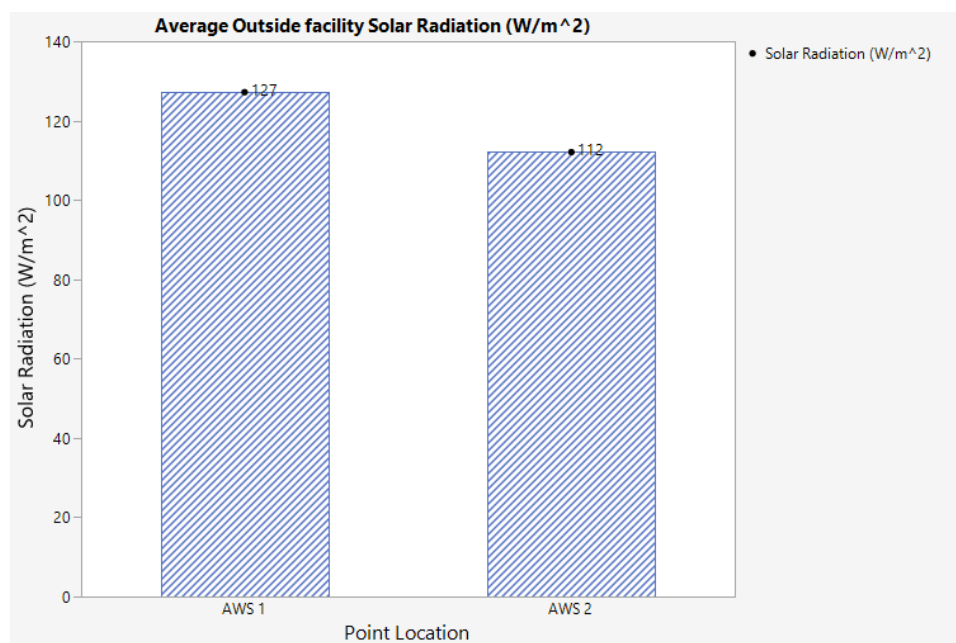


Figure 17. Comparison Average Solar Radiation at Outside Facility (Source: Research Team, 2024)

Daily Rain

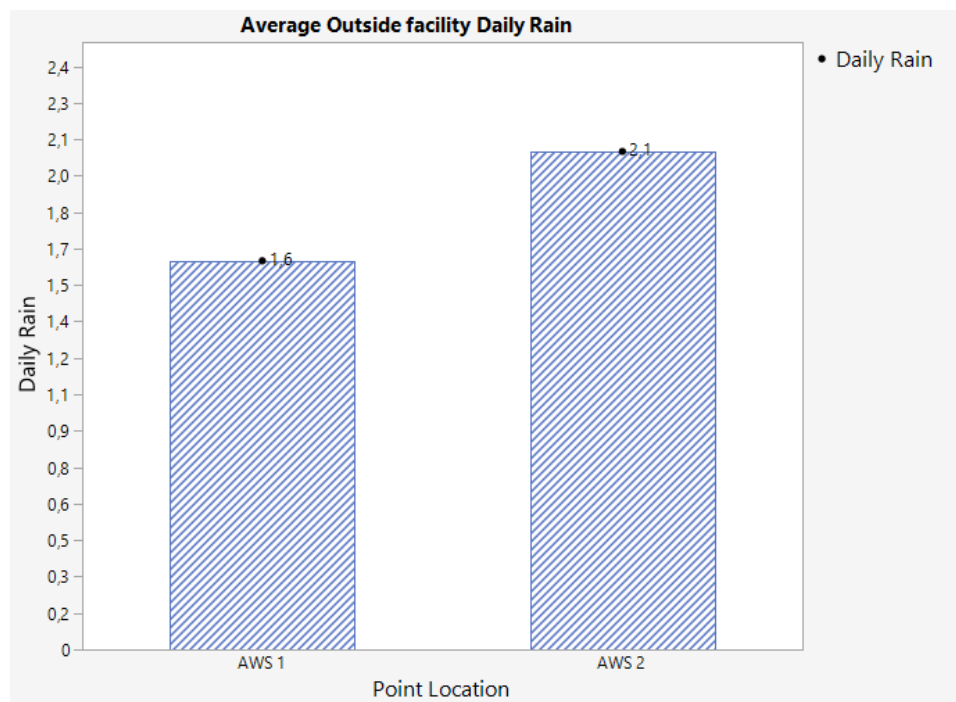


Figure 18. Comparison Average Daily Rain at Outside Facility (Source: Research Team, 2024)

Inside Facility Overall Conditions

Air Temperature Average

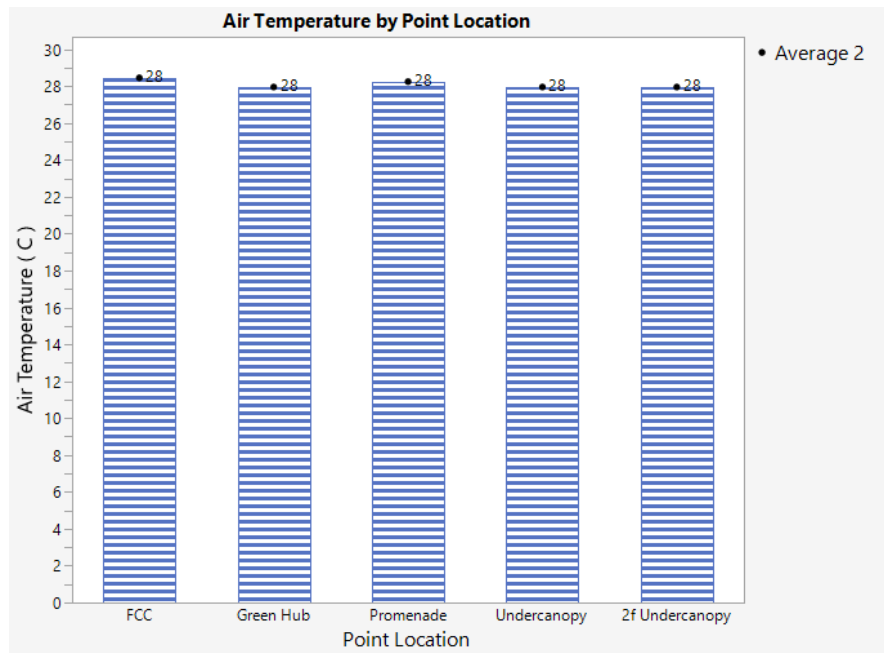


Figure 19. Air Temperature Average at Inside Facility (Source: Research Team, 2024)

Humidity Average

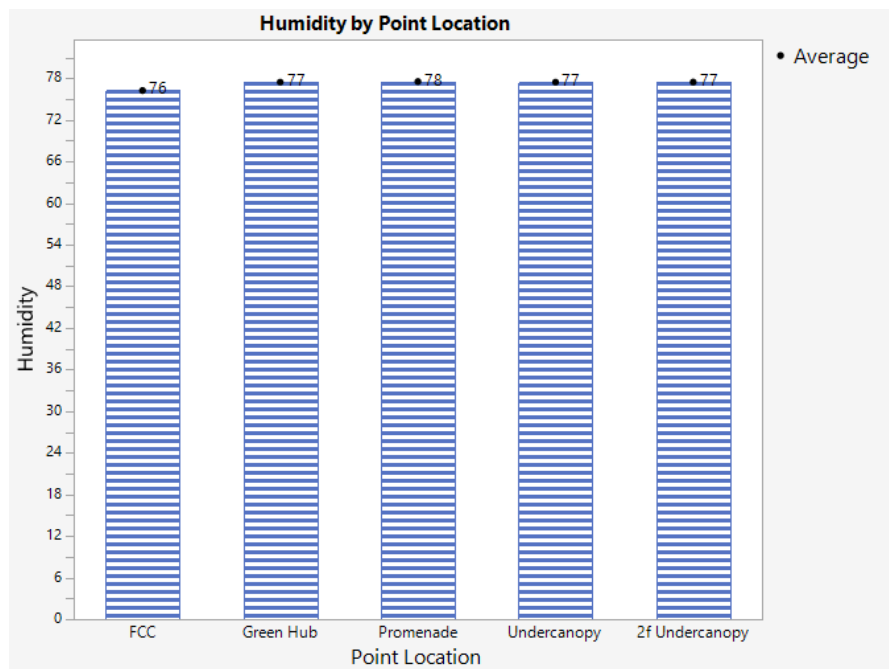


Figure 20. Humidity Average at Inside Facility (Source: Research Team, 2024)

Illuminance Average

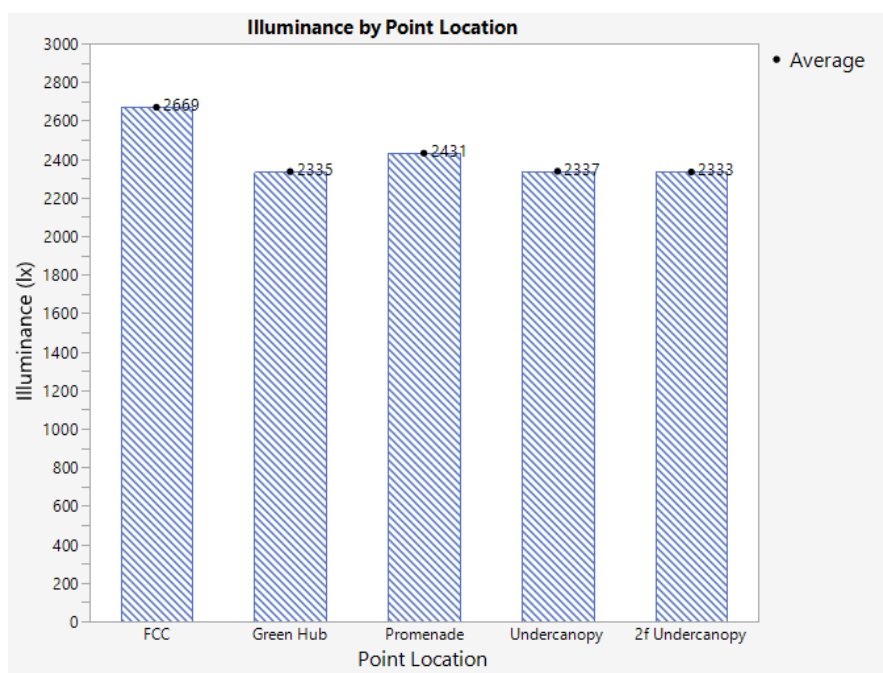


Figure 21. Illuminance Average at Inside Facility (Source: Research Team, 2024)

Wet Bulb Globe Temperature Average

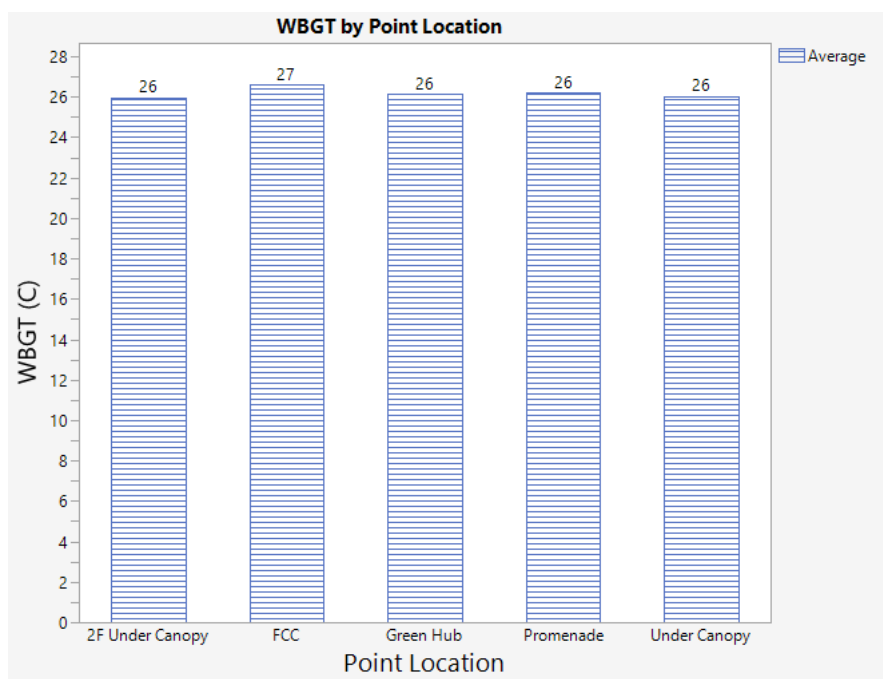


Figure 22. WBGT Average at Inside Facility (Source: Research Team, 2024)

Globe Temperature Average

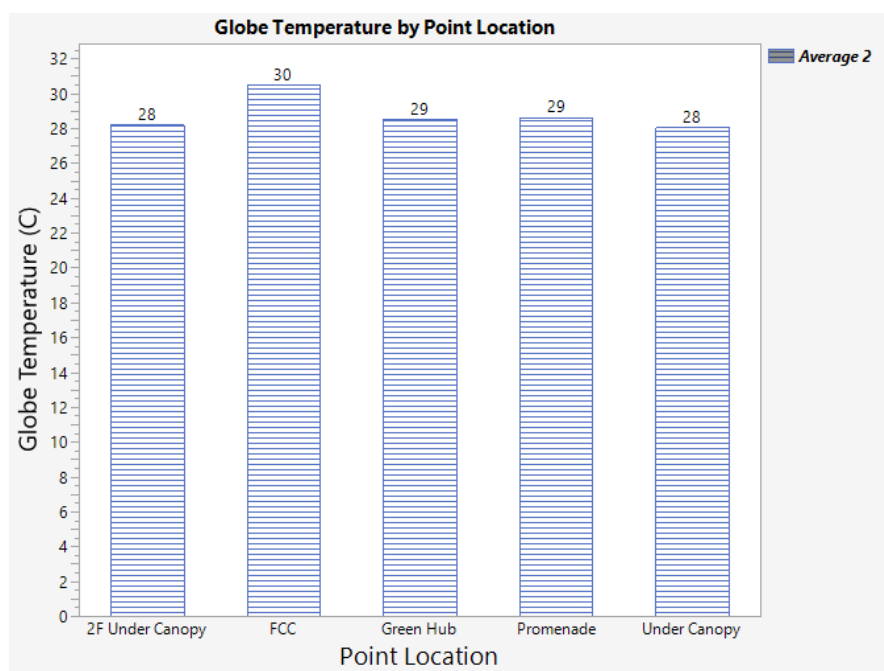


Figure 23. Globe Temperature Average at Inside Facility (Source: Research Team, 2024)

Wet Temperature

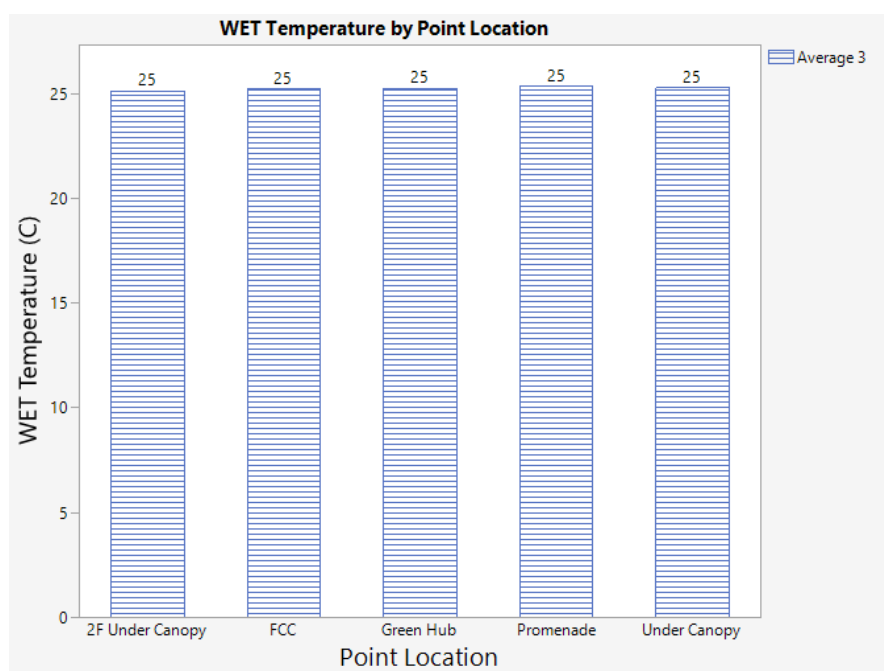


Figure 24. WET Temperature Average at Inside Facility (Source: Research Team, 2024)

Dew Point

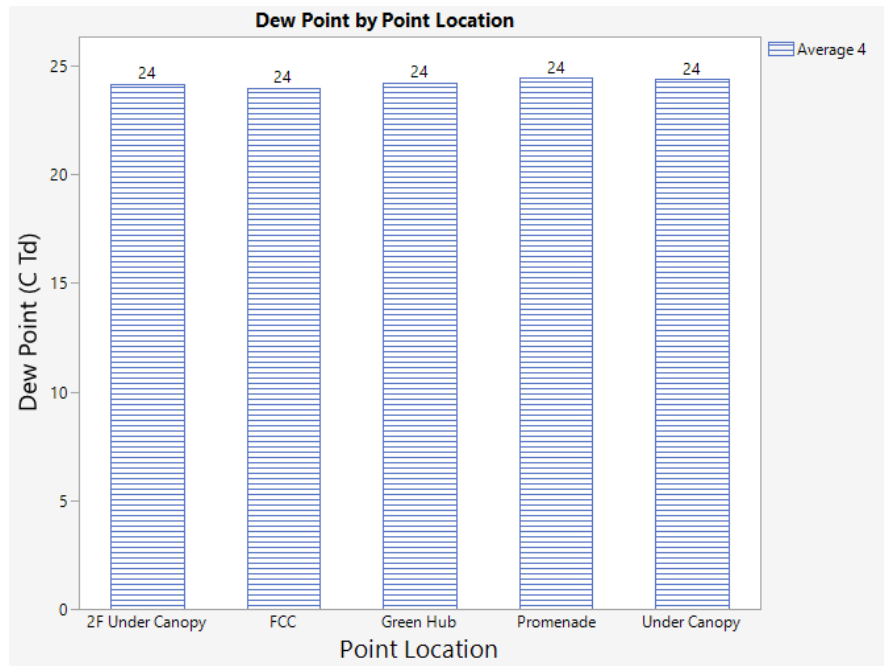


Figure 25. Dew Point Average at Inside Facility (Source: Research Team, 2024)

Air Velocity

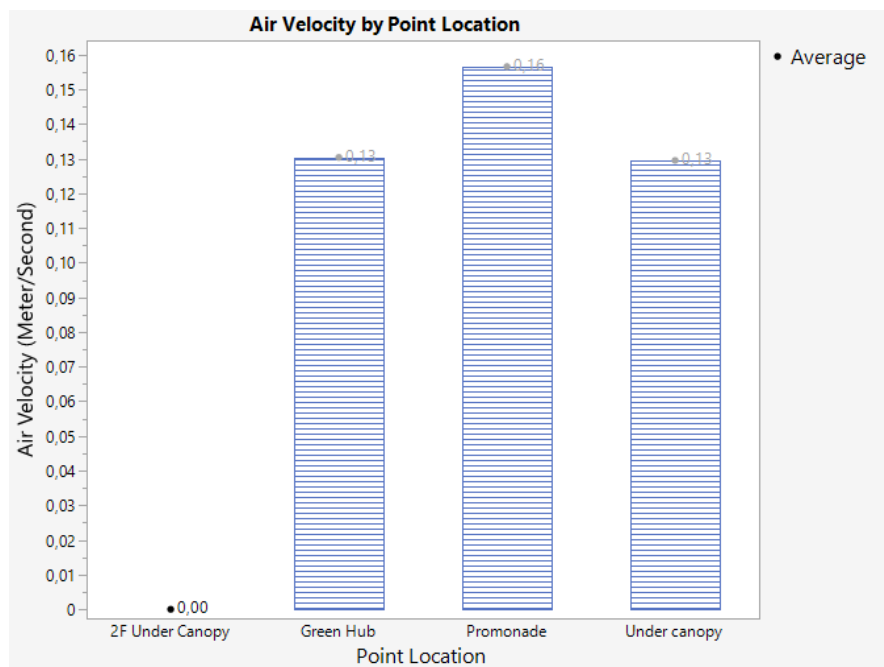


Figure 26. Air Velocity Average at Inside Facility (Source: Research Team, 2024)

Analyses

Daily Fluctuations and Mean Trends

This section presents the statistical analysis of environmental parameters collected at the Grand Outlet Karawang Outlet during the operational period from 26 November to 5 December. Using boxplot visualization, this analysis highlights the daily variability and mean trends in parameters such as air temperature, humidity, air velocity, and WBGT, as measured across various monitoring points. The boxplots represent the data distribution, including the median, interquartile range, and outliers, for each operational date, providing a comprehensive overview of environmental fluctuations. These insights are critical for understanding the temporal trends and variability in thermal conditions within the facility, which are directly tied to evaluating thermal comfort and environmental load impacts on the microclimate

WBGT Trends at Green Hub

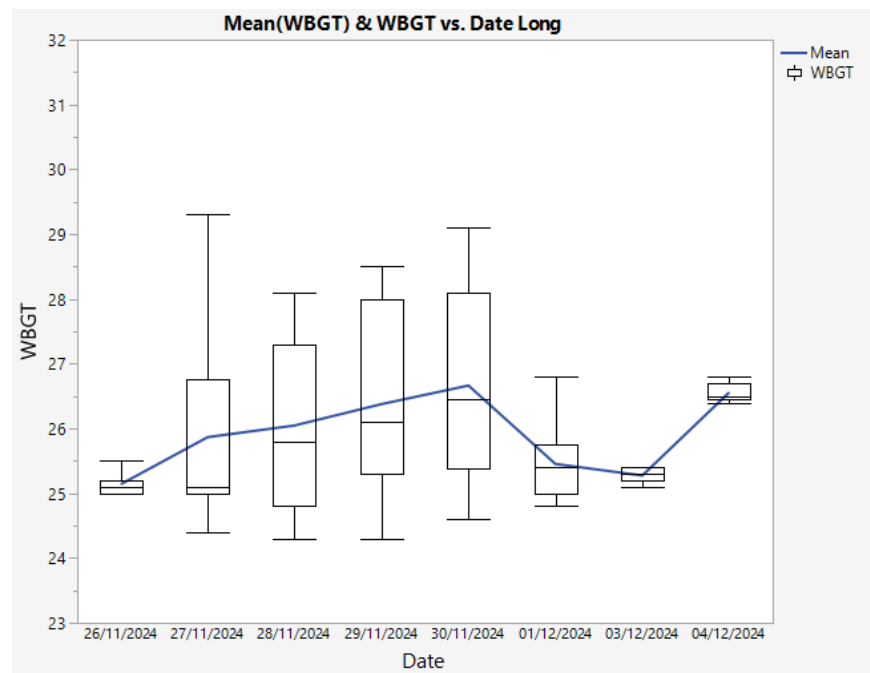


Figure 27. WBGT Fluctuations and Mean Trends (Source: Research Team, 2024)

Globe Trends at Green Hub

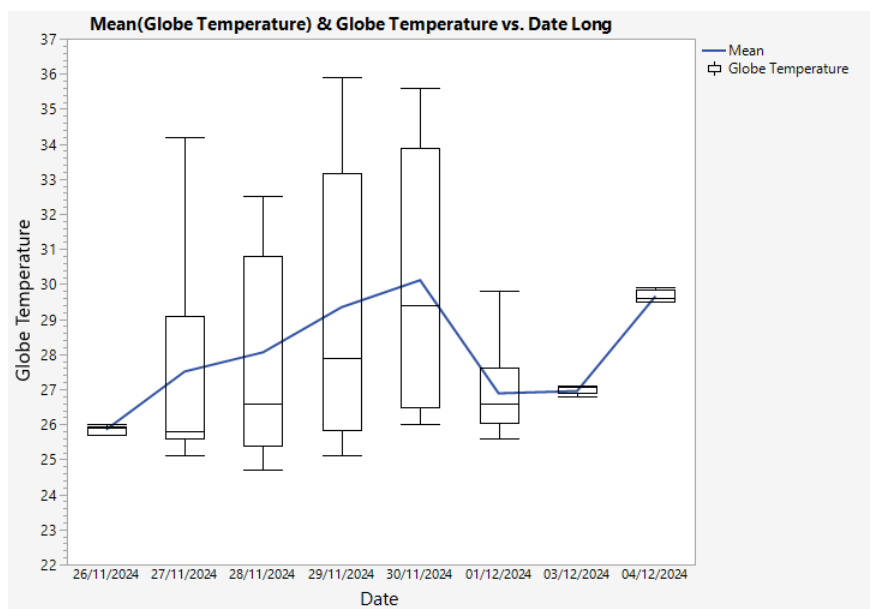


Figure 28. Globe Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

WET Trends at Green Hub

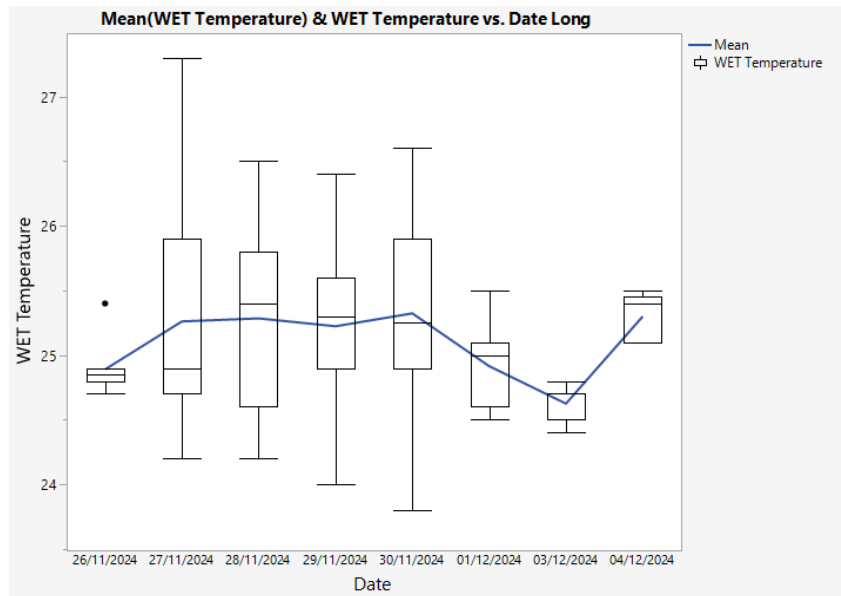


Figure 29. WET Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Dew Point Trends at Green Hub

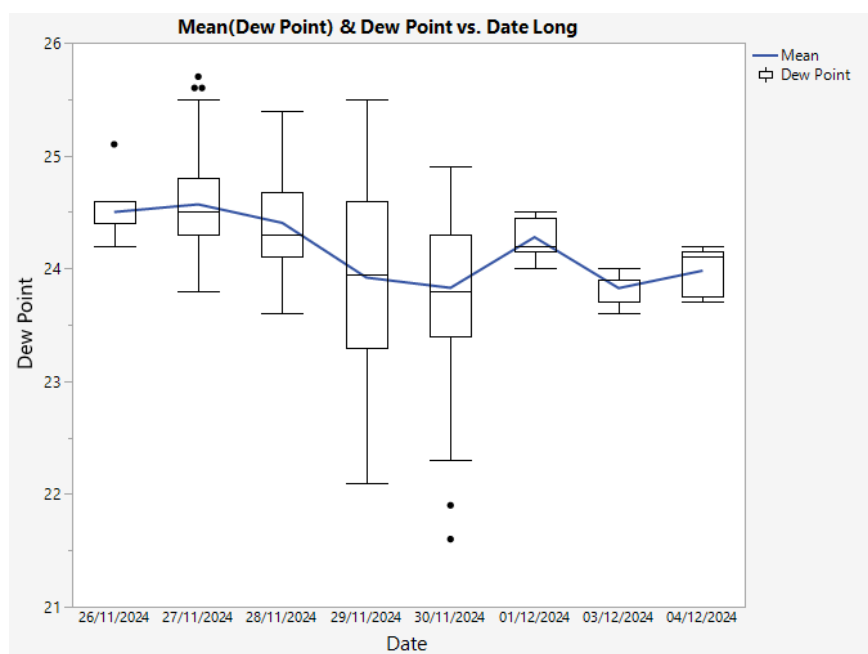


Figure 30. Dew Point Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Temperature Trends at Green Hub

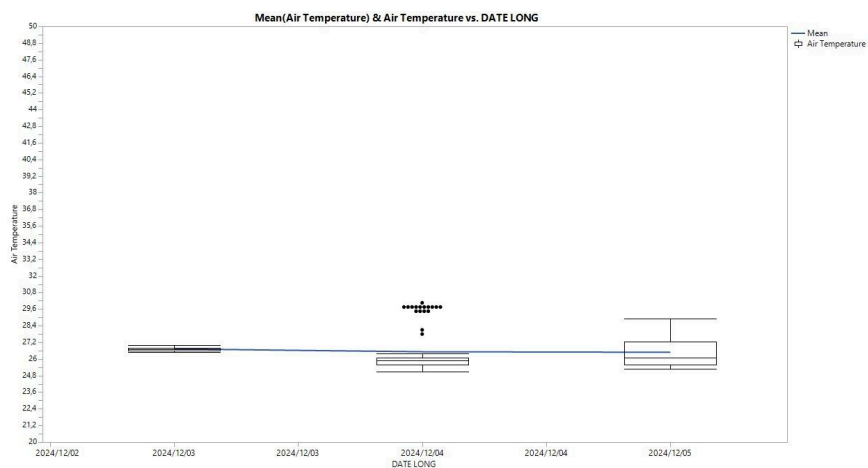


Figure 31. Air Temperature Fluctuations and Mean Trends With Anemometer Instrument (Source: Research Team, 2024)

Air Temperature Trends at Green Hub

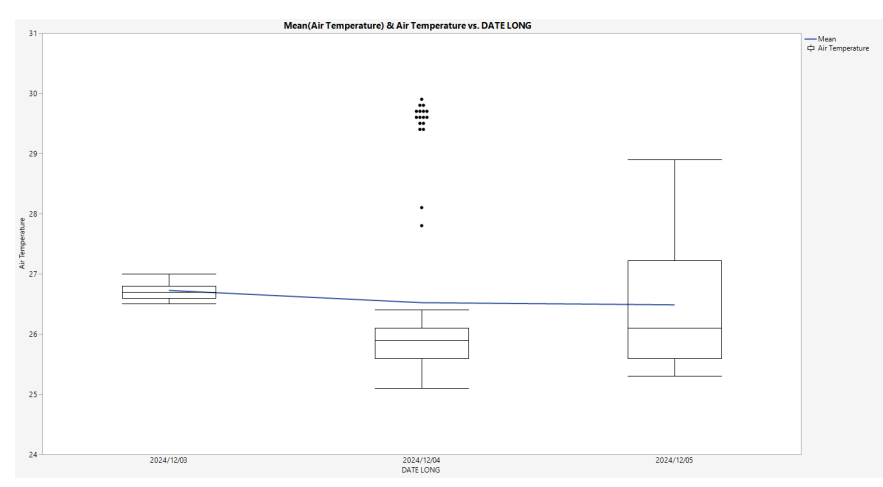


Figure 32. Air Temperature Fluctuations and Mean Trends With Anemometer Instrument (Source: Research Team, 2024)

Air Temperature Trends at Green Hub

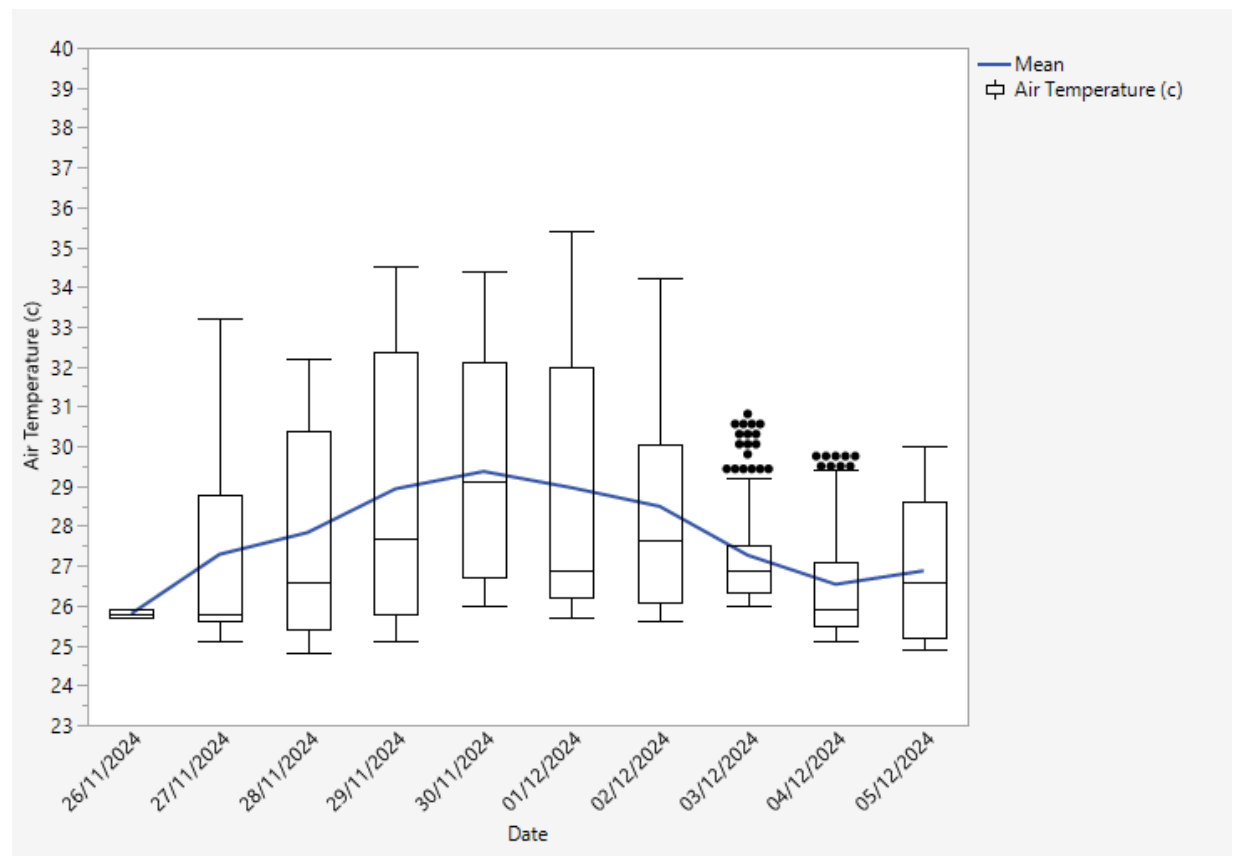


Figure 33. Air Temperature Fluctuations and Mean Trends With T and D Instrument (Source: Research Team, 2024)

Illuminance Trends at Green Hub

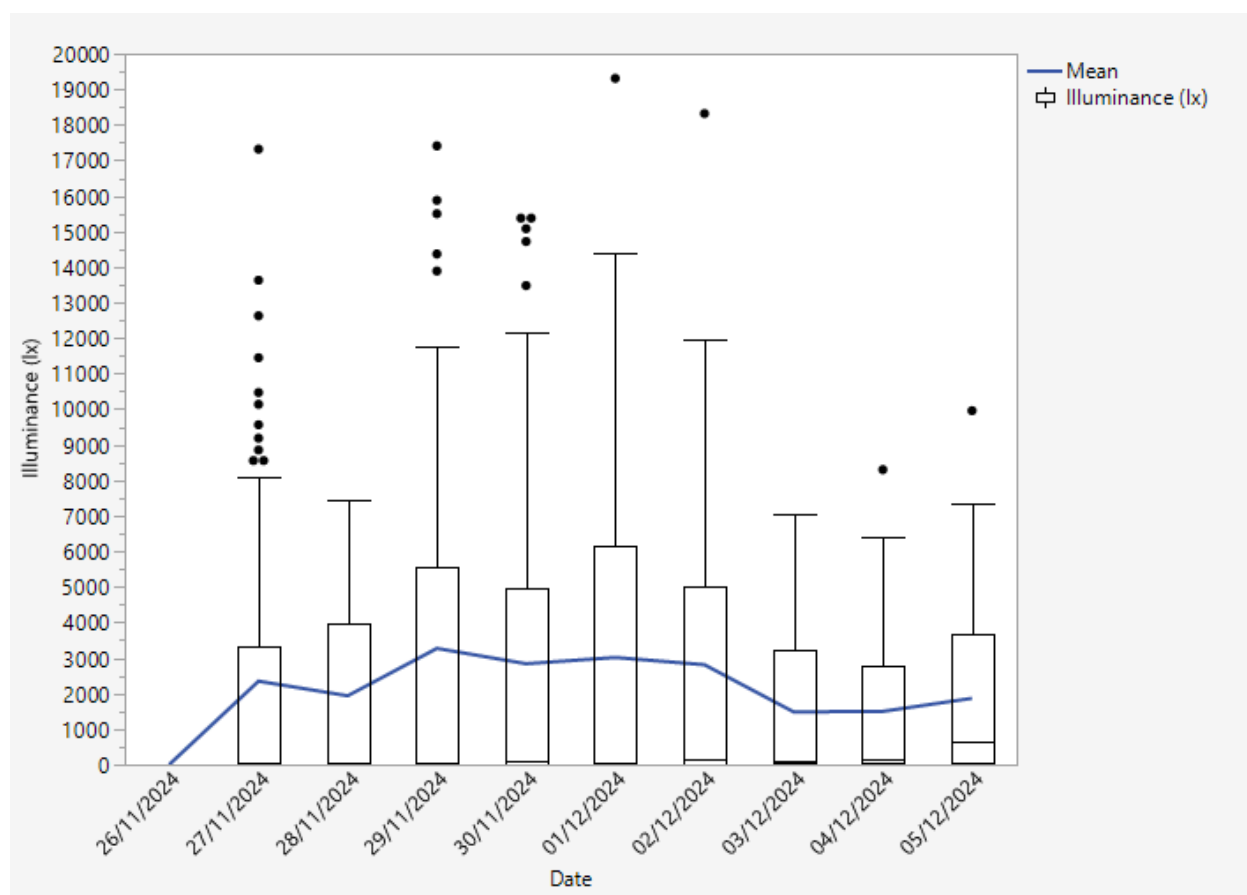


Figure 34. Illuminance Fluctuations and Mean Trends (Source: Research Team, 2024)

Humidity Trends at Green Hub

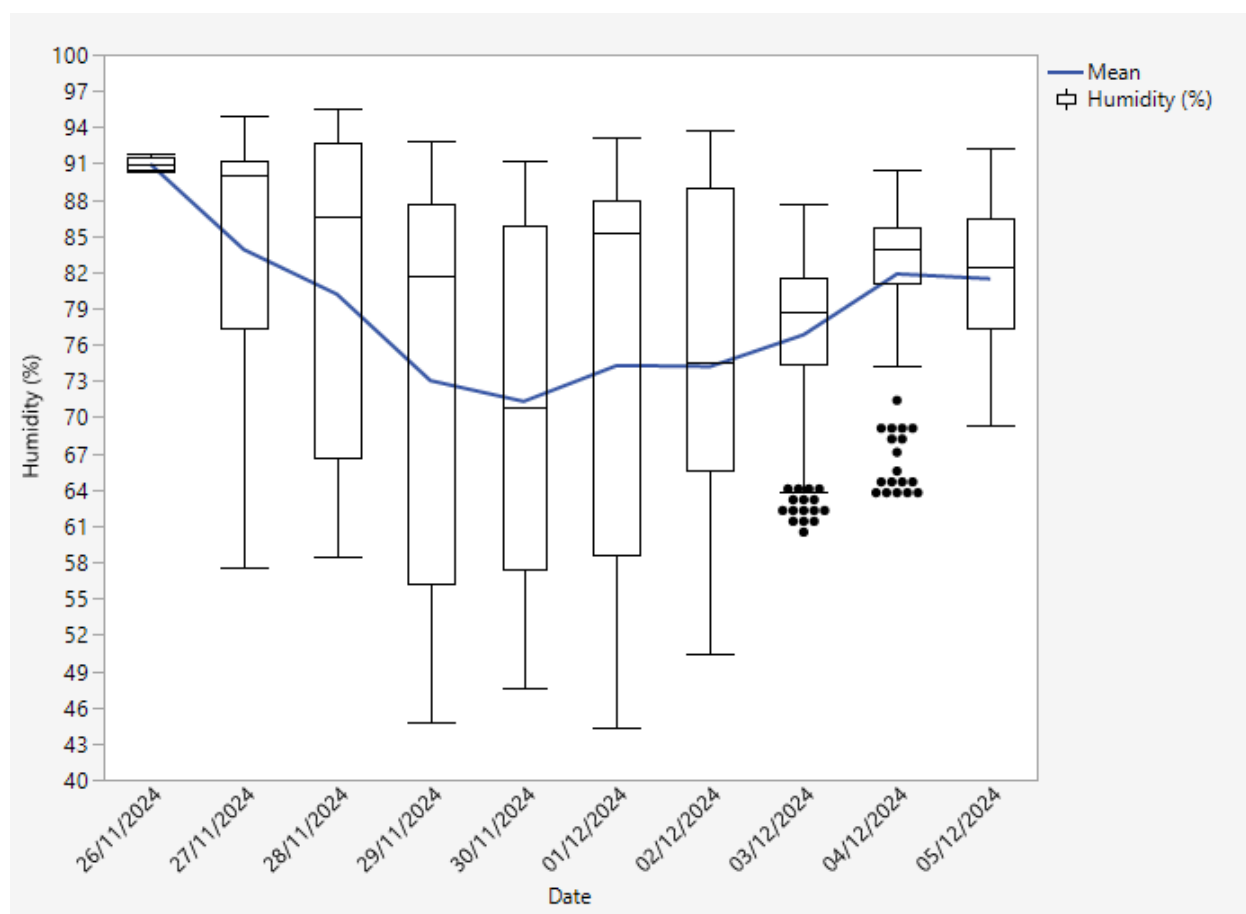


Figure 35. Humidity Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Velocity Trends at Green Hub

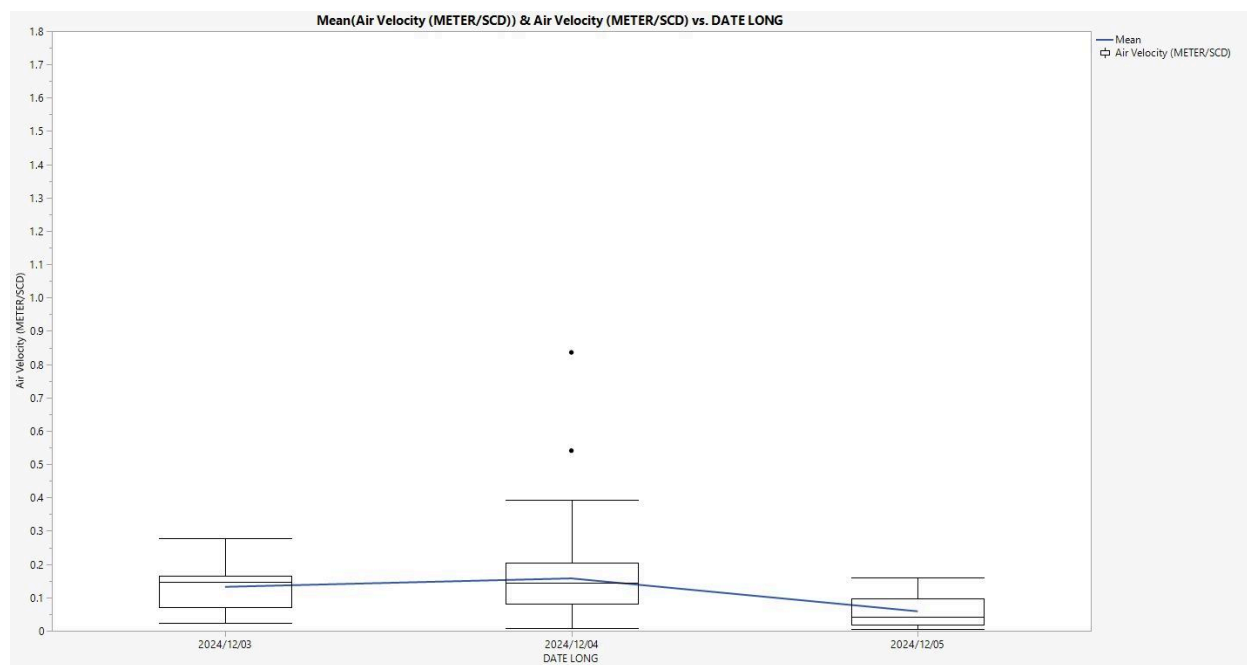


Figure 36. Air Velocity Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Velocity Trends at Green Hub

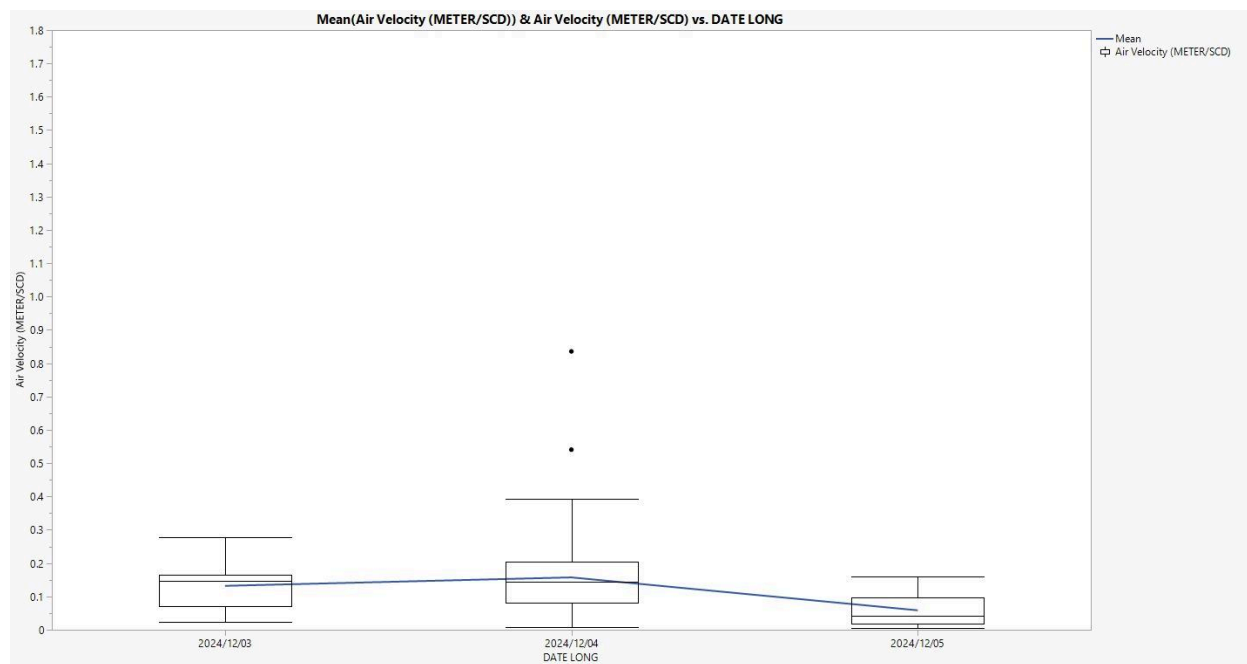


Figure 37. Air Velocity Fluctuations and Mean Trends (Source: Research Team, 2024)

WBGT Trends at Under Canopy

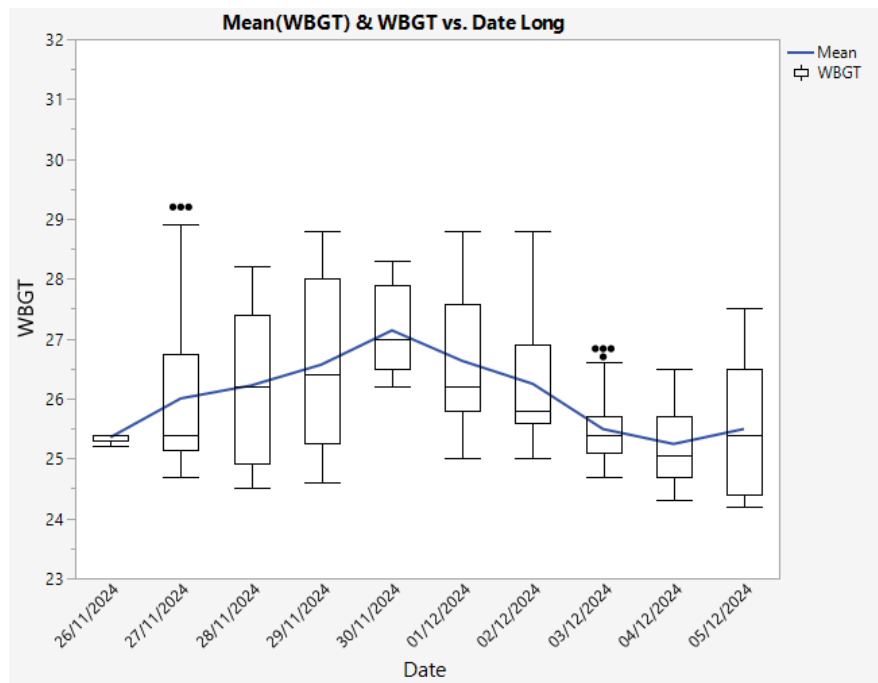


Figure 38. WBGT Fluctuations and Mean Trends (Source: Research Team, 2024)

Globe Trends at Under Canopy

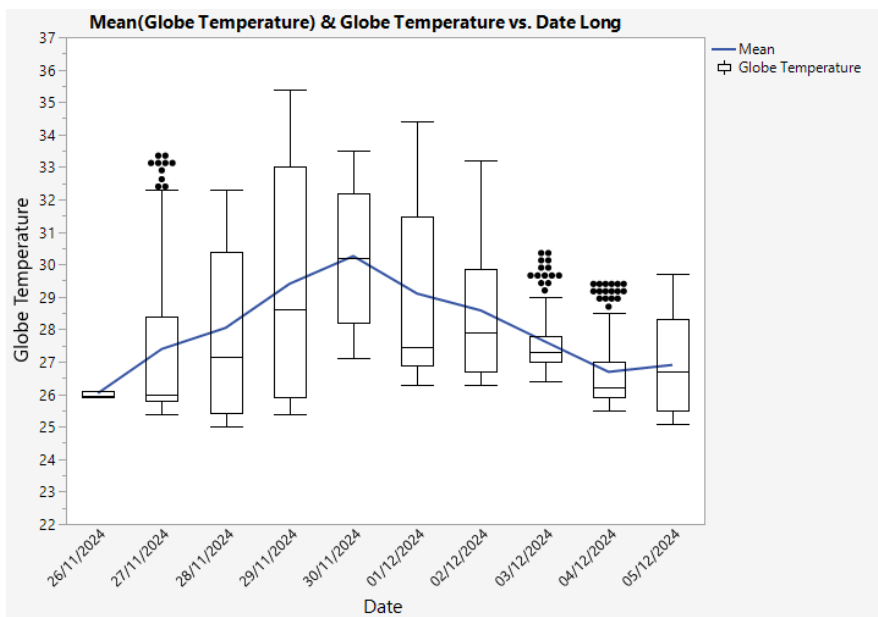
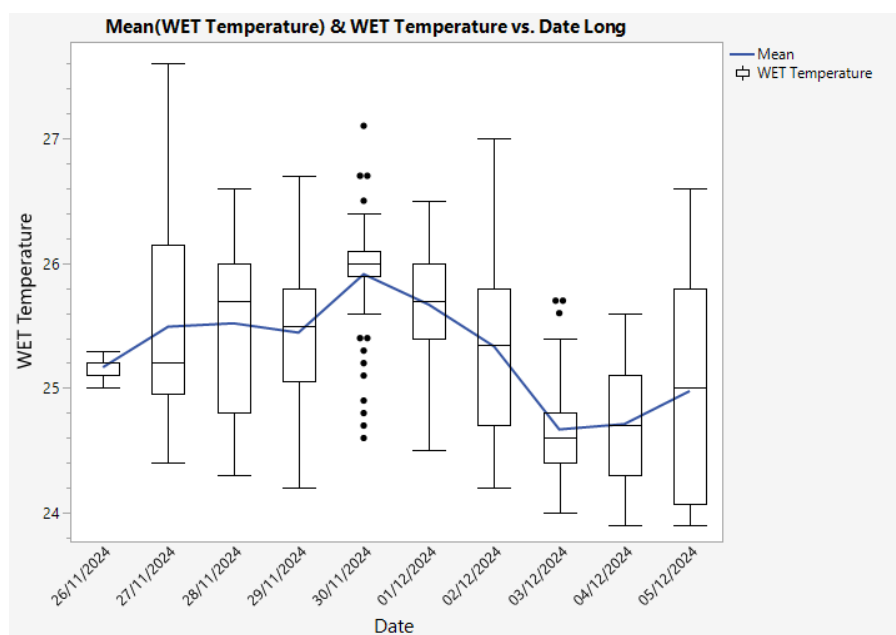


Figure 39. Globe Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

WET Trends at Under Canopy



Air Temperature Trends at Under Canopy

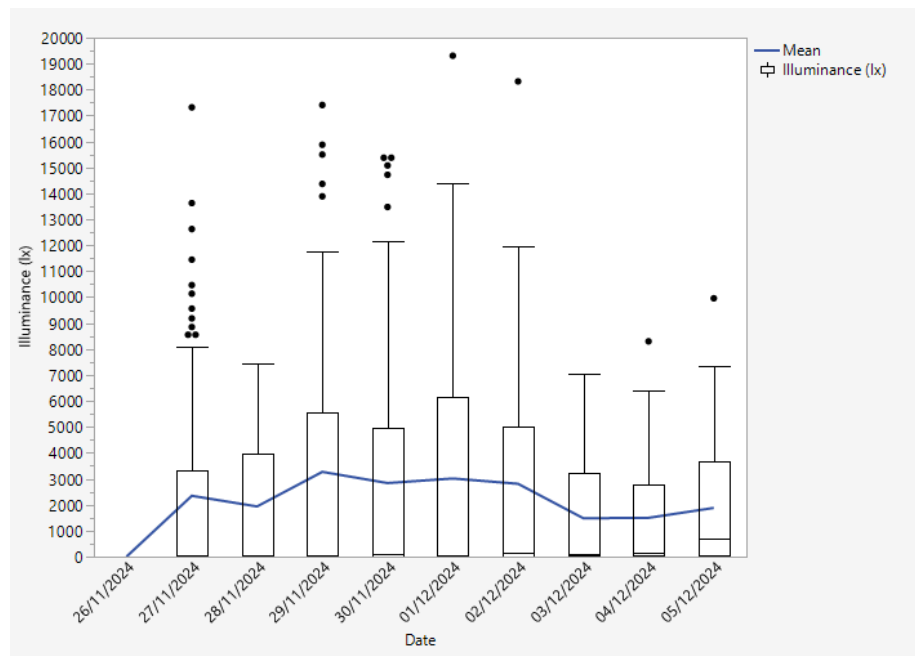


Figure 42. Air Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Illuminance Trends at Under Canopy

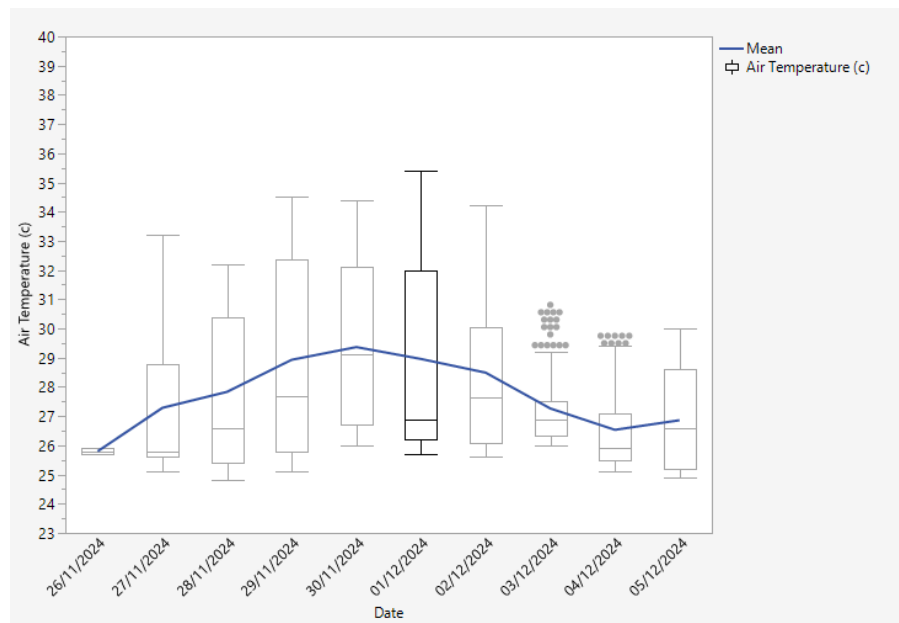


Figure 43. Illuminance Fluctuations and Mean Trends (Source: Research Team, 2024)

Humidity Trends at Under Canopy

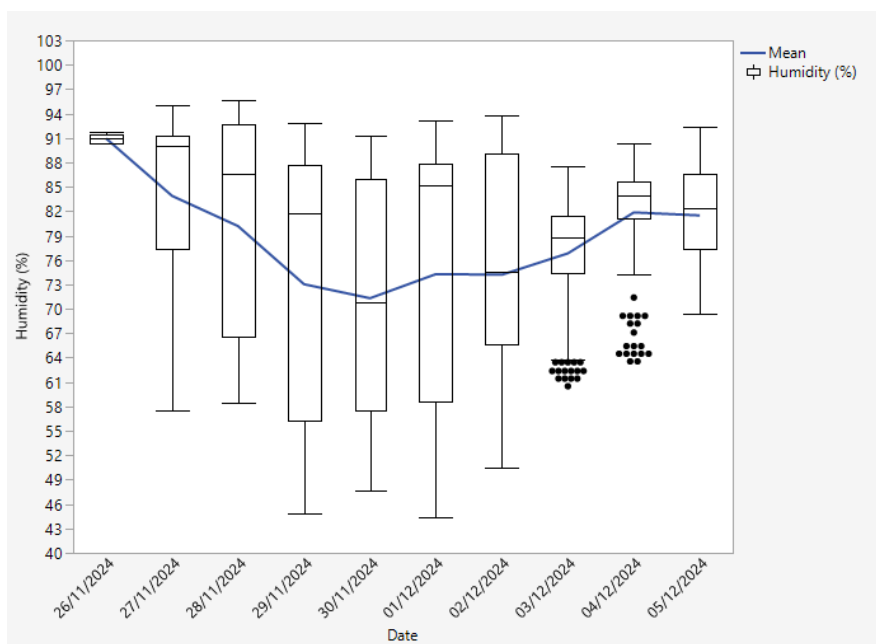


Figure 44. Humidity Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Velocity Trends at Under Canopy

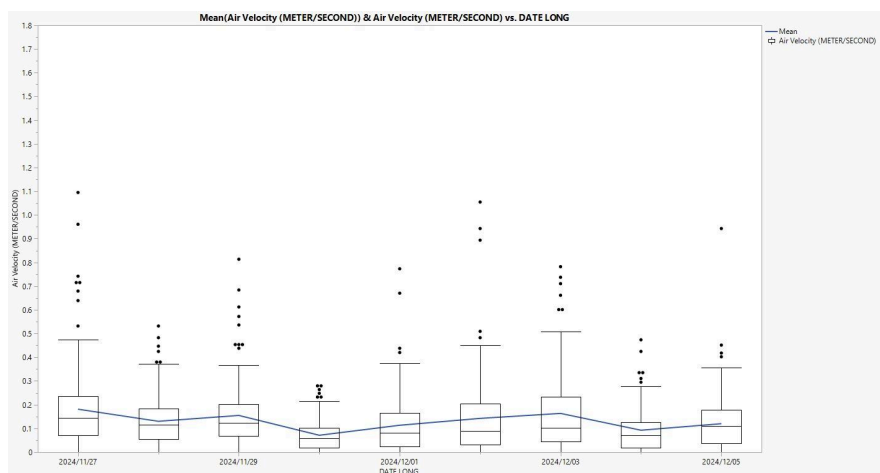


Figure 45. Air Velocity Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Velocity Trends at Under Canopy

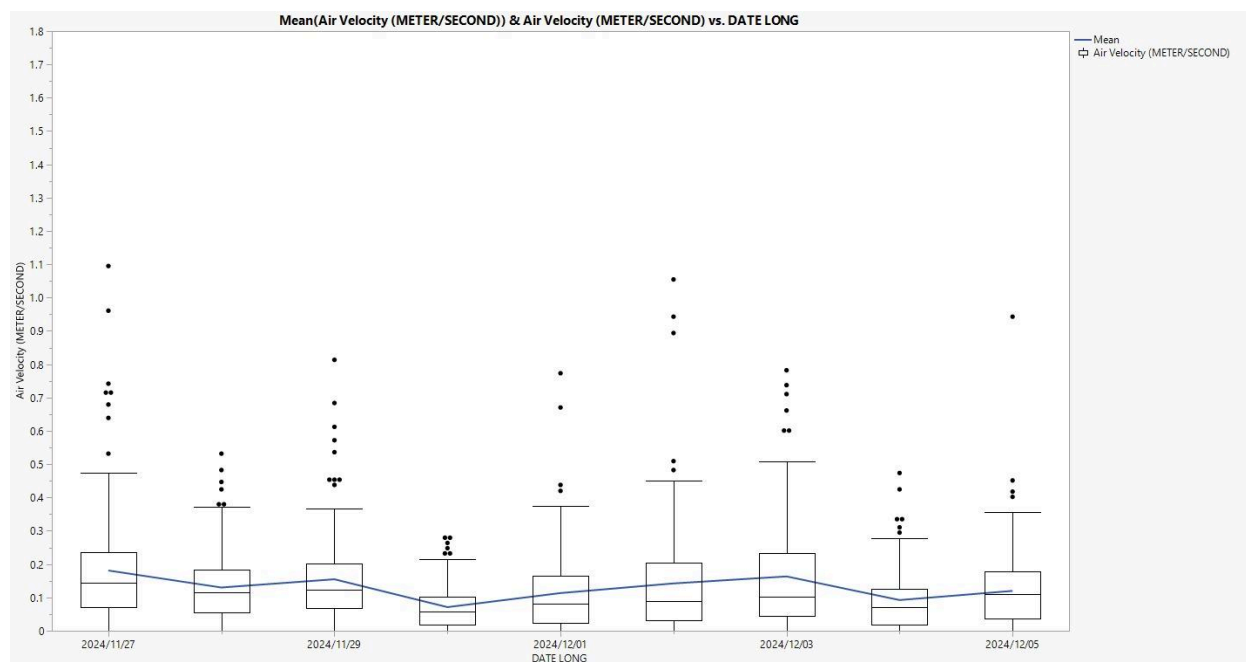


Figure 46. Air Velocity Fluctuations and Mean Trends (Source: Research Team, 2024)

WBGT Trends at Under Canopy

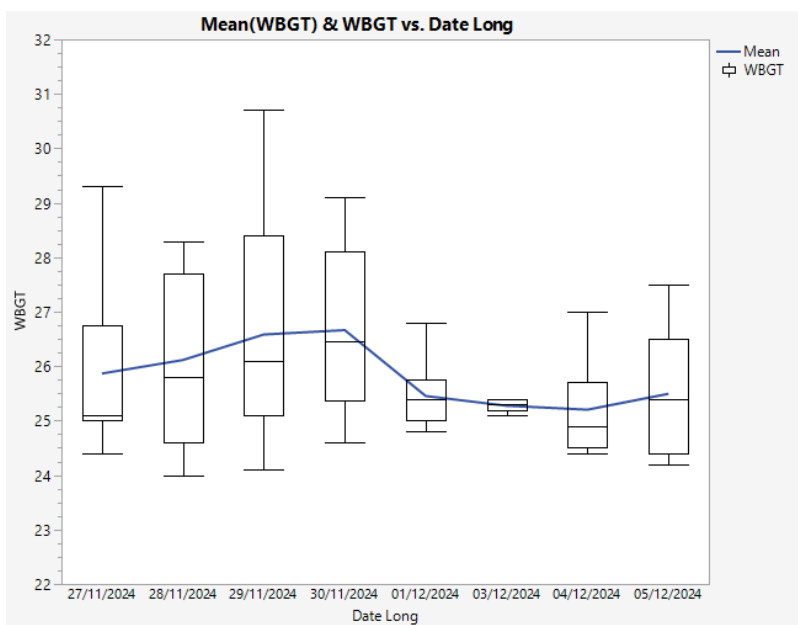


Figure 47. WBGT Fluctuations and Mean Trends (Source: Research Team, 2024)

Globe Trends at Under Canopy

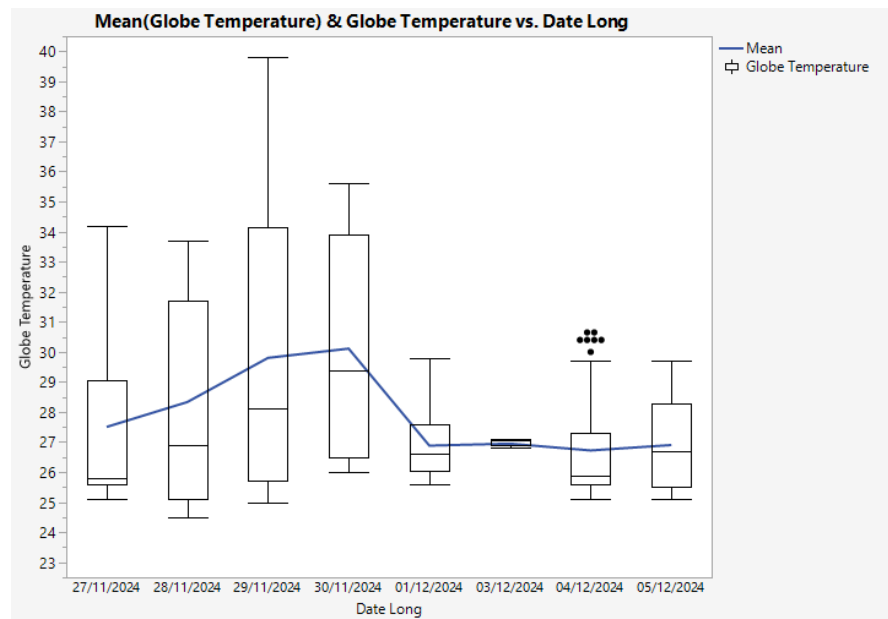


Figure 48. Air Velocity Fluctuations and Mean Trends (Source: Research Team, 2024)

WET Trends at Under Canopy

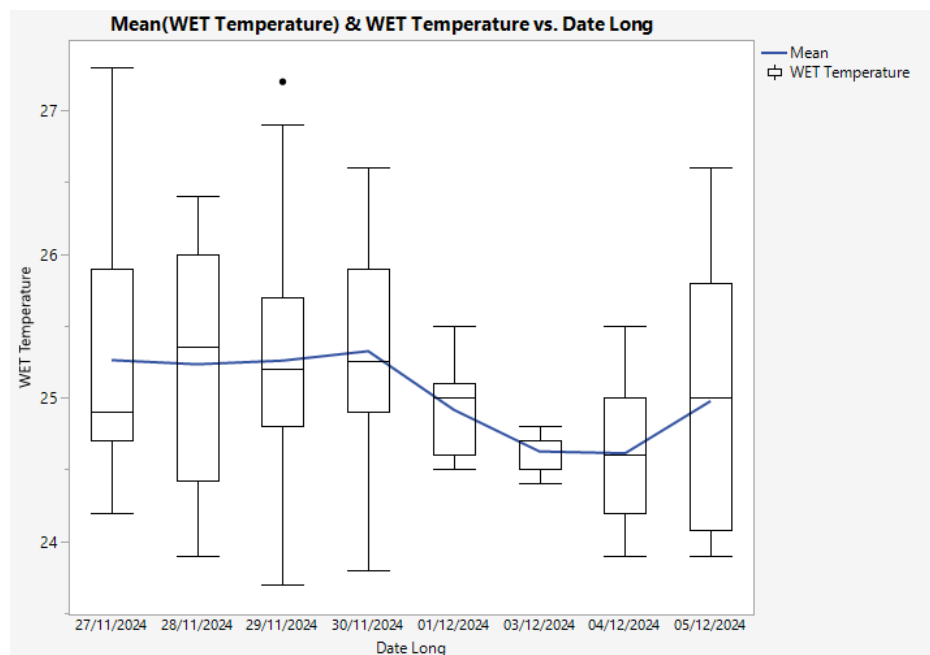


Figure 49. WET temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Dew Point Trends at Under Canopy

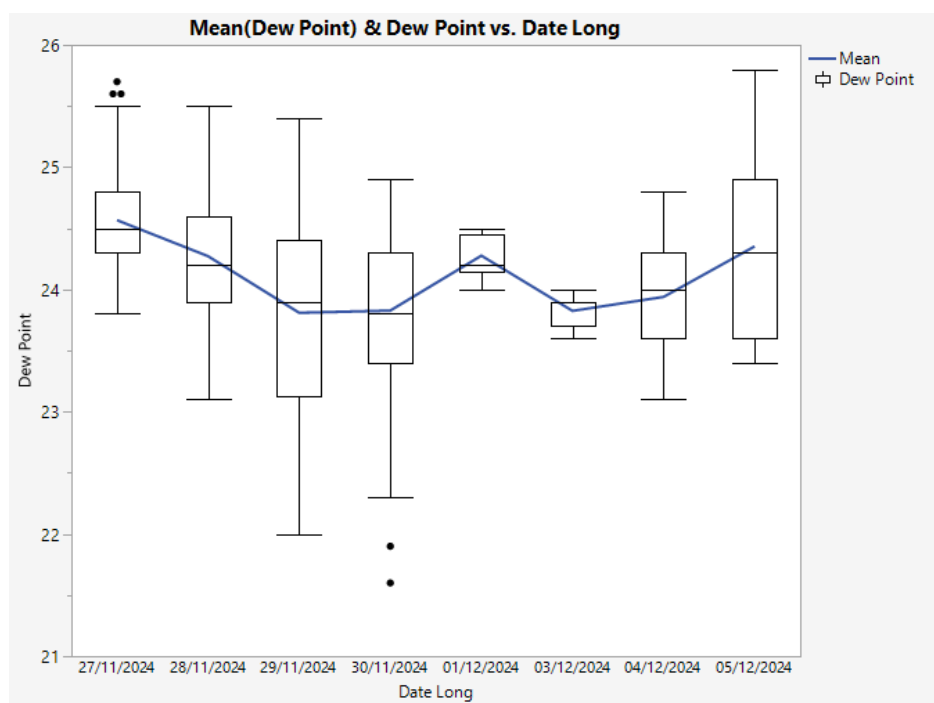


Figure 50. Dew Point Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Temperature Trends at Under Canopy

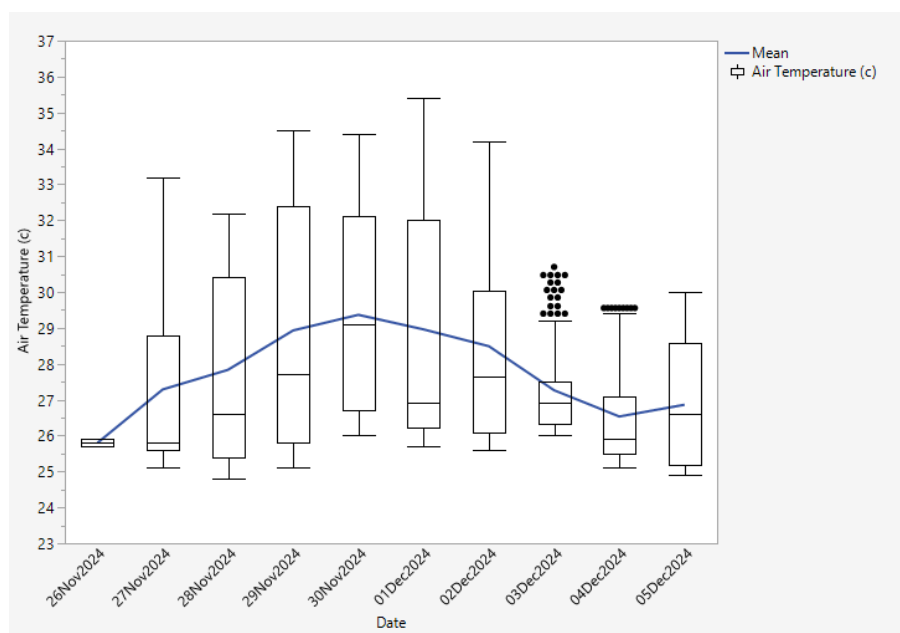


Figure 51. Air Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Illuminance Trends at Under Canopy

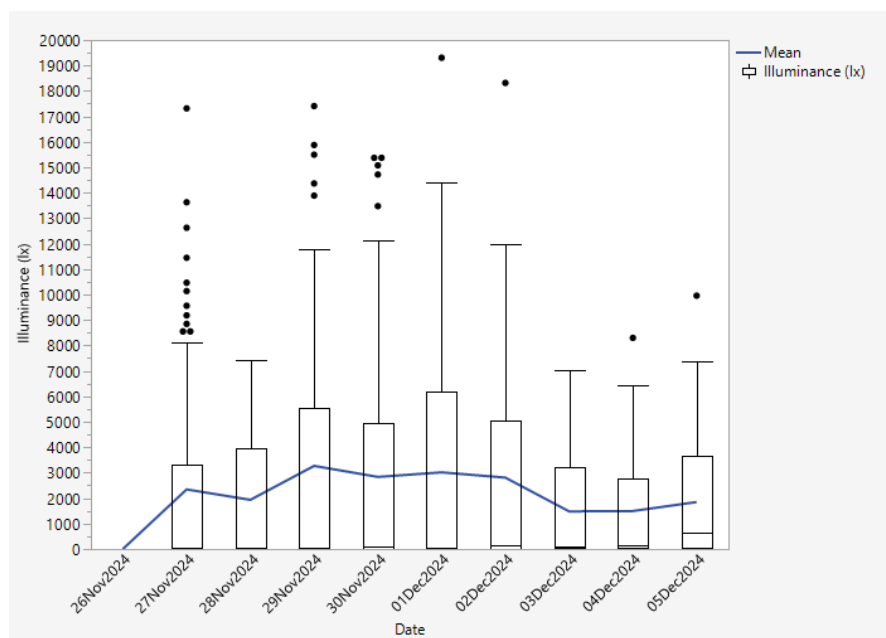


Figure 52. Illuminance Fluctuations and Mean Trends (Source: Research Team, 2024)

Humidity Trends at Under Canopy

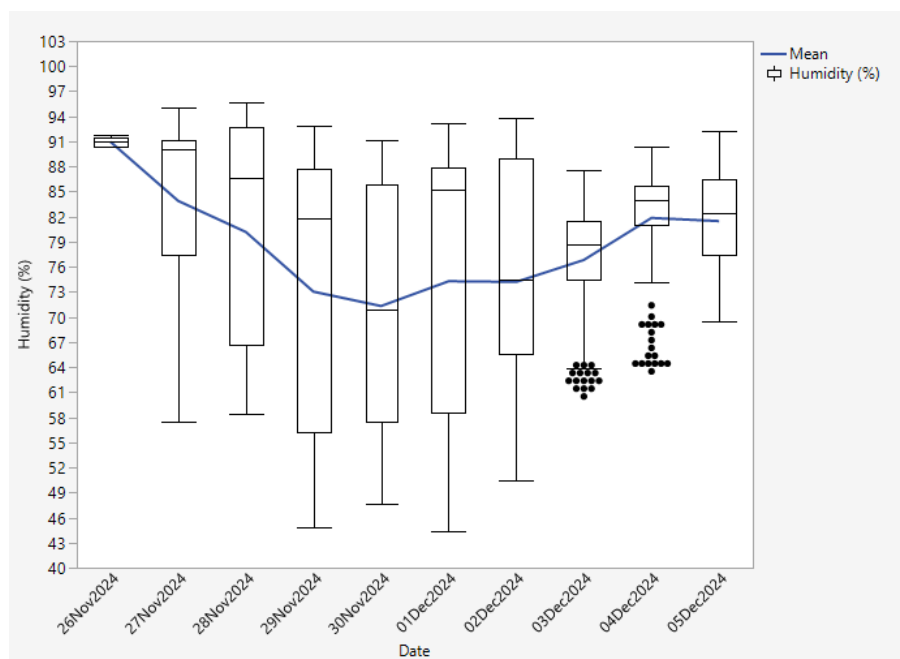


Figure 53. Humidity Fluctuations and Mean Trends (Source: Research Team, 2024)

Humidity Trends at Under Canopy

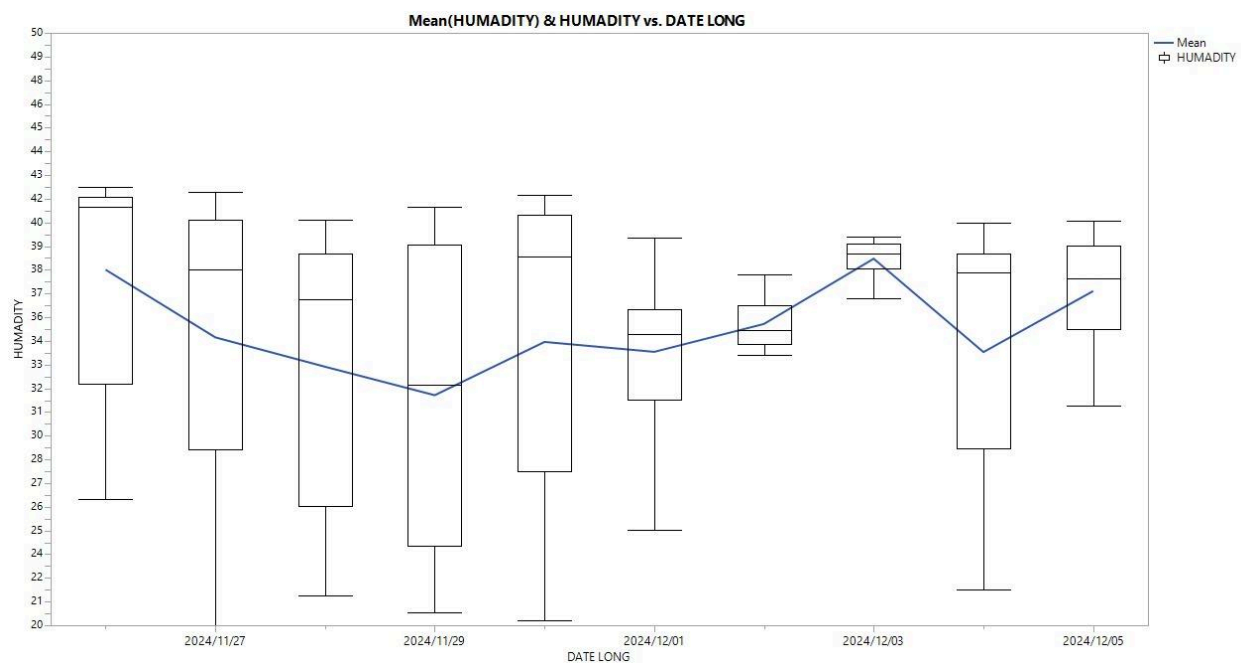


Figure 54. Humidity Fluctuations and Mean Trends (Source: Research Team, 2024)

WBGT Trends at Promenade

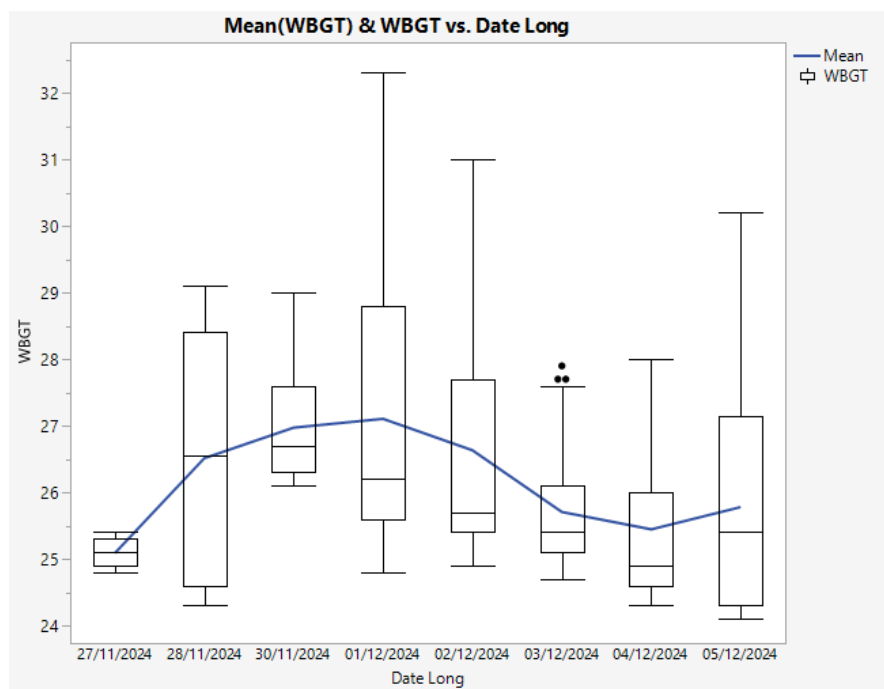


Figure 55. WBGT Fluctuations and Mean Trends (Source: Research Team, 2024)

Globe Trends at Promenade

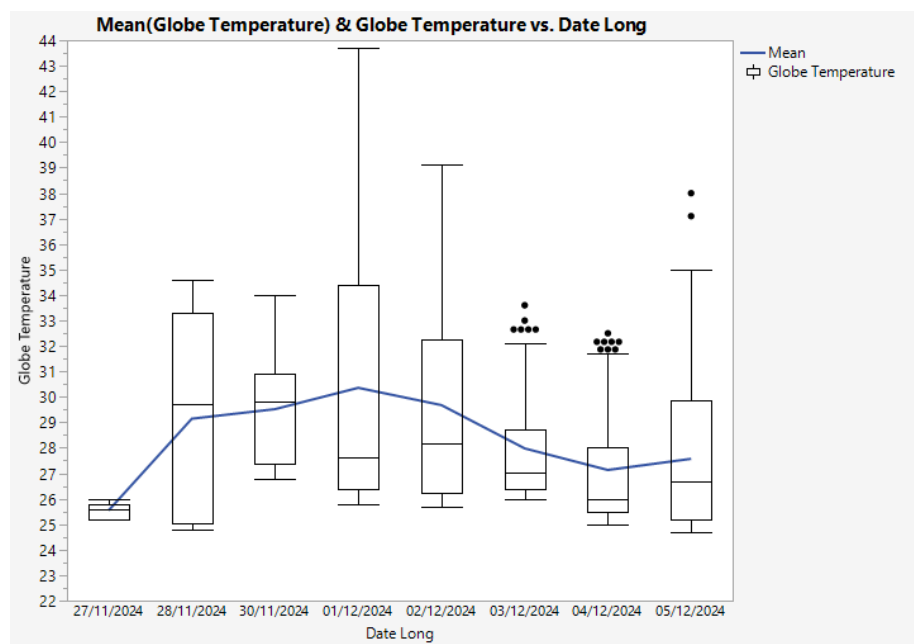


Figure 55. Globe Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

WET Trends at Promenade

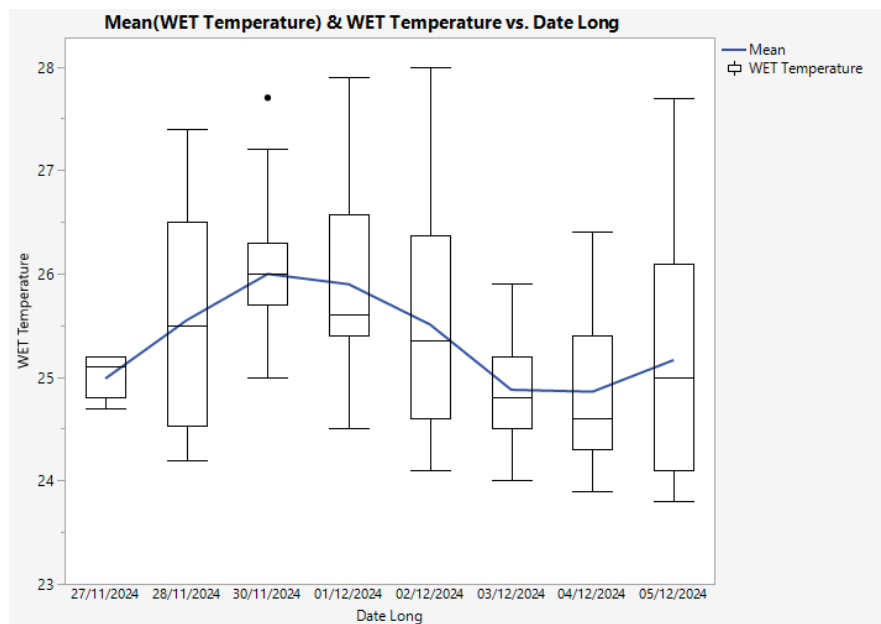


Figure 56. WET Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Dew Point Trends at Promenade

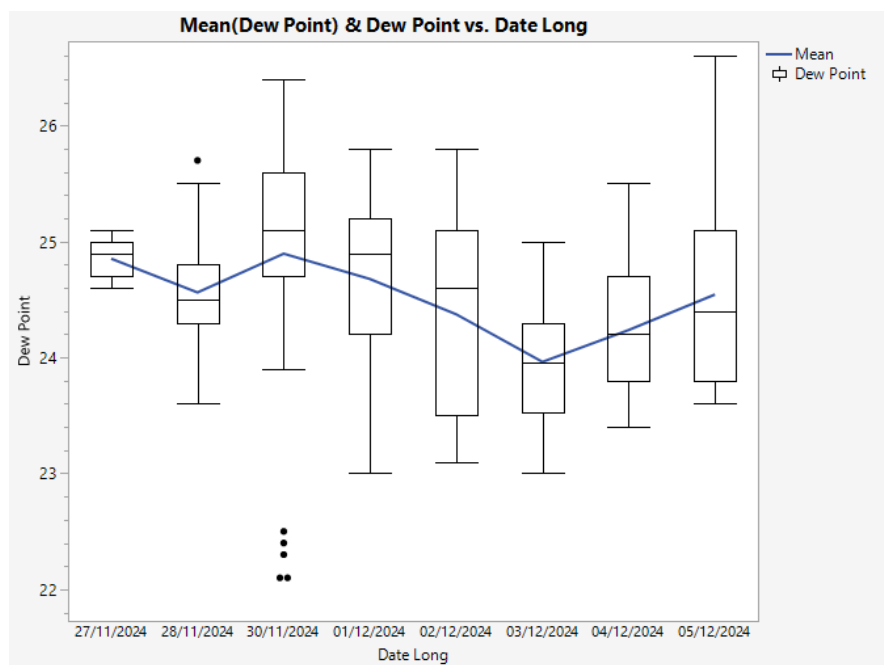


Figure 57. Dew Point Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Temperature Trends at Promenade

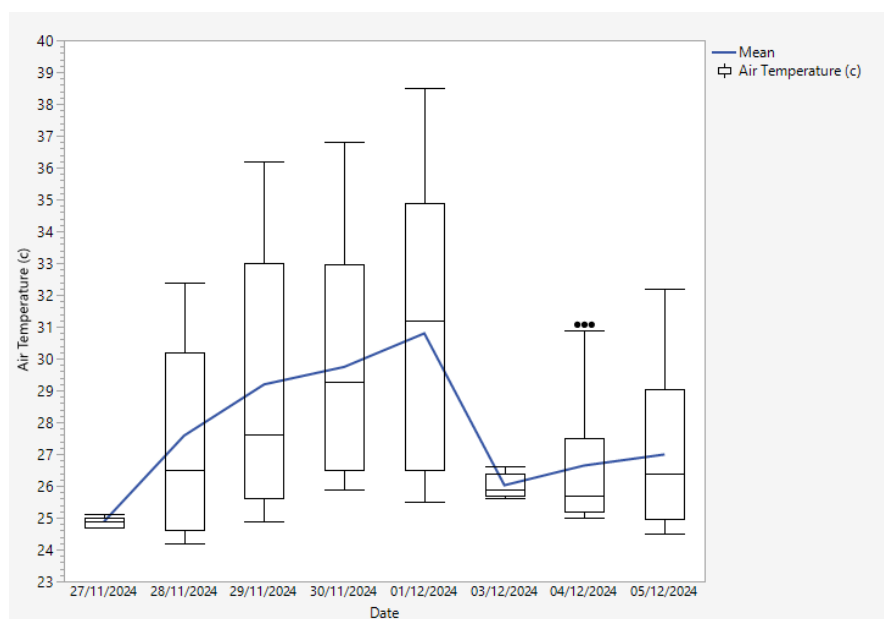


Figure 58. Air Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Temperature Trends at Promenade

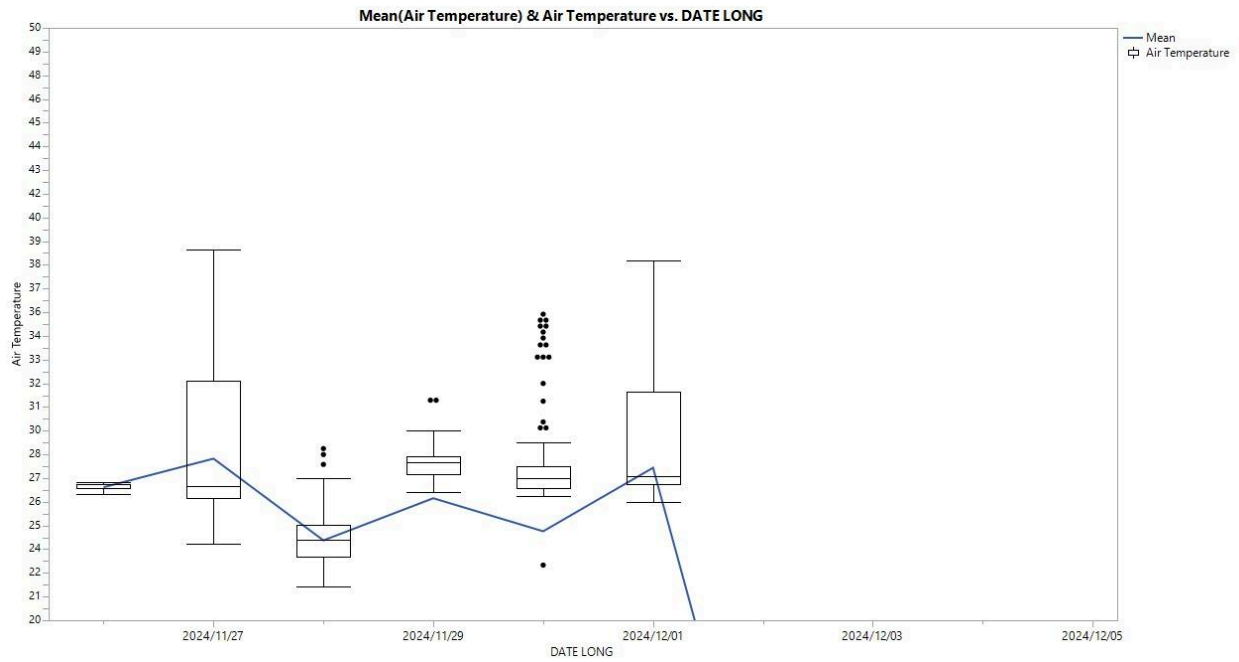


Figure 59. Air Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Illuminance Trends at Promenade

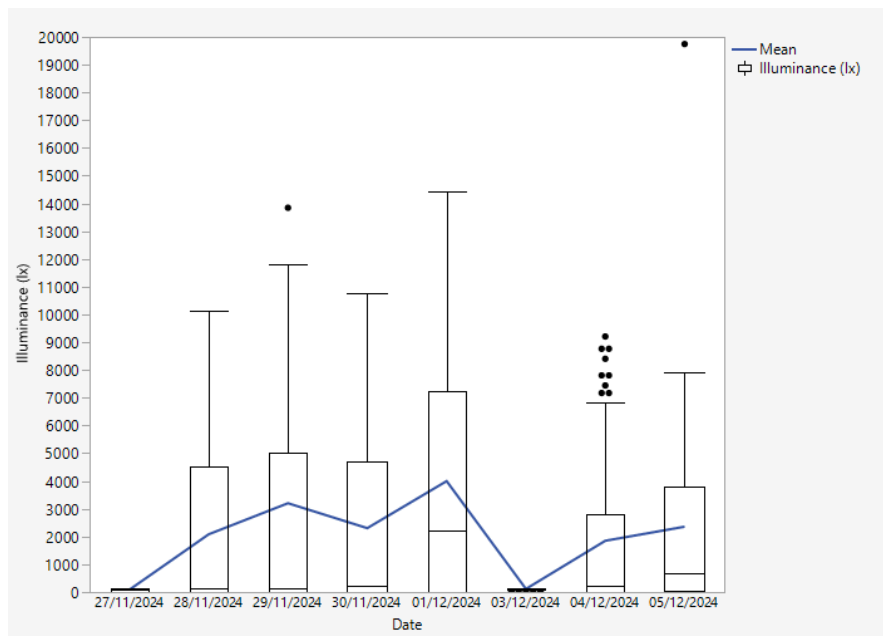


Figure 60. Illuminance Fluctuations and Mean Trends (Source: Research Team, 2024)

Humidity Trends at Promenade

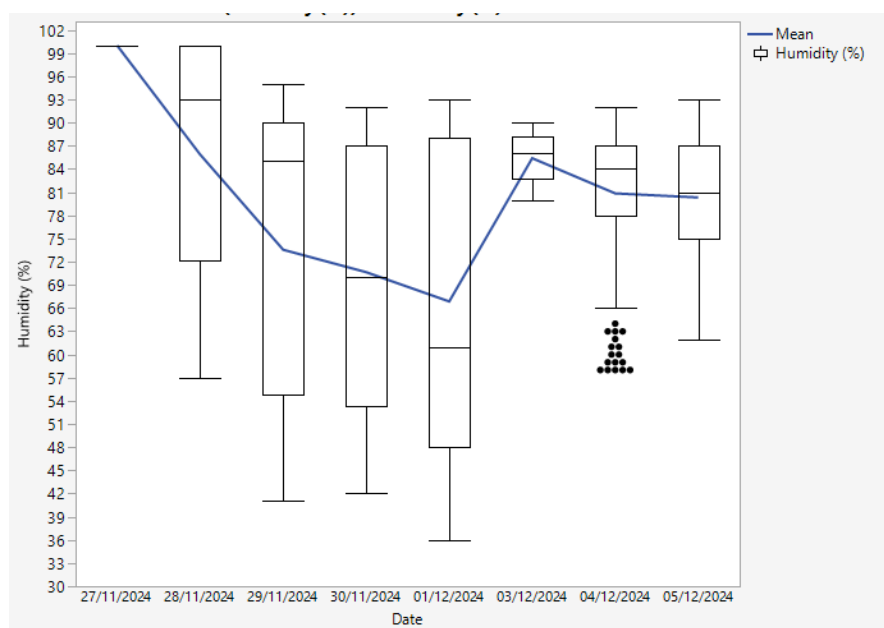


Figure 61. Humidity Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Temperature Trends at Promenade

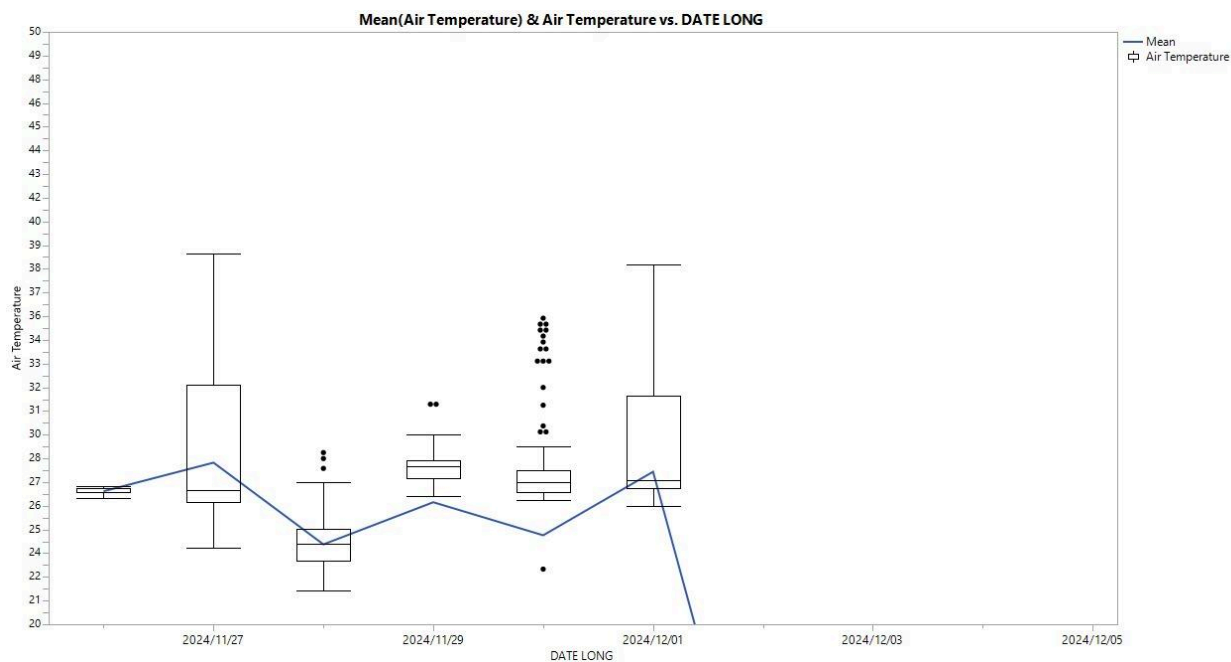


Figure 62. Air Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Velocity Trends at Promenade

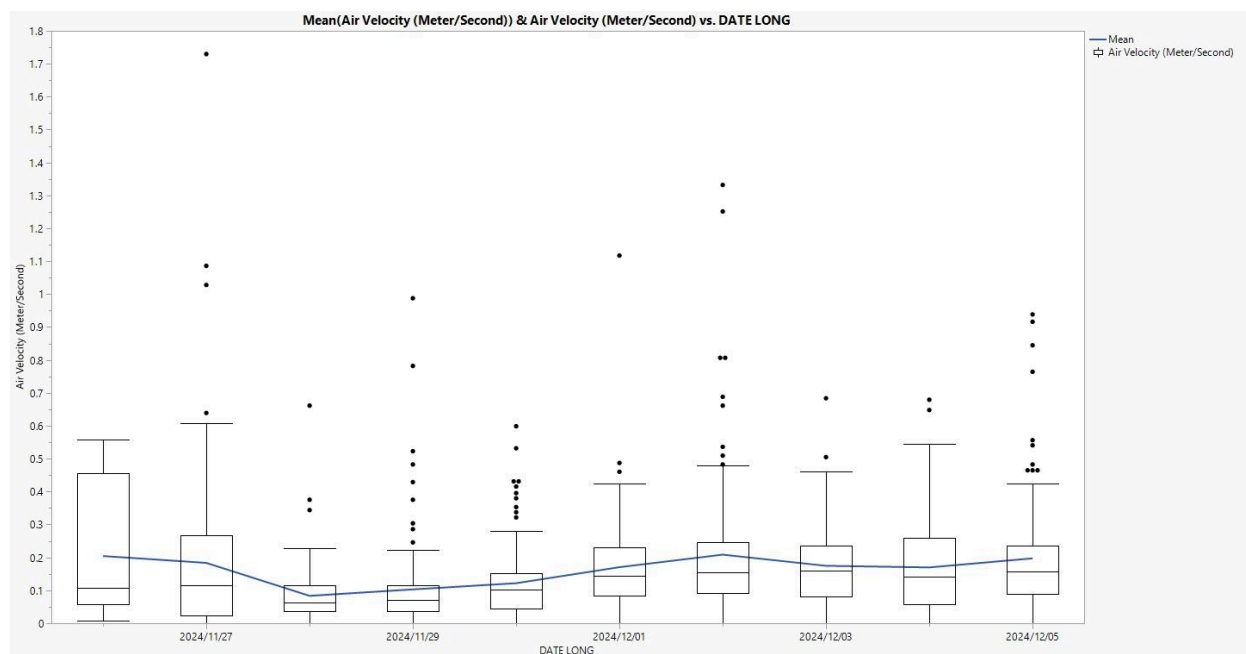


Figure 63. Air Velocity Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Velocity Trends at FCC

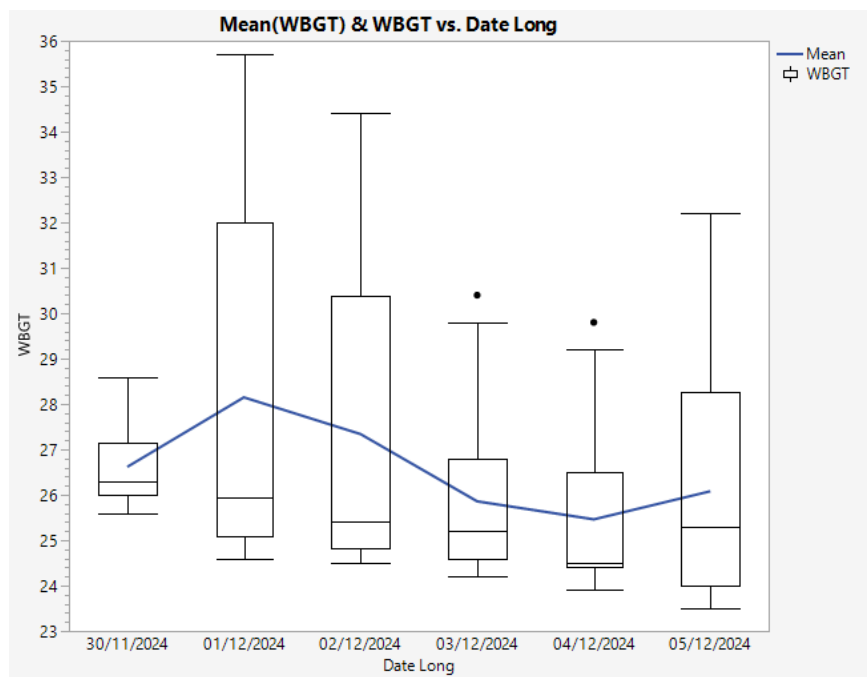


Figure 64. WBGT Fluctuations and Mean Trends (Source: Research Team, 2024)

Globe Trends at FCC

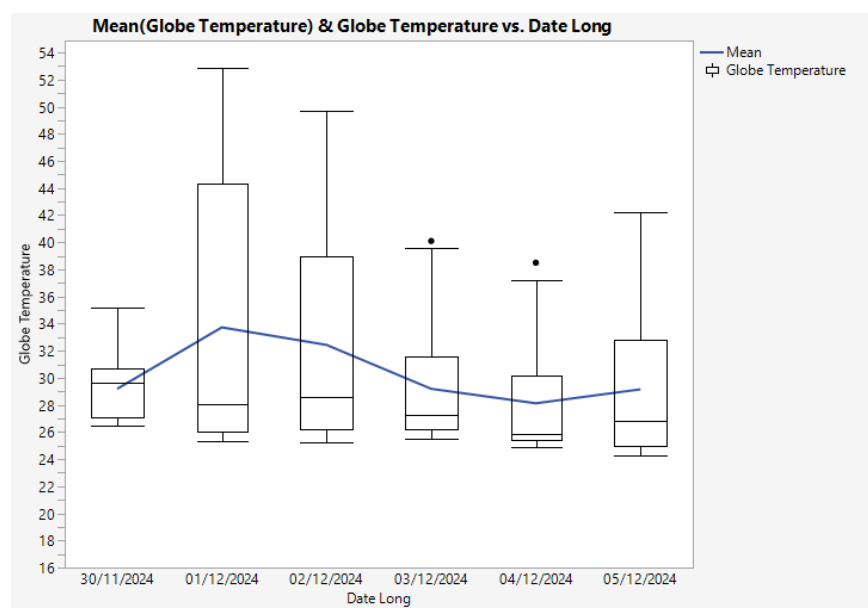


Figure 65. Globe Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

WET Trends at FCC

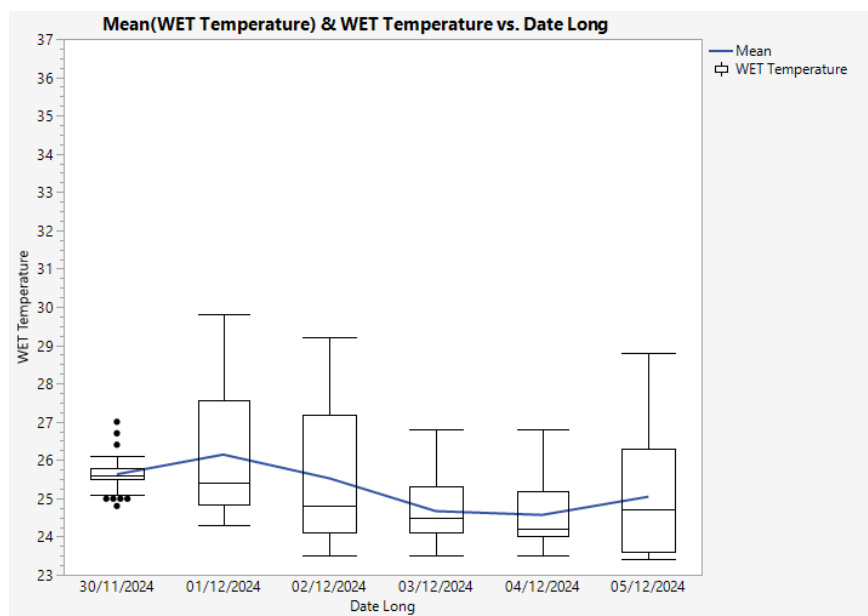


Figure 66. WET Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Dew Point Trends at FCC

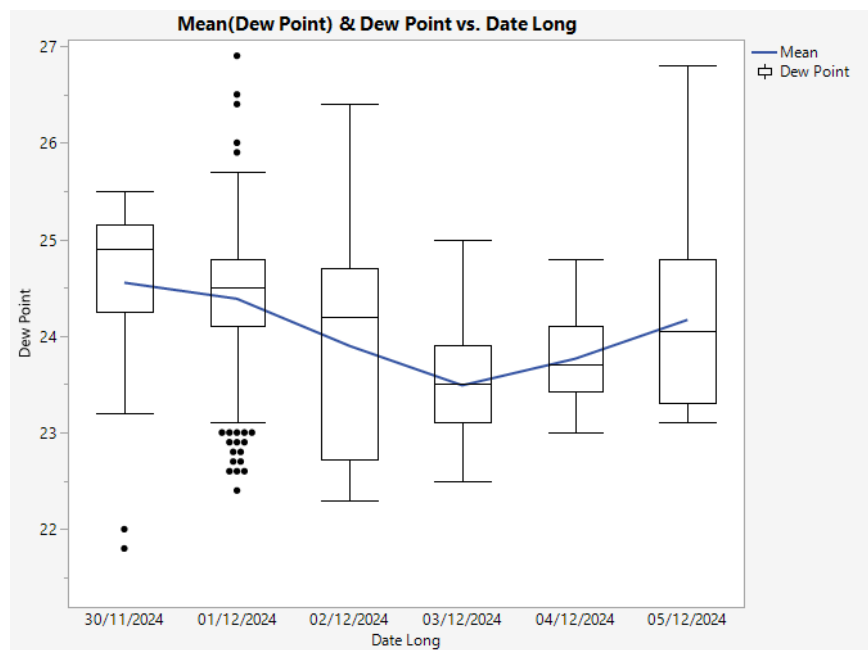


Figure 67. Dew Point Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Temperature Trends at FCC

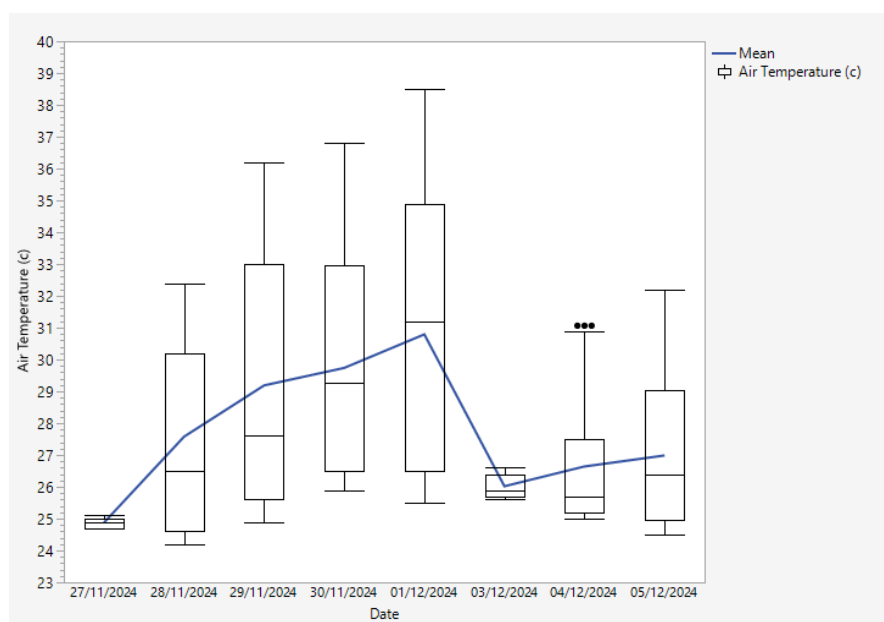


Figure 68. Air Temperature Fluctuations and Mean Trends (Source: Research Team, 2024)

Illuminance Trends at FCC

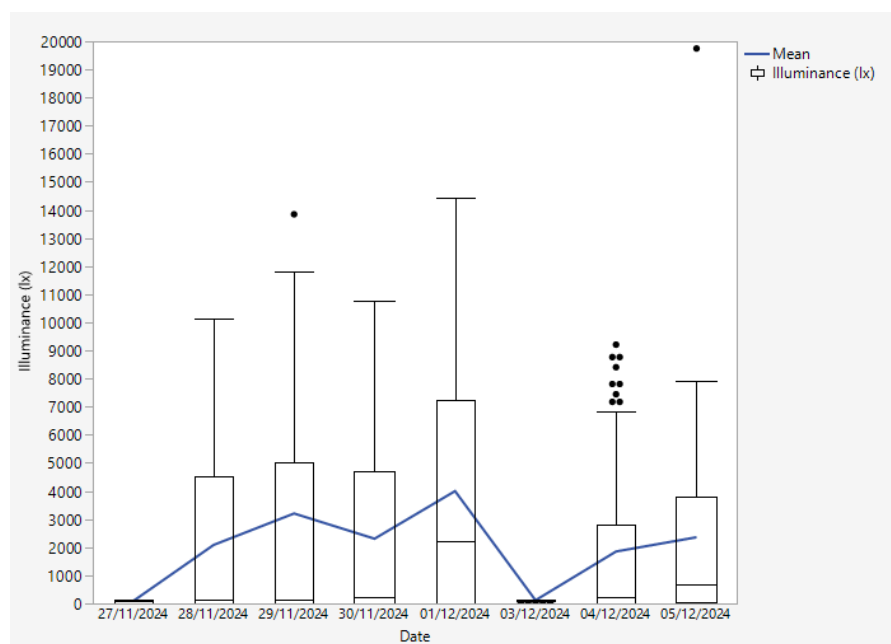


Figure 69. Illuminance Fluctuations and Mean Trends (Source: Research Team, 2024)

Humidity Trends at FCC

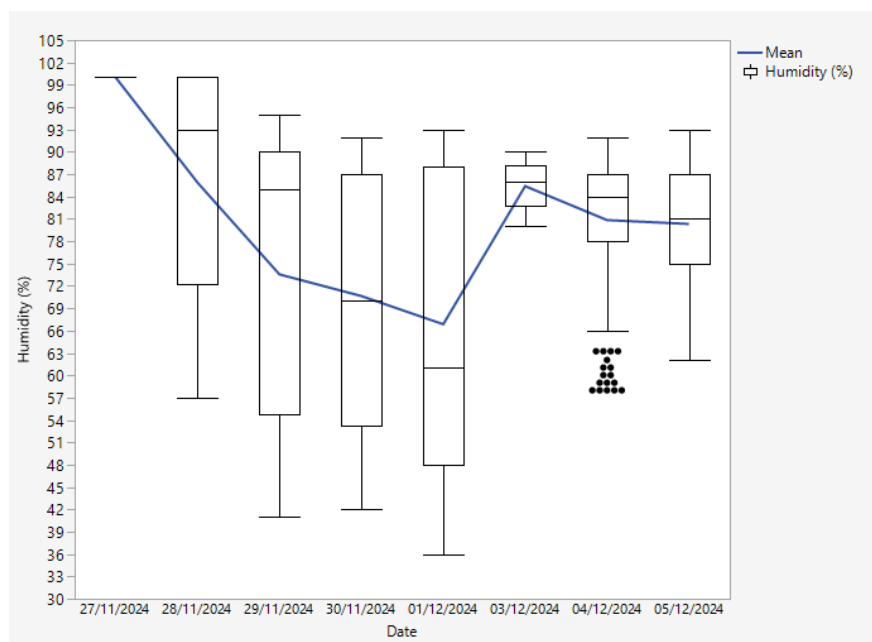


Figure 70. Humidity Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Temperature Trends at FCC

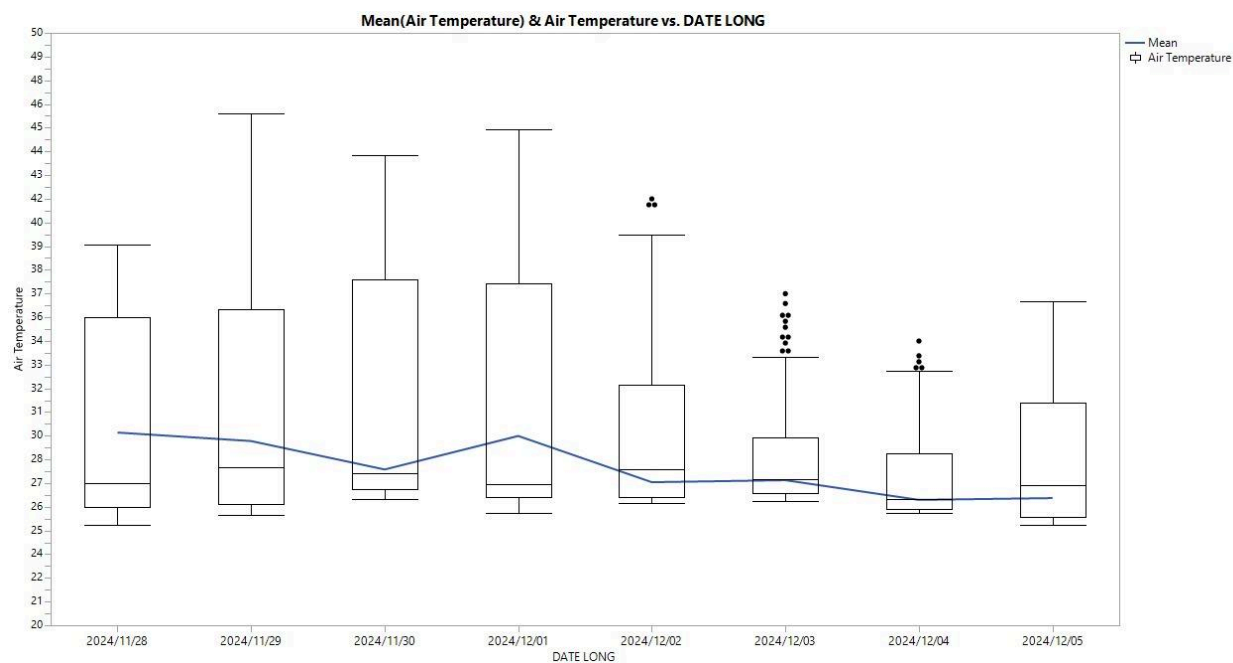


Figure 71. Illuminance Fluctuations and Mean Trends (Source: Research Team, 2024)

Air Velocity Trends at FCC

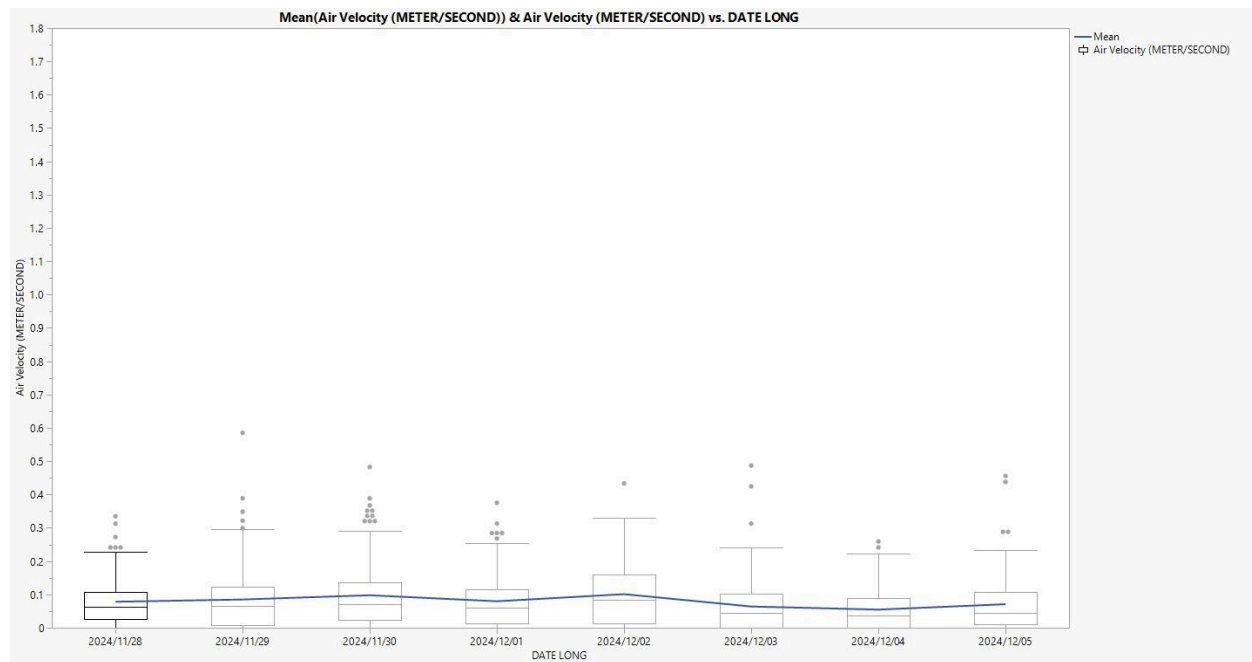


Figure 72. Air Velocity Fluctuations and Mean Trends (Source: Research Team, 2024)

Comparison Study

To evaluate the relationship between outside and inside environmental parameters at the The Grand Outlet, East Jakarta Karawang Karawang, bivariate analysis was conducted to determine the significance of external conditions on internal thermal environments. This analysis included Fit Line and Fit Mean methods to visualize the correlations and trends between key parameters such as outside air temperature, humidity, wind speed, and solar radiation, and inside WBGT, air velocity, and temperature. The Fit Line highlights the linear relationship between variables, while the Fit Mean provides insights into central tendencies and variability. This approach enables a deeper understanding of how external factors influence Semi-Outdoor conditions, offering valuable insights for optimizing microclimate management and thermal comfort strategies.

Bivariate Fit of Air Temperature (c) By Outdoor Temperature (C) AWS 1

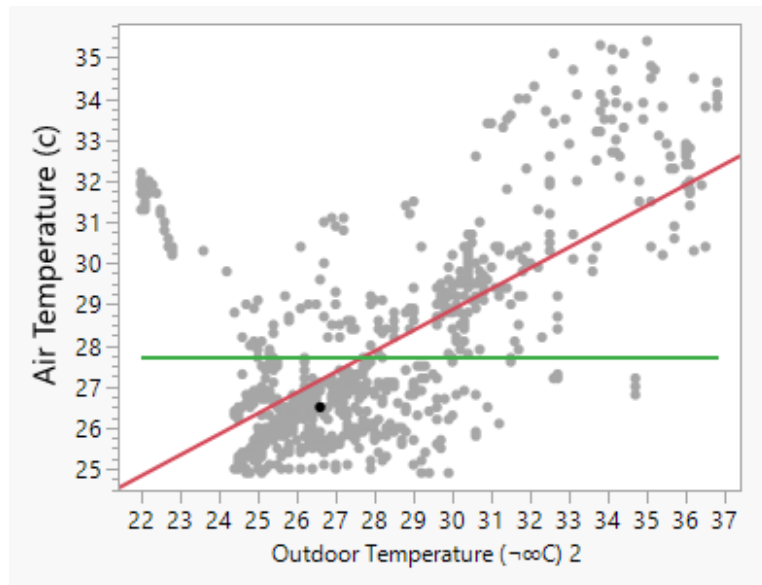


Figure 73. Bivariate fit graph of Air Temperature AWS 1 (Source: Research Team, 2024)

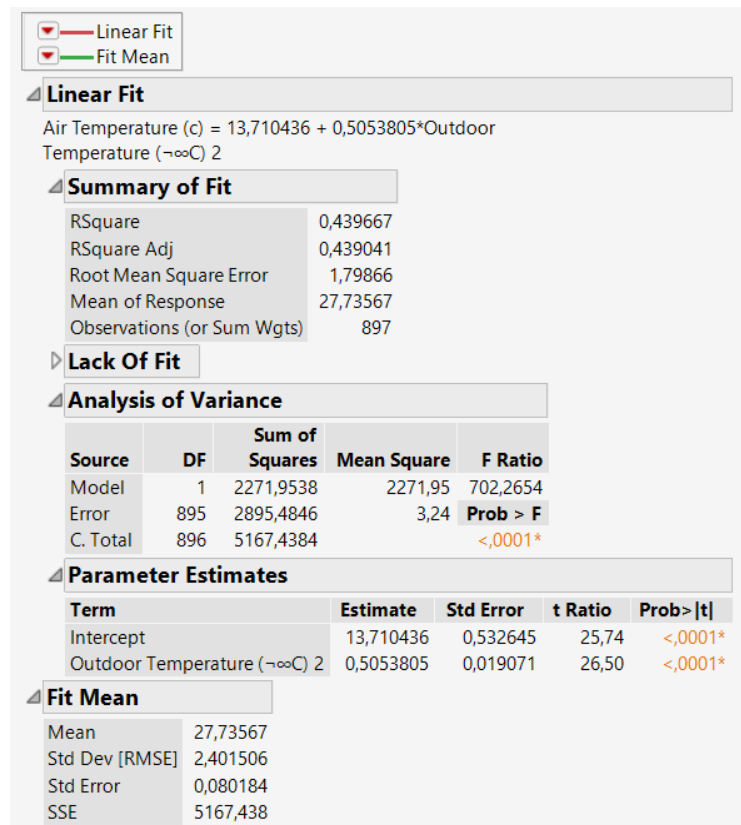


Figure 74. Bivariate fit data of Air Temperature AWS 1 (Source: Research Team, 2024)

Bivariate Fit of Air Temperature (c) By Outdoor Temperature (C) AWS 2

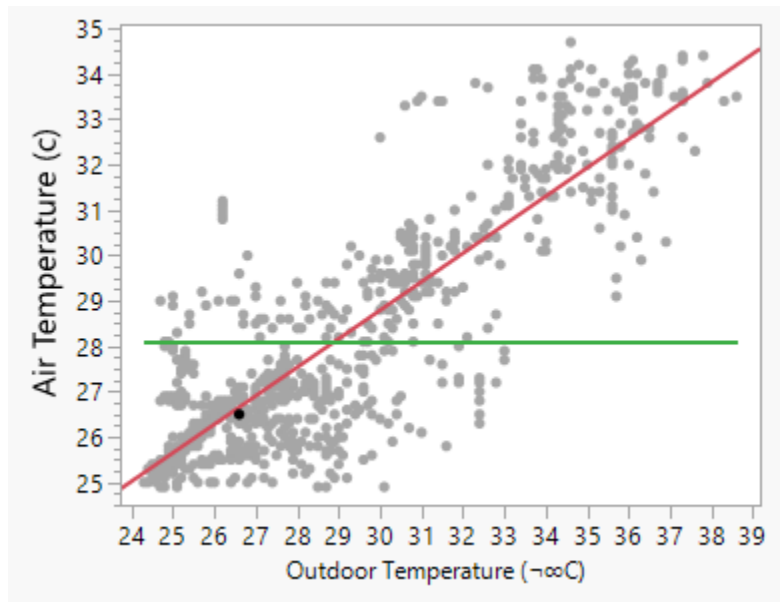


Figure 75. Bivariate fit graph of Air Temperature AWS 2 (Source: Research Team, 2024)

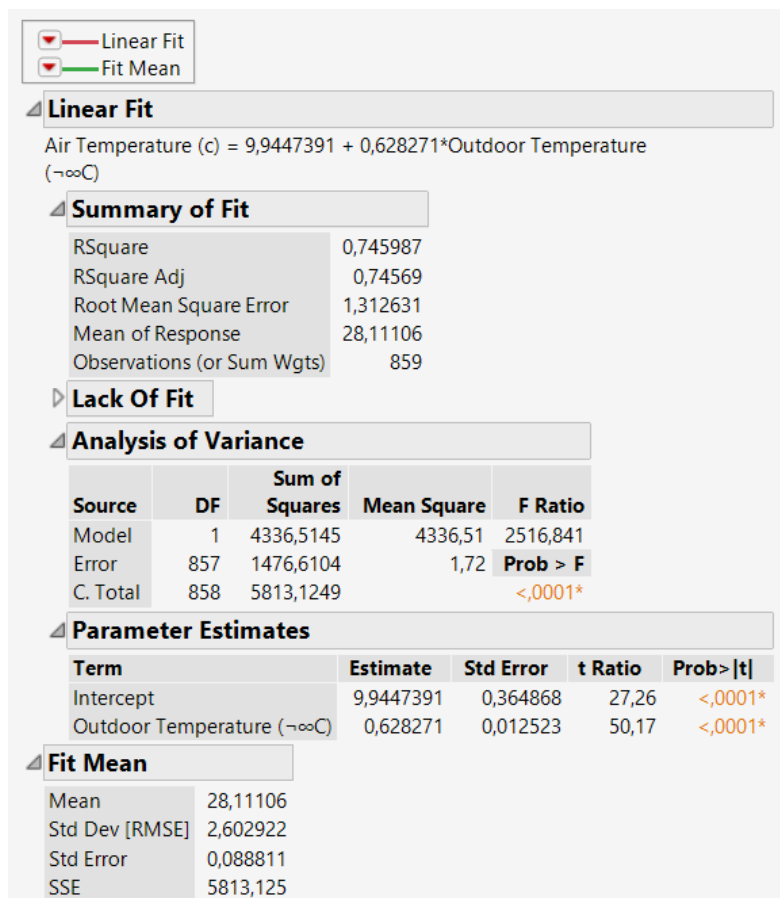


Figure 76. Bivariate fit data of Air Temperature AWS 2 (Source: Research Team, 2024)

Bivariate Fit of Humidity (%) 3 By Humidity (%) AWS 1

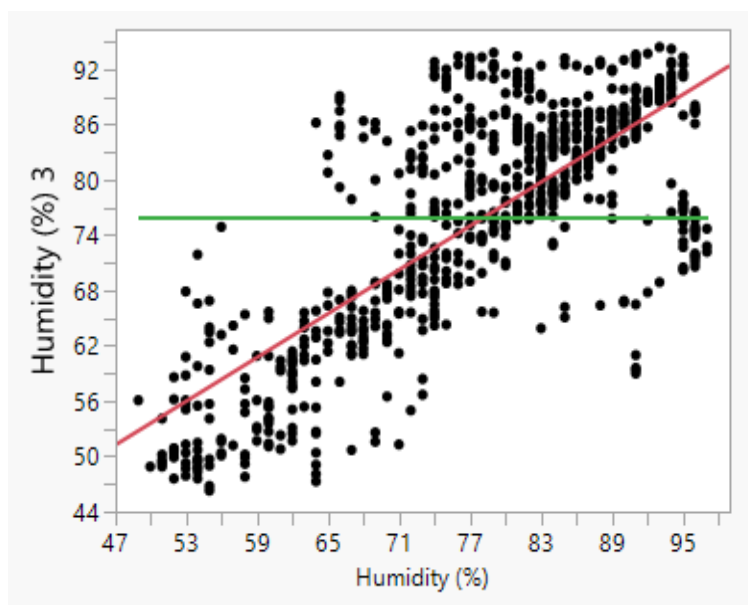


Figure 77. Bivariate fit graph of Humidity AWS 1 (Source: Research Team, 2024)

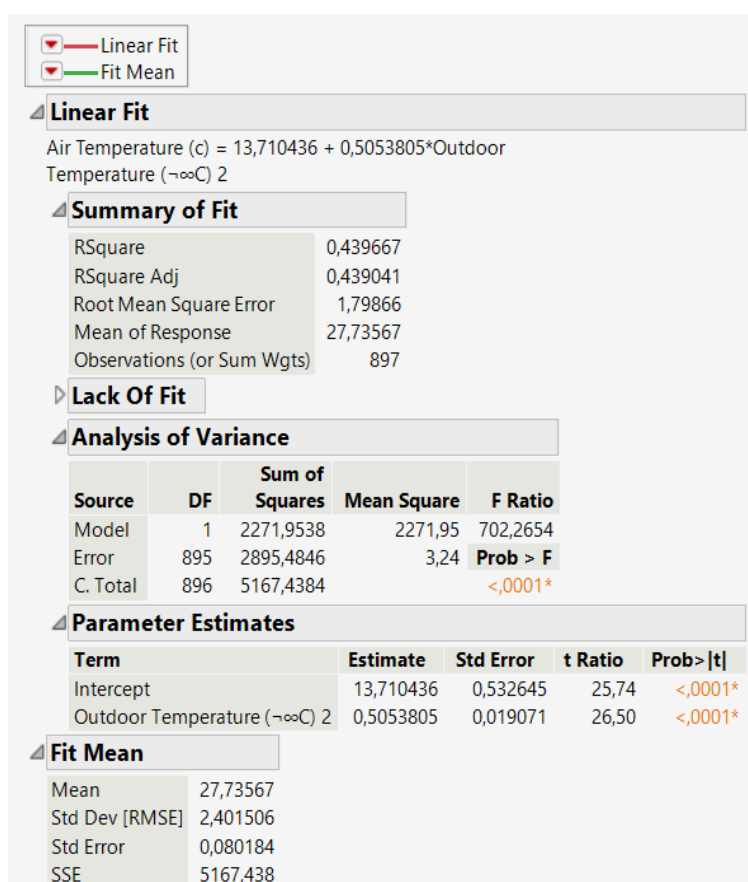


Figure 78. Bivariate fit data of Humidity AWS 1 (Source: Research Team, 2024)

Bivariate Fit of Humidity (%) 3 By Humidity (%) AWS 2

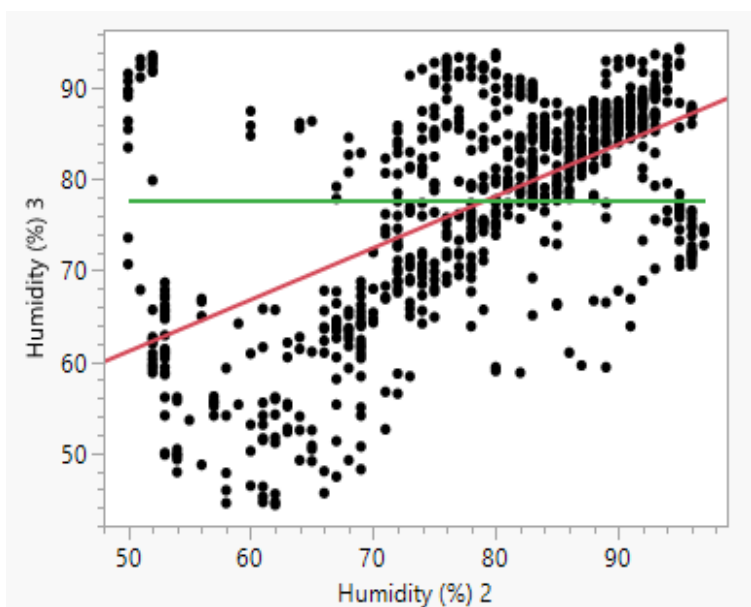


Figure 79. Bivariate fit graph of Humidity AWS 2 (Source: Research Team, 2024)

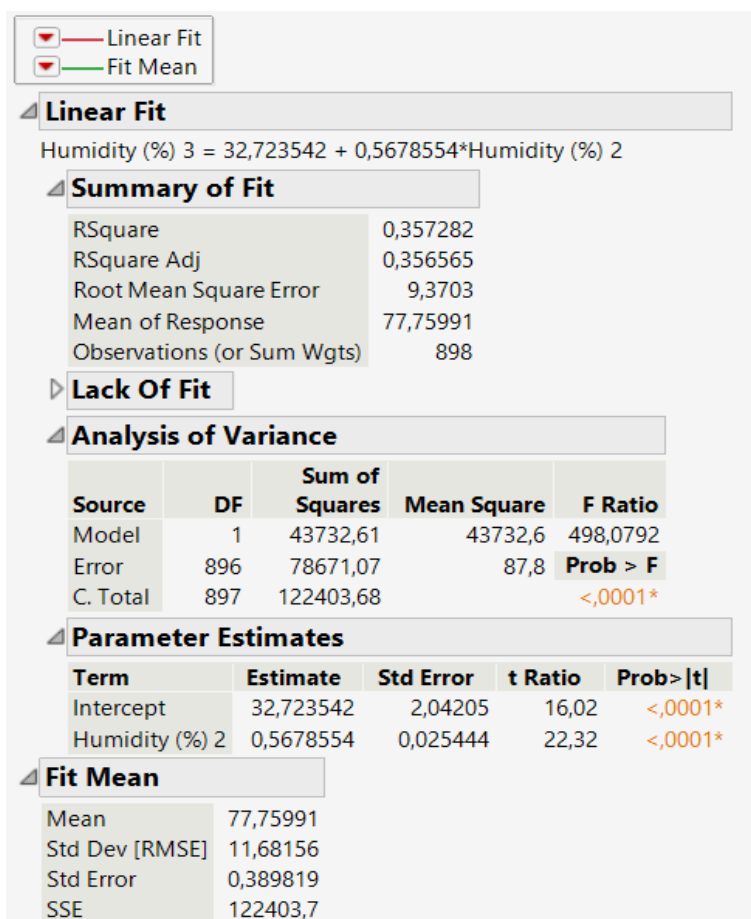


Figure 80. Bivariate fit data of Humidity AWS 2 (Source: Research Team, 2024)

Bivariate Fit of Daily Rain (mm) By Humidity (%)

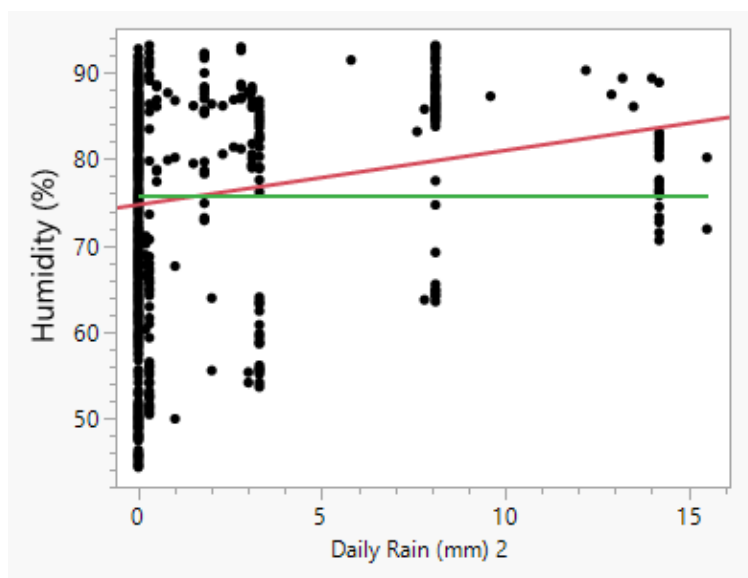


Figure 81. Bivariate fit graph of Daily Rain (Source: Research Team, 2024)

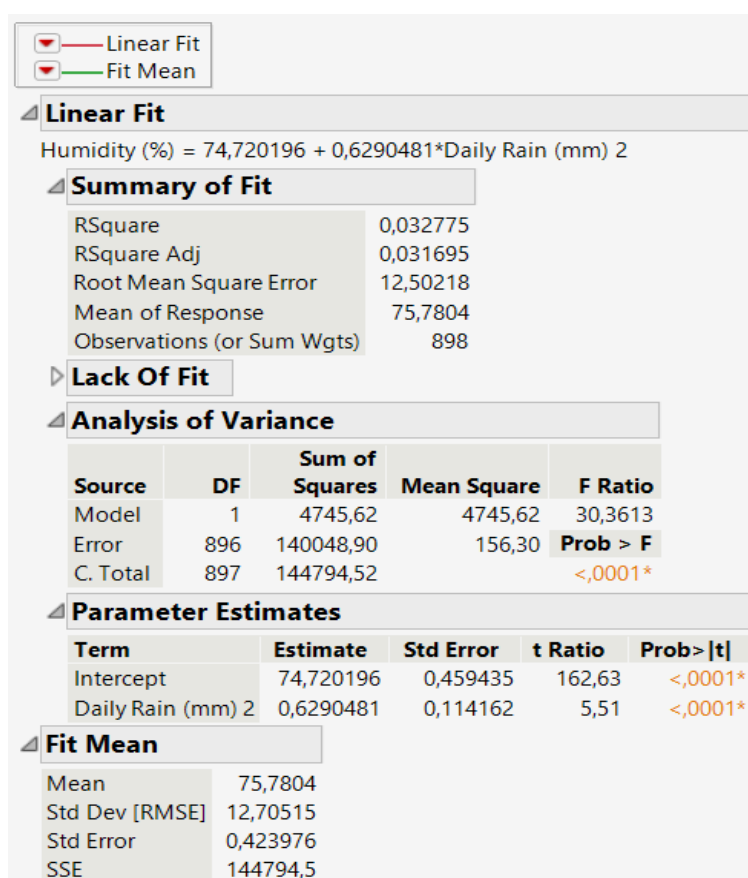


Figure 82. Bivariate fit data of Daily Rain (Source: Research Team, 2024)

Outdoor (Outside Facility) to Semi-Outdoor (Inside Facility)

The comparison analysis between outdoor and Semi-Outdoor air temperature data reveals the relationship between external environmental conditions and internal microclimatic responses. Outdoor air temperature data, recorded using Ambient Weather Stations (AWS) placed on the facility's rooftops, was compared to Semi-Outdoor air temperature measurements taken at 5 key points inside the facility.

The analysis includes nighttime data, which highlights fluctuations in temperature, with the lowest values typically occurring in the early morning hours. Despite these fluctuations, Semi-Outdoor air temperatures remain consistently lower than outdoor values across all measurement points. This difference underscores the effectiveness of the facility's architectural features, such as canopy, fan, and corridor design in mitigating external heat loads in The Grand Outlet, East Jakarta Karawang. The previous correlation analysis shows a statistically significant relationship between outdoor and Semi-Outdoor air temperatures, emphasizing the influence of external conditions while showcasing the facility's ability to maintain a more stable and comfortable Semi-Outdoor environment.

Outdoor to Green Hub

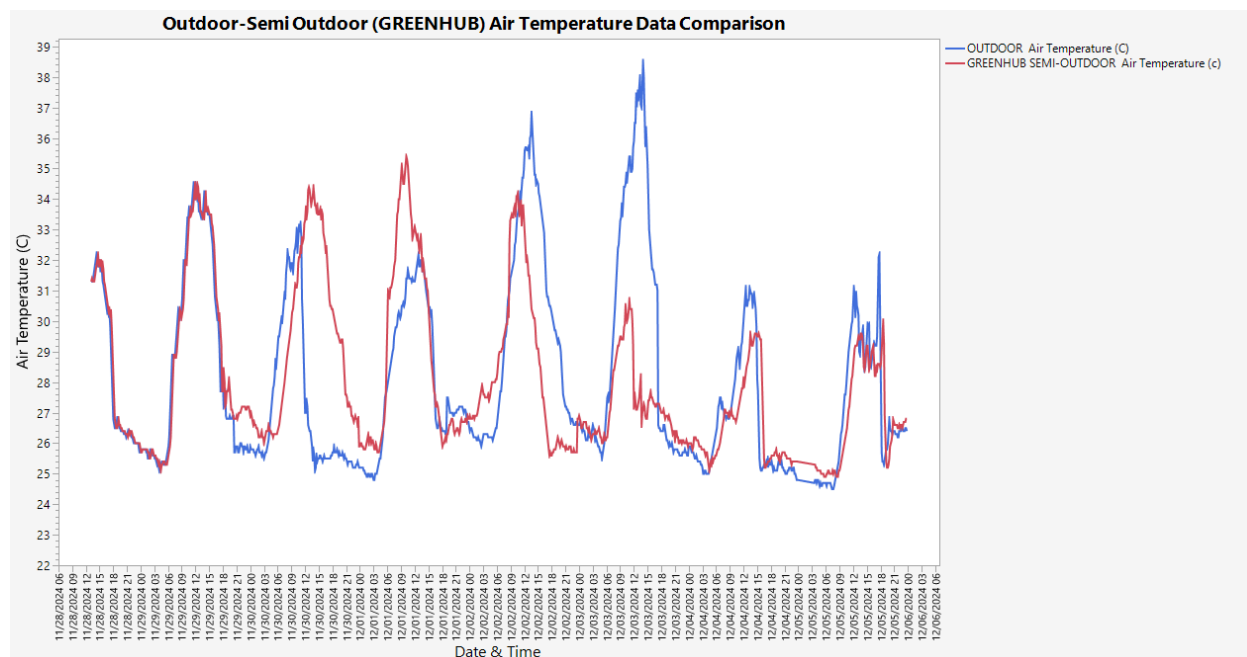


Figure 83 Outdoor to Green Hub. (Source: Research Team, 2024)

The graph above compares the air temperatures between the outdoor environment (AWS 1) and the Semi-Outdoor Green Hub over the monitoring period. The blue line represents the

outdoor air temperature, while the red line shows the Semi-Outdoor air temperature. These measurements provide insight into the relationship between external environmental conditions and internal thermal regulation.

The outdoor temperature demonstrates significant diurnal fluctuations, with sharp peaks during the daytime reaching 35°C to 37°C and drops during the nighttime and early morning, often ranging from 24°C to 26°C. These variations align with natural solar radiation patterns, where heating dominates during the day, and cooling occurs at night.

In contrast, the Semi-Outdoor air temperature consistently remains lower than the outdoor temperature throughout the period. While Semi-Outdoor temperatures also peak during the daytime, they remain within a more stable range of 26°C to 33°C, reflecting the effectiveness of the Green Hub's thermal regulation. This stability highlights the role of architectural features such as shading, insulation, and ventilation in maintaining a more comfortable Semi-Outdoor environment.

At night, both Semi-Outdoor and outdoor temperatures decrease, though the outdoor temperatures drop more significantly compared to the Semi-Outdoor values. The Semi-Outdoor environment shows less variability, suggesting that the facility's design mitigates extreme external temperature changes, maintaining a consistent thermal environment.

Overall, the trends of both Semi-Outdoor and outdoor temperatures follow a similar pattern, indicating that outdoor conditions significantly influence Semi-Outdoor temperatures. However, the observed attenuation of Semi-Outdoor temperature peaks highlights the effectiveness of the Green Hub's microclimate management, offering a moderated and more stable environment compared to fluctuating outdoor conditions.

Outdoor to Promenade

Building on the insights from the Green Hub, the comparison between outdoor and Semi-Outdoor temperatures at the Promenade further illustrates the impact of external environmental conditions on Semi-Outdoor thermal environments. Similar to the Green Hub, the Promenade experiences lower Semi-Outdoor temperatures compared to the outdoor environment, reinforcing the effectiveness of the facility's design in mitigating external heat loads.

However, the Promenade demonstrates a slightly wider range of fluctuations compared to the Green Hub, particularly during the daytime. This is likely due to its open and semi-exposed nature, which allows for greater interaction with outdoor airflows and solar radiation. Despite this, the Promenade still maintains a consistent trend of lower daytime peaks and stable nighttime temperatures, underscoring the importance of architectural features such as shading structures, vegetation and strategic layouting in controlling thermal conditions.

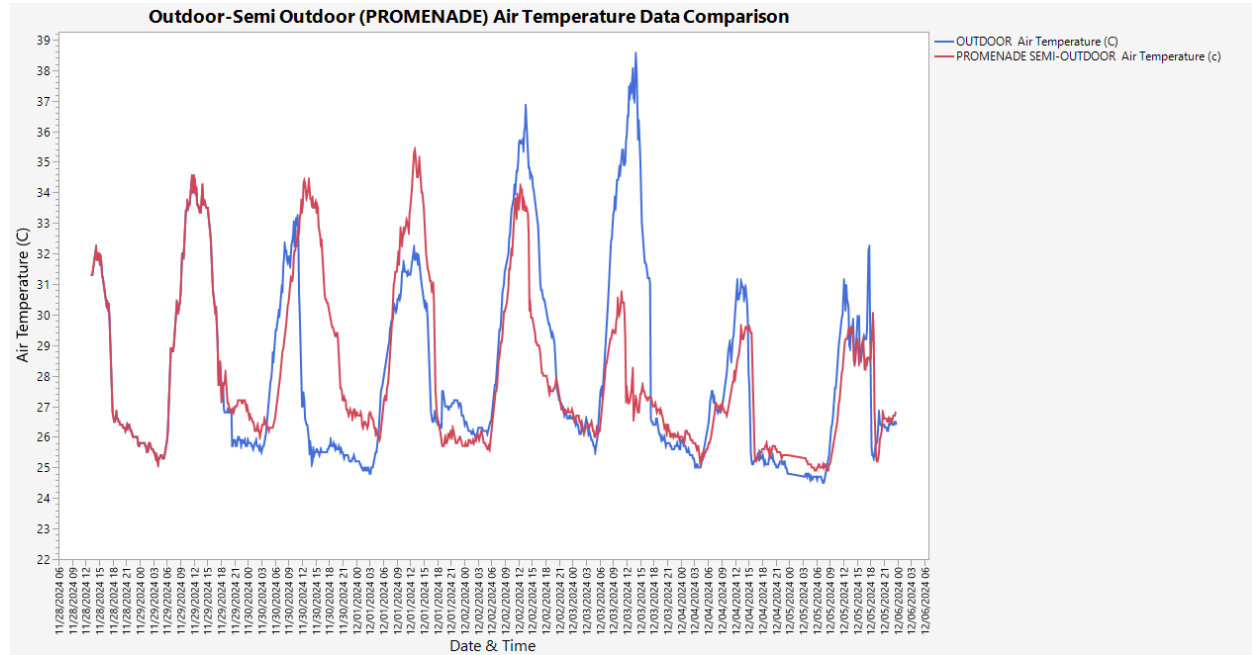


Figure 84 Outdoor to Promenade. (Source: Research Team, 2024)

Based on the graph above, the outdoor temperature shows significant diurnal fluctuations, with daytime peaks reaching 35°C to 38°C and nighttime lows ranging from 17°C to 23°C. These sharp variations reflect the typical tropical climate, where solar radiation drives daytime heating, and cooling occurs during the night.

In contrast, the Semi-Outdoor Promenade temperature demonstrates a more stable range, generally peaking between 29°C and 33°C during the day and remaining above 23°C at night. While Semi-Outdoor temperatures also follow the general trend of outdoor fluctuations, they consistently remain lower, indicating effective thermal mitigation through shading and ventilation.

Same as the previous result, during the nighttime, outdoor temperatures show a sharp decline, often dipping below Semi-Outdoor values, whereas the Semi-Outdoor environment maintains a

relatively consistent thermal condition. This stability suggests that the Promenade's design effectively buffers against extreme cooling, ensuring thermal comfort even during cooler hours.

In the graph, a noticeable anomaly is observed where the Semi-Outdoor air temperature (red line) exceeds the outdoor air temperature (blue line), particularly around 11/29/2024 at approximately 15:00 and similar points in the dataset. This deviation is unusual, as Semi-Outdoor temperatures are typically expected to be lower than outdoor values due to the mitigating effects of microclimate, or physical design in specific area.

One possible explanation for this anomaly is the presence of localized heat sources within the Promenade. Activities, high occupancy levels, or heat-generating equipment, such as lighting or mechanical systems, could temporarily elevate Semi-Outdoor temperatures. Additionally, ventilation issues, such as reduced airflow or malfunctioning systems, might have contributed to heat accumulation Semi-Outdoors, especially during peak outdoor heat hours.

Another factor could be measurement device calibration. The Semi-Outdoor temperature sensor may have experienced a calibration drift or temporary malfunction, resulting in higher recorded values. It is also possible that the Promenade's architectural design allowed for direct solar gain or radiant heat transfer, especially during specific times of the day when unshaded surfaces or glass elements might have been exposed to intense sunlight.

External weather conditions, such as low wind speed or high solar radiation, could also amplify Semi-Outdoor heat retention more than usual, further contributing to the observed spike. Lastly, the anomaly could be related to data synchronization or logging errors between Semi-Outdoor and outdoor sensors, creating the appearance of higher Semi-Outdoor temperatures during certain moments.

Overall, the graph highlights the strong influence of outdoor conditions on Semi-Outdoor temperatures while emphasizing the Promenade's ability to moderate extreme temperature fluctuations. The consistent trend of lower Semi-Outdoor temperatures compared to outdoor values underscores the importance of architectural and environmental controls in maintaining a comfortable and stable microclimate within the facility.

Outdoor to Under Canopy

The graph below comparing outdoor and Semi-Outdoor air temperatures at the Under Canopy location reveals a similar pattern to the Promenade and Green Hub, with outdoor temperatures

(blue line) showing larger fluctuations compared to the more stable Semi-Outdoor temperatures (red line). However, some unique characteristics emerge in this space, providing additional insights into its thermal behavior.

Outdoor temperatures fluctuate significantly, with daytime peaks ranging between 35°C and 37°C and nighttime lows dropping to 19°C to 23°C. These variations align with typical diurnal patterns driven by solar radiation and nighttime cooling. In contrast, Semi-Outdoor temperatures under the canopy remain more stable, generally ranging between 25°C to 33°C. Nighttime Semi-Outdoor temperatures tend to stay slightly higher than outdoor values, reflecting the heat retention properties of the canopy structure.

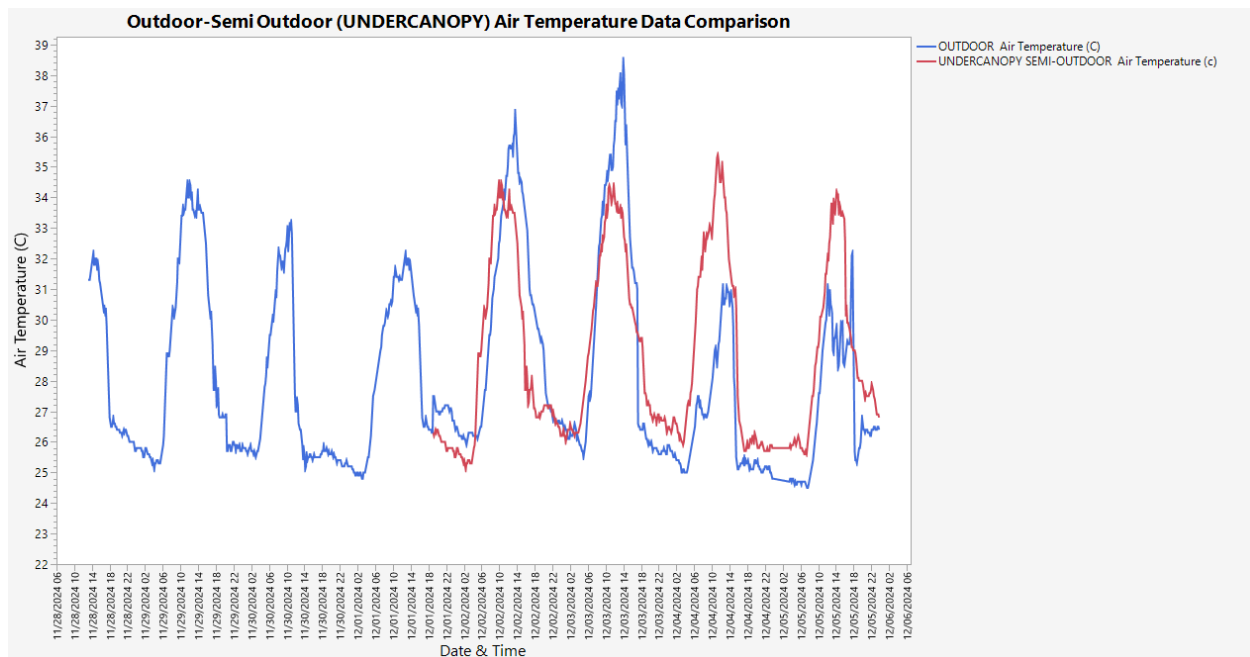


Figure 85 Outdoor to Under canopy 1F. (Source: Research Team, 2024)

Notably, there are occasional anomalies where Semi-Outdoor temperatures surpass outdoor temperatures, particularly during nighttime or early morning hours (e.g., 11/30/2024 and 12/01/2024). This could be caused by reduced ventilation, localized heat sources, or the canopy's retention of heat accumulated during the day. These anomalies are consistent with patterns observed in other areas but appear more pronounced in this semi-exposed space.

Compared to the Promenade and Green Hub, the Under Canopy area shows smaller differences between Semi-Outdoor and outdoor temperatures, indicating that the canopy provides partial insulation and shading while still allowing significant interaction with external

conditions. This analysis highlights the need for improved ventilation or shading strategies to further mitigate localized heat retention, especially during cooler nighttime periods.

Outdoor to 2F Under Canopy

The graph for Under Canopy 2F below shows a similar trend, with outdoor air temperatures (blue line) exhibiting significant diurnal fluctuations and Semi-Outdoor air temperatures (red line) remaining more stable. However, the second-floor canopy reveals more pronounced Semi-Outdoor temperature anomalies during specific periods, reflecting unique thermal behavior at this elevated position.

Outdoor temperatures peak between 35°C and 37°C during the daytime and drop to 19°C to 23°C during the nighttime, following a typical tropical diurnal pattern. In contrast, Semi-Outdoor temperatures on the second floor range from 25°C to 33°C during the day and remain higher at night, consistently above 23°C. This stability demonstrates some degree of thermal regulation under the canopy.

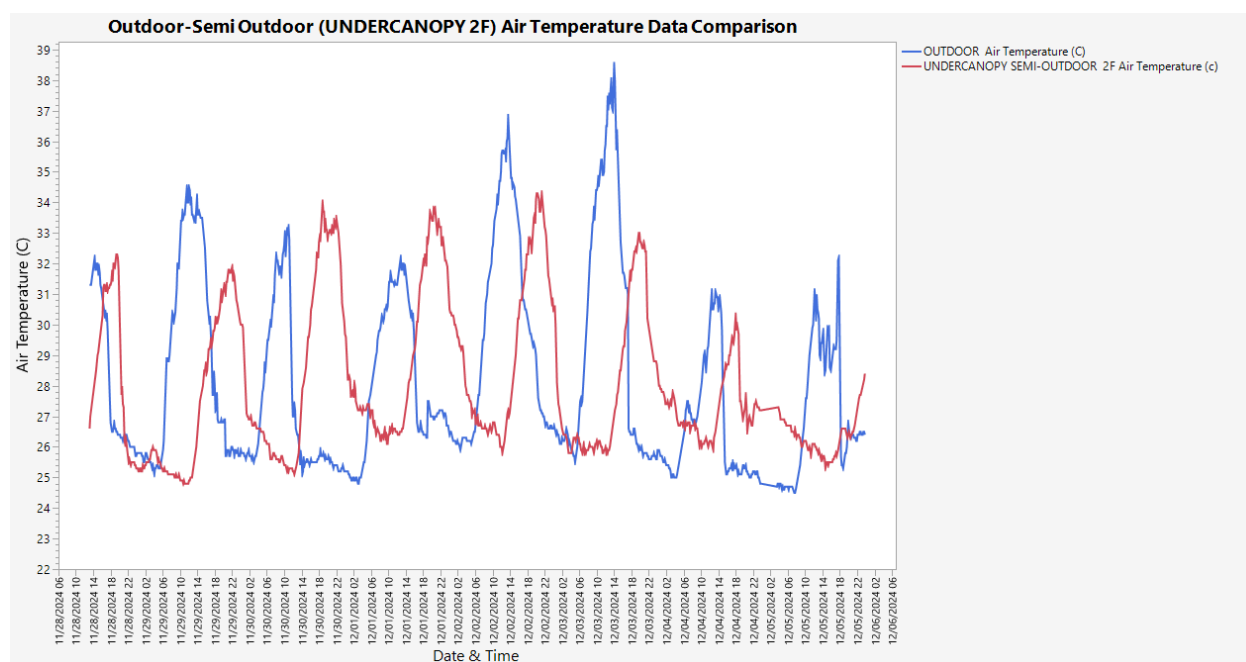


Figure 86 Outdoor to Under Canopy 2F. (Source: Research Team, 2024)

Notably, there are instances where Semi-Outdoor temperatures surpass outdoor temperatures, particularly during early morning and nighttime hours (e.g., 11/30/2024). These anomalies are likely caused by heat retention, reduced ventilation, or increased heat accumulation on the

second floor due to its elevated position and greater exposure to radiant heat compared to ground-level spaces.

When compared to the ground-level canopy, the second-floor canopy exhibits slightly higher Semi-Outdoor temperatures, highlighting the impact of altitude and design on thermal performance. While daytime peaks Semi-Outdoors remain consistently lower than outdoors, the second-floor location shows a greater tendency for heat accumulation. This analysis emphasizes the need for enhanced ventilation and shading solutions to reduce heat retention and improve thermal comfort in this semi-exposed area.

Outdoor to FCC

The graph for the FCC Point of Measurement (Front Command Centre) below illustrates the comparison between outdoor (blue line) and Semi-Outdoor (red line) air temperatures. Positioned at the very front of the The Grand Outlet, East Jakarta Karawang facility, the FCC is a semi-exposed point with minimal thermal control measures. Its location subjects it to direct solar radiation and limited shading, making it closely influenced by outdoor environmental conditions.

Outdoor air temperatures at the FCC exhibit a typical diurnal pattern, with daytime peaks reaching 35°C to 37°C and nighttime lows dropping to 19°C to 23°C. Semi-Outdoor temperatures, while slightly moderated, follow a similar trend, peaking between 28°C and 34°C during the day and maintaining levels of 24°C to 26°C at night. This correlation highlights the strong influence of outdoor conditions on Semi-Outdoor temperatures at this point.

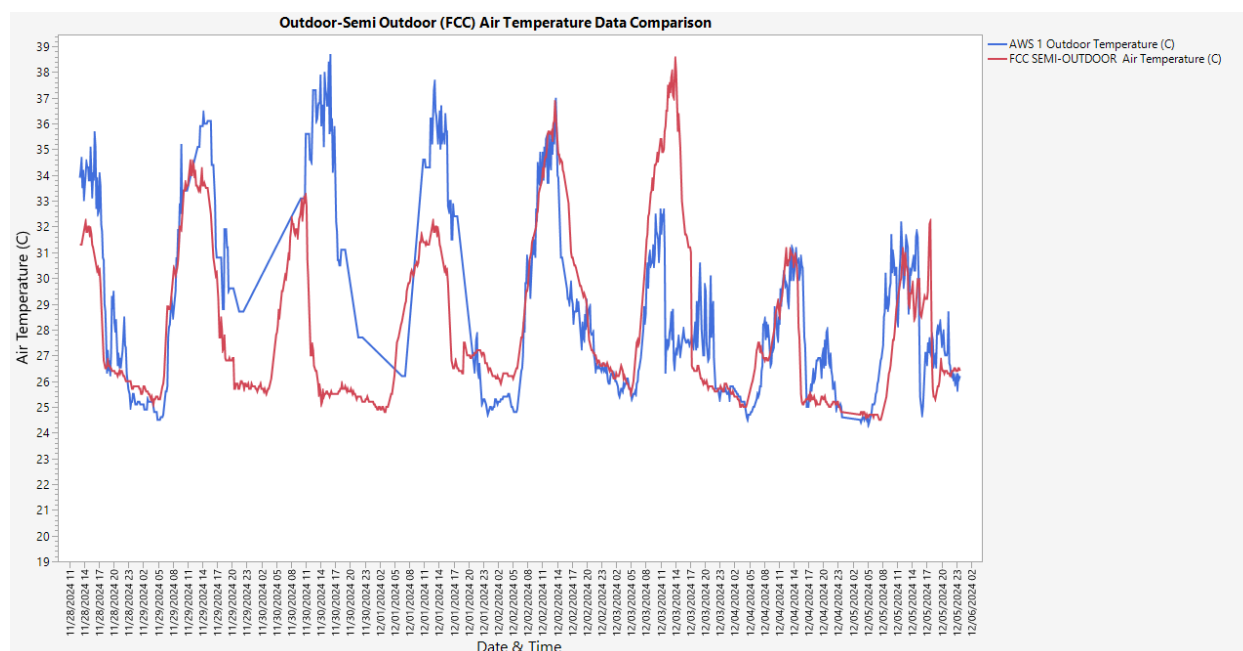


Figure 87 Outdoor to FCC. (Source: Research Team, 2024)

The limited thermal control at the FCC results in minimal differences between Semi-Outdoor and outdoor temperatures, particularly during the day. Occasionally, anomalies are observed where Semi-Outdoor temperatures exceed outdoor values, which could be attributed to heat accumulation caused by reduced ventilation or reflective heat from surrounding surfaces. At night, Semi-Outdoor temperatures remain slightly above outdoor levels, reflecting retained heat in the area.

Compared to other measurement points such as the Green Hub or Under Canopy, the FCC demonstrates the least effective thermal moderation, emphasizing its vulnerability due to its exposed location and lack of active cooling or shading strategies. This analysis highlights

Daytime Average Comparison

The average daytime comparison focuses on analyzing data collected exclusively between 6:00 AM and 6:00 PM, capturing the period influenced by solar radiation. By isolating daytime data, this analysis provides insights into the impact of solar radiation on both outdoor and indoor temperatures at various measurement points. This approach highlights how different architectural features and shading strategies mitigate heat gain during the day, enabling a clearer understanding of thermal performance under peak solar conditions. The findings offer a

more targeted perspective on how solar radiation affects the microclimate of the facility and informs strategies to enhance thermal comfort or whether the canopy has an impactful solution.

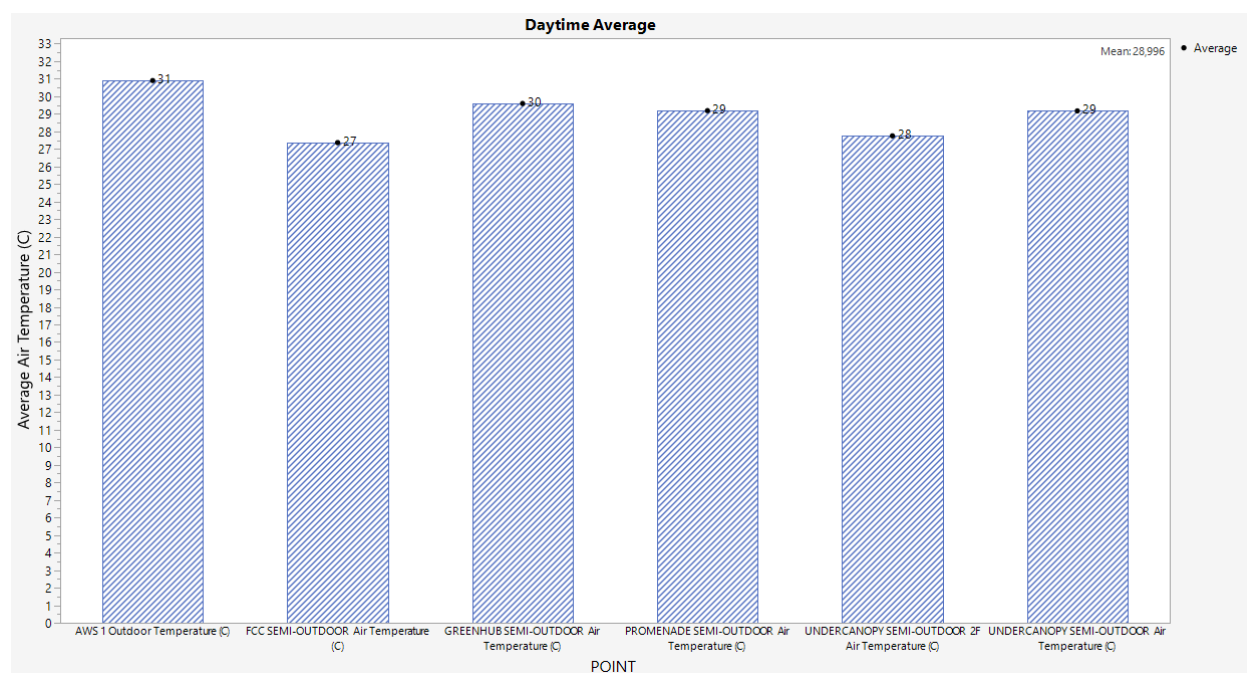


Figure 88 Daytime average data comparison. (Source: Research Team, 2024)

The graph presents the daytime average air temperature recorded across various measurement points within the Grand Outlet facility. The data is categorized into outdoor and semi-outdoor locations and focuses on the period between 6:00 AM and 6:00 PM, capturing the impact of solar radiation during daytime hours.

The outdoor measurement point (AWS 1) recorded the highest average temperature of 31°C, which aligns with expectations due to direct exposure to solar radiation and the absence of any thermal control measures. This point serves as the baseline for evaluating the effectiveness of architectural features in mitigating outdoor heat loads.

Among the semi-outdoor points, the FCC (Front Command Center), Green Hub, and Promenade all reported average air temperatures of 30°C. These locations benefit from partial shading but remain significantly influenced by outdoor conditions due to their semi-exposed nature. In contrast, the Under Canopy points (Ground Level and 2F) demonstrated the lowest average temperatures at 27°C, indicating better thermal performance likely resulting from effective shading and reduced direct solar exposure.

Overall, the comparison highlights the moderating effect of architectural elements such as canopies and shading. While outdoor temperatures are consistently higher, semi-outdoor points with design interventions show reduced heat gain during the daytime. These findings underscore the importance of optimized shading and ventilation strategies to enhance thermal comfort in semi-outdoor spaces.

Universal Thermal Climate Index Outdoor

In our study, we generate Mean Radiant Temperature (MRT) by integrating key environmental parameters such as air temperature, air velocity, and humidity, using the open-source software Rayman. MRT is a critical factor in assessing thermal comfort, as it represents the combined effects of all radiant heat exchanges between the human body and its surrounding surfaces. Once MRT is determined, we use this additional parameter to calculate the Universal Thermal Climate Index (UTCI) with the BioKlima software, which provides a more comprehensive evaluation of outdoor thermal comfort by incorporating the combined influences of air temperature, humidity, radiation, and wind speed.

The comparison between outdoor air temperature, UTCI, and MRT is essential to understand the true impact of environmental conditions on human thermal perception. While air temperature alone provides a basic measure of heat, it does not account for the effects of radiation and wind, which can significantly alter how heat is experienced by individuals. UTCI, on the other hand, serves as a refined metric that integrates multiple climatic variables, offering a realistic representation of thermal stress in outdoor environments. By comparing these parameters, we can identify discrepancies between perceived and actual thermal conditions, assess microclimate variations, and provide more accurate recommendations for outdoor comfort and urban planning. This analysis is crucial for designing climate-responsive urban spaces, optimizing outdoor environments for human well-being, and mitigating the effects of extreme heat or cold stress in different climatic regions.

Process Flow for UTCI Calculation and Comparison

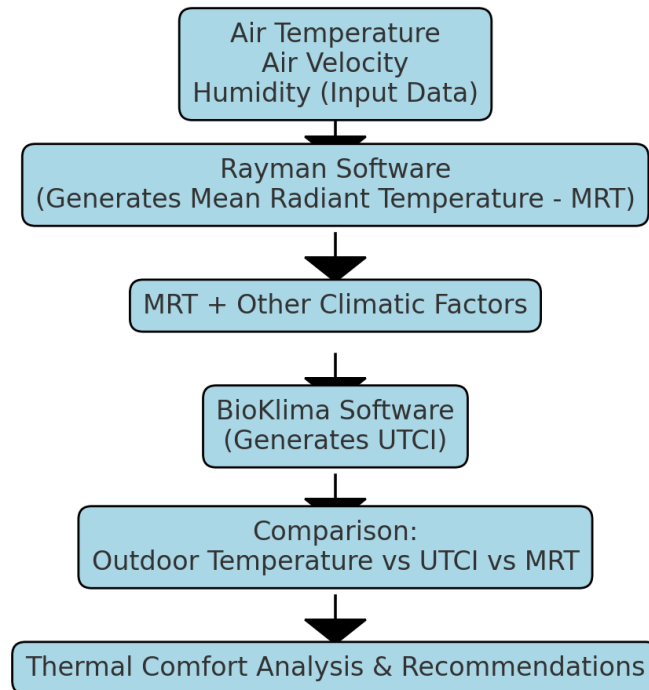


Figure 89. Process Flow for UTCI Calculation and Comparison

The graph below illustrates the relationship between air temperature (T_a), Mean Radiant Temperature (MRT), and the Universal Thermal Climate Index (UTCI) throughout a typical day, with data recorded hourly. The outdoor data used in this analysis was obtained using AWS 1 (Automatic Weather Station), ensuring accurate measurements of environmental parameters such as air temperature, humidity, and wind speed. The Y-axis represents temperature values in degrees Celsius ($^{\circ}\text{C}$), while the X-axis denotes the time of day, from 12:00 AM to 11:00 PM. Each line represents a specific parameter: air temperature (T_a) as the black line, MRT as the blue line, and UTCI as the orange line.

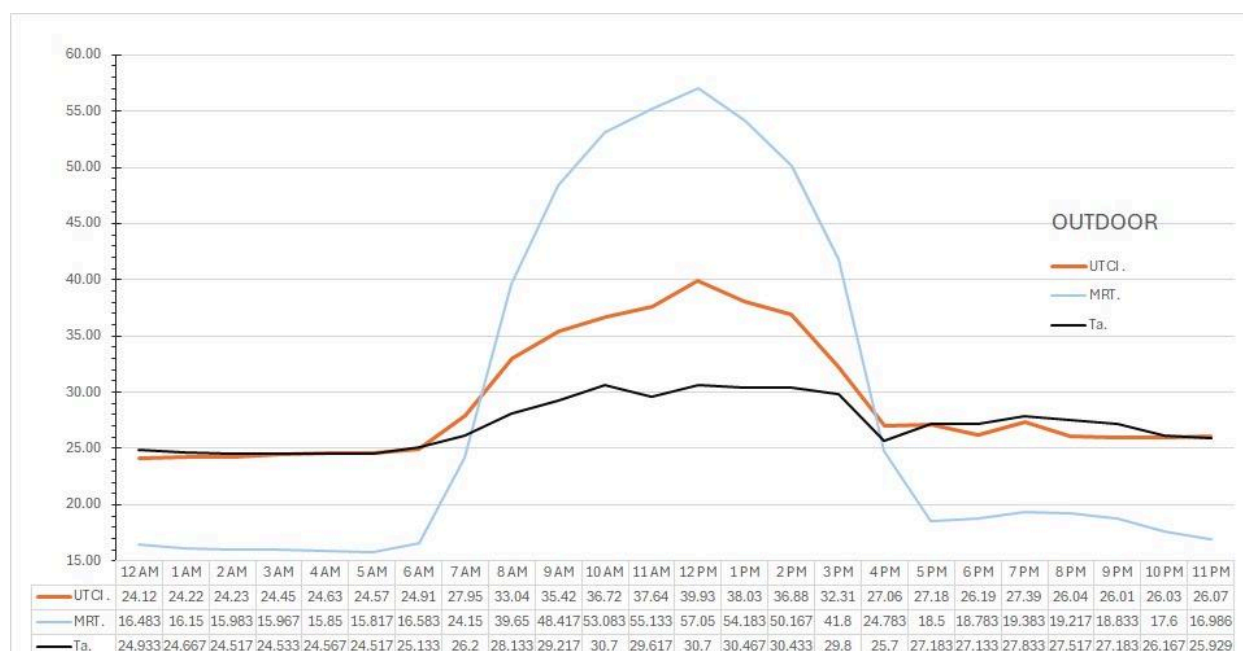


Figure 90 Outdoor UTCI and Air Temperature Comparison. (Source: Research Team, 2024)

The air temperature (T_a) starts at a relatively low level ($\sim 24^\circ\text{C}$) during the night and early morning hours, gradually increases during the morning, peaks around noon at approximately $28\text{--}29^\circ\text{C}$, and then decreases into the evening. The Mean Radiant Temperature (MRT), which reflects the effects of solar and surface radiation, displays a much more pronounced peak compared to air temperature. It remains close to air temperature during the early morning and late evening but rises sharply during midday, reaching around 50°C due to maximum solar radiation. This significant difference highlights the impact of radiant heat during the day.

The UTCI, represented by the orange line, integrates the effects of air temperature, MRT, wind speed, and humidity to assess perceived thermal stress. Its trend closely follows that of MRT, peaking around $38\text{--}40^\circ\text{C}$ at midday, slightly lower than MRT due to the moderating effects of wind and humidity. During the early morning and late evening, UTCI values align closely with air temperature, indicating lower thermal stress.

Universal Thermal Climate Index at Key Points (Semi-Outdoor)

The analysis involves comparing UTCI, Air Temperature, and Mean Radiant Temperature (MRT) across key locations, including Greenhub, Promenade, Undercanopy, and FCC. However, the 2F Undercanopy could not be included due to the absence of air velocity data, which is required

to calculate MRT in Rayman. Consequently, UTCI could not be generated for this location due to the incomplete environmental dataset.

The analysis utilizes hourly averaged data collected from 27 November to 5 December 2024 at the key points. As previously explained, the parameters air temperature, humidity, and air velocity are critical inputs for generating MRT using Rayman. These four parameters are then used to calculate UTCI with the BioKlima software. This approach ensures a comprehensive evaluation of thermal conditions at each location, except for the 2F Undercanopy, where data limitations restrict the analysis.

Green Hub

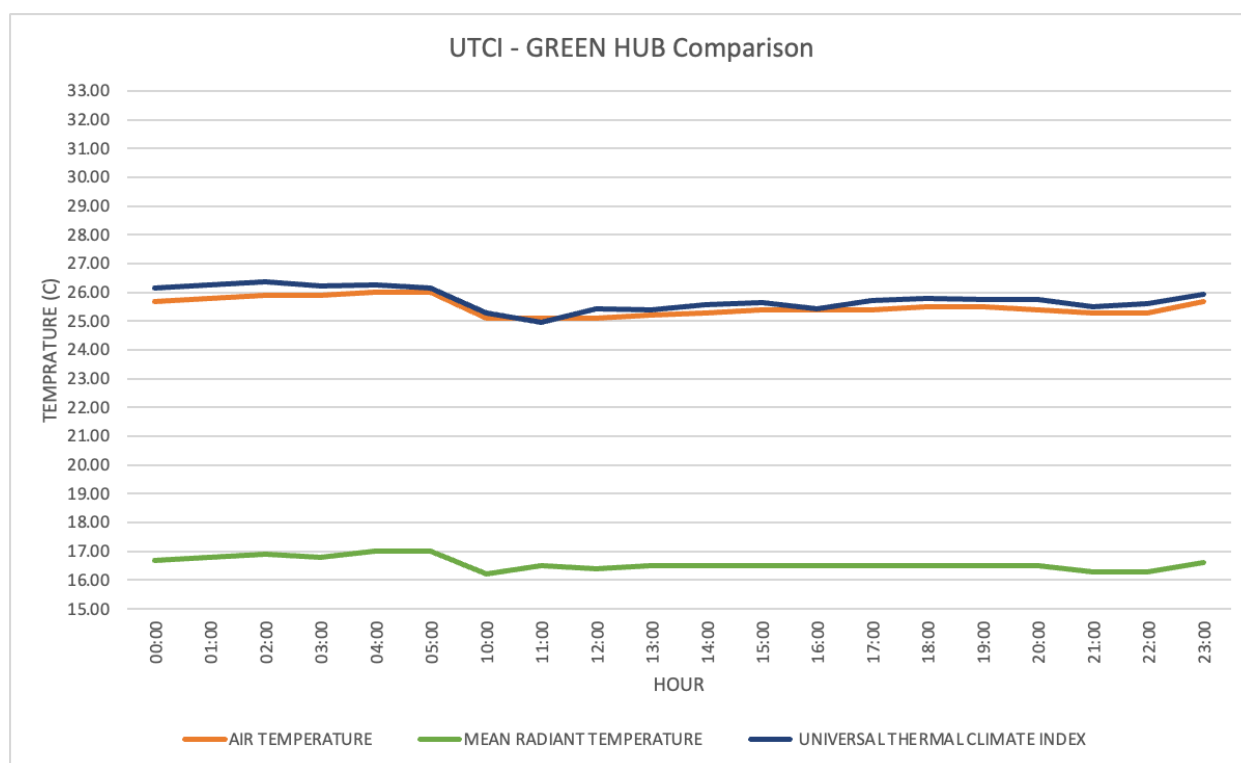


Figure 91. UTCI-Green Hub air temperature comparison. (Source: Research Team, 2024)

The graph compares the Universal Thermal Climate Index (UTCI), air temperature (T_a), and Mean Radiant Temperature (MRT) in the Green Hub. A key observation is that the UTCI values are nearly identical to the air temperature throughout the day. This can be attributed to minimal radiative impact, as the MRT values, represented by the green line, remain consistently low compared to air temperature. This suggests that the Green Hub likely provides significant

shading or reduced exposure to direct solar radiation, effectively minimizing the influence of radiation on thermal comfort.

In this scenario, air temperature appears to be the dominant factor influencing UTCI. The low MRT values indicate limited heat transfer from surrounding surfaces or solar radiation, causing UTCI to closely reflect the air temperature. Additionally, the environmental conditions such as wind speed and humidity may be relatively stable or neutral in this location, further contributing to the alignment between UTCI and air temperature.

The UTCI values consistently staying within a moderate range indicate that the Green Hub offers a thermally comfortable environment with reduced heat stress. This is likely due to design features such as vegetation, shading structures, or a controlled microclimate. In conclusion, the Green Hub demonstrates the effectiveness of environmental design in mitigating thermal stress, emphasizing the importance of shaded and controlled spaces for maintaining outdoor thermal comfort. By limiting the impact of radiation and stabilizing climatic factors, the Green Hub achieves a balanced and comfortable thermal environment.

Promenade

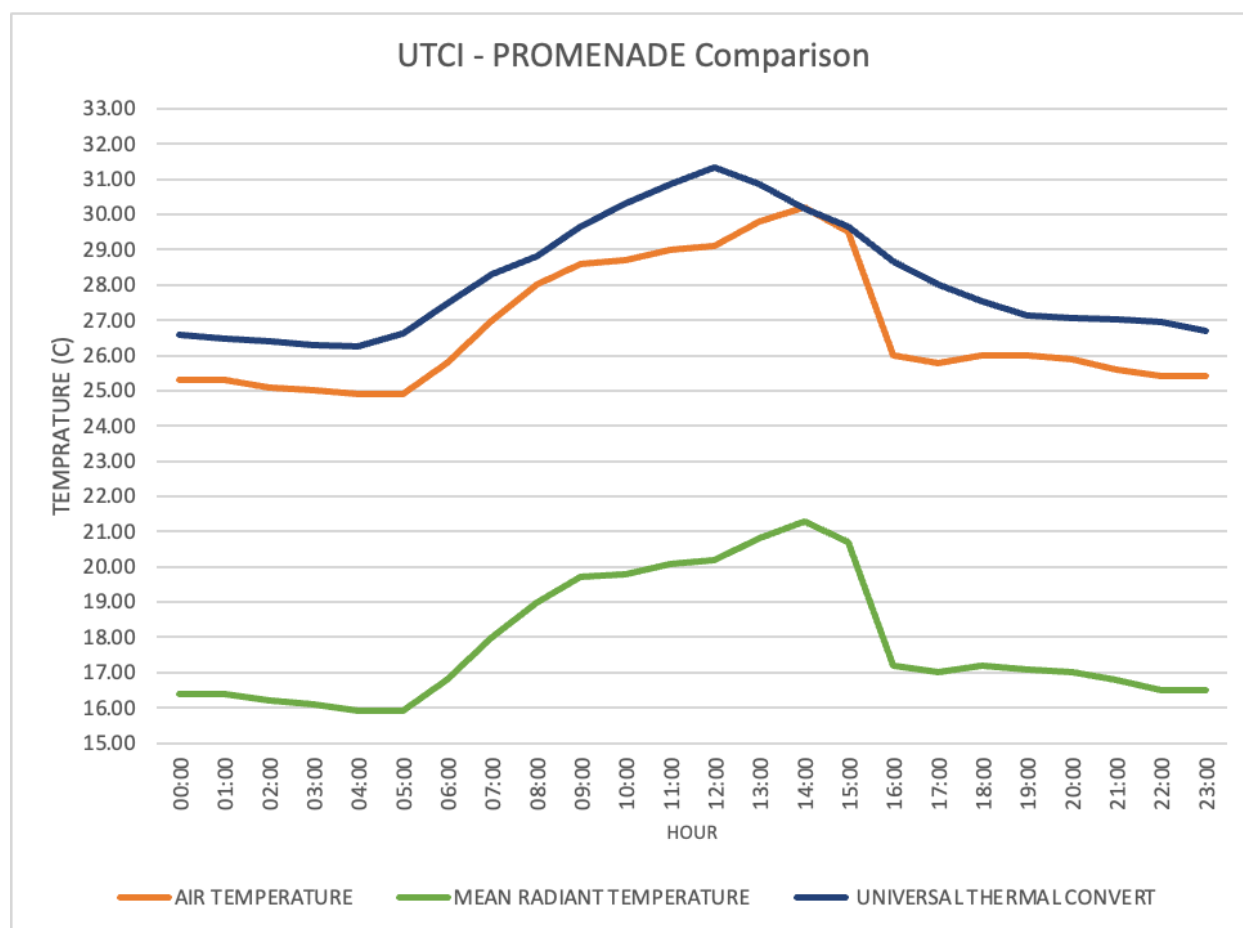


Figure 92. UTCI-Promenade air temperature comparison. (Source: Research Team, 2024)

Unlike the Green Hub, there is a significant difference between UTCI and air temperature during the daytime, particularly around midday. The Mean Radiant Temperature (MRT), represented by the green line, rises substantially during the day, peaking around 13:00–14:00 and exceeding 30°C. This suggests strong exposure to solar radiation in the Promenade, likely due to limited shading or the presence of reflective surfaces.

The UTCI, represented by the blue line, closely follows the pattern of MRT rather than air temperature, peaking higher than air temperature during midday. This indicates that radiative heat significantly contributes to increased thermal stress in the area. The high UTCI values during midday suggest that conditions in the Promenade are less thermally comfortable during this time, making it less suitable for outdoor activities. In contrast, during the early morning and

evening, MRT values drop significantly, causing UTCI to align more closely with air temperature. This indicates improved thermal comfort during these periods.

In conclusion, the elevated Mean Radiant Temperature (MRT) in the Promenade area during the day results in higher UTCI values, reflecting increased thermal stress and reduced comfort. The lack of shading or the presence of reflective surfaces appears to amplify the impact of radiation. To enhance thermal comfort in the Promenade, interventions such as adding shading elements, incorporating vegetation, or utilizing materials with low solar reflectance could be implemented. These measures could mitigate the radiative impact and create a more thermally comfortable environment throughout the day.

Undercanopy

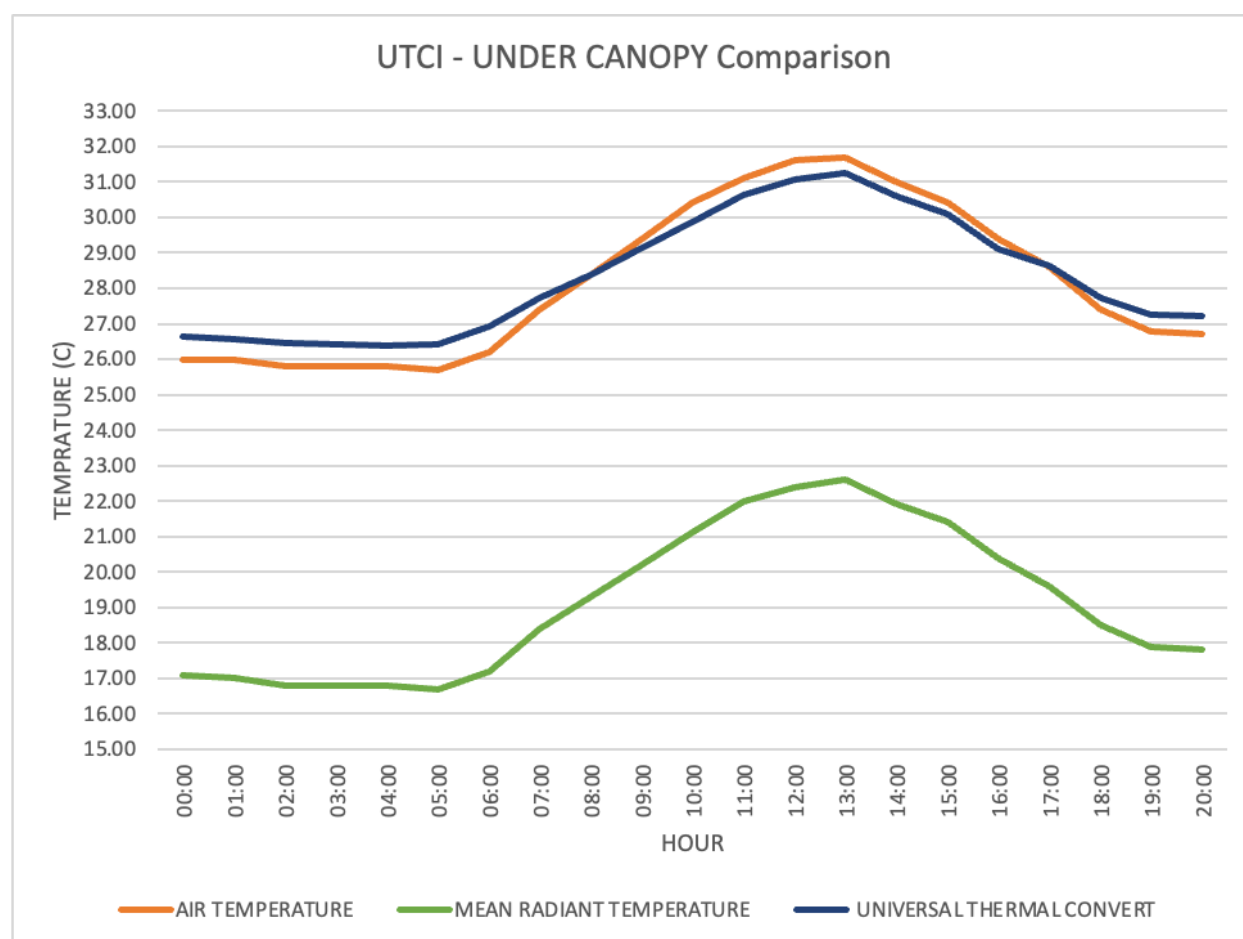


Figure 93. UTCI-Undercanopy air temperature comparison. (Source: Research Team, 2024)

The graph compares the Universal Thermal Climate Index (UTCI), air temperature (T_a), and Mean Radiant Temperature (MRT) in the Under Canopy area. The UTCI closely follows the air temperature throughout the day, with only slight divergence, while MRT shows a noticeable midday peak but remains significantly lower than the patterns observed in more exposed areas like the Promenade. This indicates that the canopy effectively reduces exposure to solar radiation, moderating the radiative impact.

The Mean Radiant Temperature (MRT) rises during the day and peaks around 13:00 but remains considerably lower than UTCI and air temperature. This suggests that the shading provided by the canopy minimizes the contribution of radiation to thermal stress. Consequently, the UTCI, which closely tracks air temperature, indicates that perceived thermal comfort in this area is predominantly influenced by air temperature rather than MRT. The shading mitigates the midday heat, leading to reduced thermal stress and a more comfortable environment during the hottest parts of the day.

During the early morning and late evening hours, MRT is nearly constant and aligns with air temperature, ensuring consistent thermal comfort throughout these periods. The lack of significant divergence between UTCI, air temperature, and MRT reflects the consistent shading and protection offered by the canopy.

In conclusion, the Under Canopy area demonstrates the effectiveness of shading in reducing solar radiation and thermal stress. The lower MRT values and the close alignment of UTCI with air temperature suggest a thermally comfortable environment throughout the day. This analysis highlights the importance of shading structures, like canopies, in improving thermal comfort and mitigating the impact of radiative heat in outdoor spaces.

Front Command Center

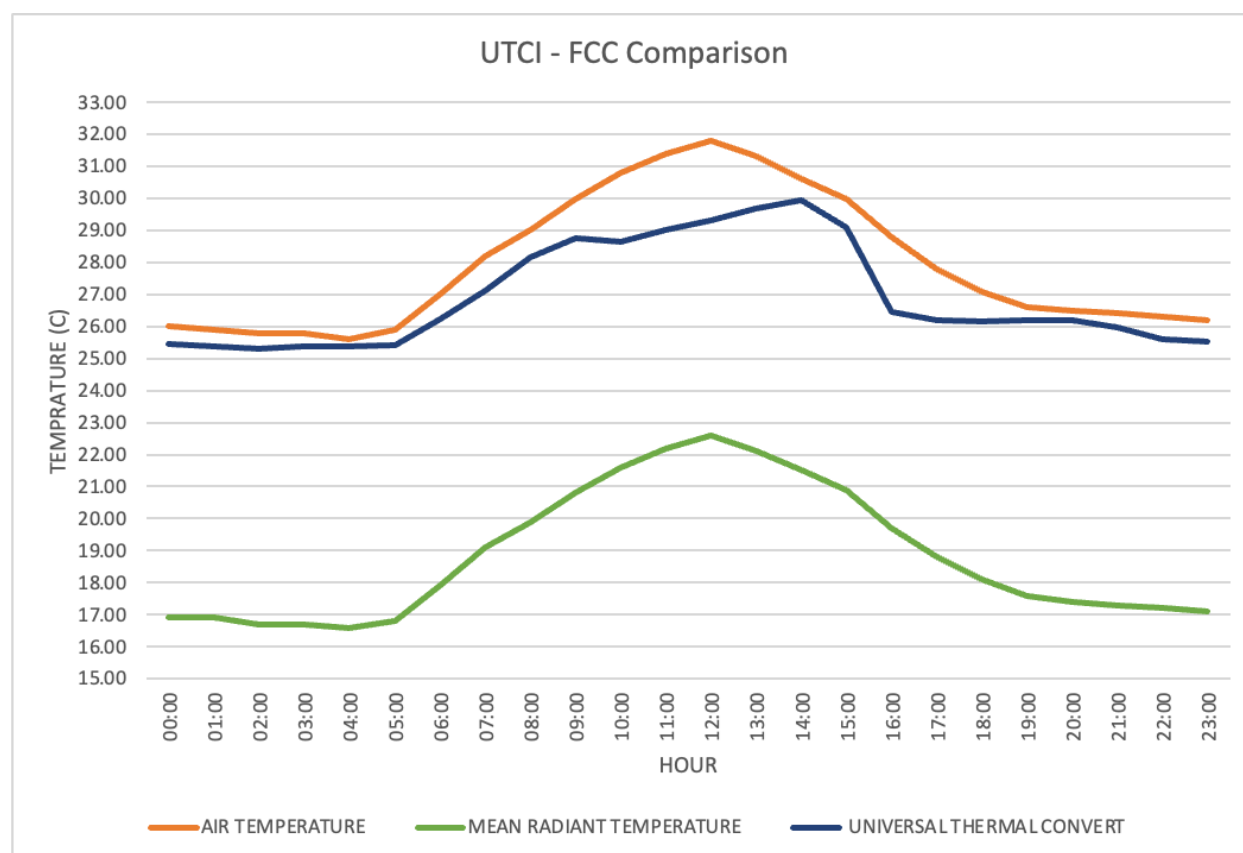


Figure 94. UTCI-FCC air temperature comparison. (Source: Research Team, 2024)

The graph compares the Universal Thermal Climate Index (UTCI), air temperature (T_a), and Mean Radiant Temperature (MRT) in the FCC (Facility Control Center) area, highlighting the significant impact of radiative heat during the daytime. The Mean Radiant Temperature (MRT), represented by the green line, rises sharply during the day and peaks around midday (12:00–13:00), indicating strong exposure to solar radiation or reflective surfaces in the FCC area. This sharp increase in MRT significantly influences the UTCI, which diverges from air temperature during the late morning to early afternoon. The elevated UTCI values during this period suggest increased thermal stress, as the perceived heat is amplified by the high MRT values.

The close alignment between UTCI and air temperature during the early morning and late evening indicates improved thermal comfort when MRT values drop significantly. This highlights that the absence of solar radiation during these hours reduces thermal stress, making outdoor

conditions more comfortable. However, during midday, the elevated UTCI reflects unfavorable conditions for outdoor activities due to the increased radiative heat and its contribution to perceived thermal stress.

In conclusion, the FCC area experiences noticeable thermal stress during peak daylight hours, primarily driven by high MRT values. This suggests that the environment is strongly affected by solar radiation and possibly reflective surfaces, reducing thermal comfort during midday. To improve comfort, measures such as adding shading structures or reducing reflective materials could be implemented. The consistent alignment of UTCI and air temperature during non-peak hours emphasizes the importance of mitigating radiative impacts to maintain thermal comfort throughout the day.

Conclusion Universal Thermal Climate Index at Key Points (Semi-Outdoor)

Table 2. Comparison of UTCI and MRT at Key Points

Location	Key Observations	Thermal Comfort	Recommendations
Green Hub	UTCI aligns closely with air temperature.	Effective shading results in low thermal stress.	Maintain shading design.
	MRT values remain consistently low throughout the day.	Comfortable conditions maintained all day.	Minimal interventions needed.
Promenade	Significant divergence between UTCI and air temperature during midday.	High MRT causes increased thermal stress during peak hours.	Introduce shading structures.
	MRT peaks sharply (~13:00).	Less comfortable environment at midday.	Reduce reflective surfaces. Add vegetation for cooling.
Under Canopy	MRT rises during midday but remains lower than in exposed areas.	Moderate radiative impact.	Ensure canopy design remains effective.
		Shading effectively mitigates thermal stress.	Minor improvements for additional cooling if required.

	UTCI aligns closely with air temperature.	Consistent comfort throughout the day.	
FCC	MRT peaks around midday, though lower than in Promenade. UTCI diverges moderately from air temperature during midday.	Moderate thermal stress during peak hours. Improved comfort compared to Promenade but less than shaded areas.	Add shading elements. Improve airflow or introduce cooling measures. Reduce reflective surfaces.

1. Shading Effectiveness

Locations with effective shading, like the Green Hub and Under Canopy, exhibit lower MRT values and better thermal comfort throughout the day.

In contrast, the Promenade and FCC show higher MRT and UTCI during midday, indicating the need for additional shading or reflective surface management.

2. Radiative Impact:

MRT significantly influences UTCI in exposed areas like the Promenade and FCC. The UTCI rises above air temperature during peak hours, highlighting the impact of solar radiation on thermal stress.

3. Design Recommendations:

Incorporating shading structures, vegetation, or reflective materials in open areas like the Promenade and FCC could reduce MRT and improve overall thermal comfort.

Maintaining shaded zones, as demonstrated in the Green Hub and Under Canopy, ensures consistent thermal comfort and lower thermal stress levels.

Findings and Recommendations



The graph shows an interesting finding where the UTCI outdoor values are lower than those observed under the canopy, even during nighttime hours. This suggests potential issues with the design or configuration of the under-canopy space, which may be contributing to higher thermal stress compared to the outdoor environment. This anomaly could arise due to several factors:

1. Orientation of the Canopy Area: The orientation may be causing poor ventilation or blocking natural airflow, trapping heat under the canopy and reducing its cooling efficiency.
2. Corridor Layout and Mall Design: The internal corridor layout or the mall's architectural design may influence heat accumulation or impede natural cooling processes, further elevating UTCI in the under-canopy area.
3. Canopy Materials: The materials used in the canopy design could be contributing to heat retention. For instance, materials with low reflectivity or high heat absorption could radiate heat back into the space, increasing thermal stress.

Based on the analysis of various locations within the Grand Outlet, including the Green Hub, Promenade, Under Canopy, and FCC, along with the comparison of UTCI outdoor and under-canopy values, the findings highlight key strengths and challenges in the current design.

These insights provide a foundation for improving thermal comfort through targeted interventions and additional environmental strategies.

Effectiveness of Shading in Outdoor Areas

- a. Locations like the Green Hub exemplify the benefits of effective shading strategies, as evidenced by low MRT values (16.8°C) and minimal UTCI-Air Temperature deviations (0.2°C). These factors ensure consistently comfortable thermal conditions throughout the day.
- b. However, areas like the Promenade and FCC show significant thermal stress during peak hours, with MRT values of 30.5°C and 25.0°C, respectively, leading to elevated UTCI values (32.0°C and 29.0°C). These areas highlight the need for enhanced shading or cooling mechanisms to address radiative heat.

Key Finding: Higher UTCI Under the Canopy Than Outdoors

A notable observation is that UTCI under the canopy is higher than outdoor UTCI, even during nighttime. This suggests that the under-canopy design traps heat, contributing to greater thermal stress in this area. Potential causes include:

- a. Orientation issues, where airflow is restricted, preventing natural ventilation and cooling.
- b. Corridor layout, which may direct heat from adjacent indoor spaces toward the canopy area.
- c. Canopy materials with high thermal absorption and low reflectivity, causing heat to accumulate and radiate back into the space.

This finding indicates that, while the canopy offers shading during the day, its design is suboptimal for maintaining comfortable conditions, especially during the evening.

The Role of Vegetation and Water Features

- a. Incorporating vegetation, such as trees, vertical gardens, and green roofs, can significantly reduce radiative heat and improve thermal comfort. Vegetation provides shade, cools through evapotranspiration, and enhances the aesthetic appeal of the space.

- b. Adding water features, such as fountains, ponds, or misting systems, can help lower ambient temperatures by introducing evaporative cooling, further mitigating thermal stress in exposed areas.
- c. These elements, combined with improved shading strategies, can create a more holistic approach to thermal management across the Grand Outlet.

Time-of-Day Thermal Comfort Variations

- a. The Promenade and FCC exhibit the highest thermal stress during midday, with peak UTCI values of 32.0°C and 29.0°C, driven by high MRT values of 35.0°C and 28.0°C, respectively. These areas require immediate interventions to improve comfort during peak hours.
- b. The Green Hub remains the most thermally comfortable area, with a peak UTCI of 26.5°C, thanks to effective shading and minimal MRT values.

Testing Thermal Comfort Based on Occupants and Visitors

- a. Beyond environmental analysis, it is essential to assess thermal comfort from the perspective of occupants and visitors. This can be achieved through:
- b. Surveys and feedback to understand visitors' perceptions of heat and comfort in various areas.
- c. Wearable temperature sensors or physiological measurements to gather real-time data on how visitors experience different thermal conditions.
- d. Behavioral studies to evaluate how occupants adapt to thermal environments (e.g., seeking shade, avoiding certain areas during midday).

This user-focused approach will provide deeper insights into how the design impacts thermal comfort and identify areas for improvement based on actual user experience.

Recommendations for Canopy Design and Cooling Strategies

- a. Address Under Canopy Issues:
 - Optimize canopy orientation to improve ventilation and natural cooling.

- Reevaluate corridor layouts and connections to reduce heat transfer from indoor spaces.
 - Replace current materials with high-reflectivity, low-emissivity materials to minimize heat absorption and radiation.
- b. Enhance Promenade and FCC Areas:
- Introduce additional shading structures, such as retractable canopies or green covers.
 - Incorporate vegetation and water features to create cooling microclimates.
 - Improve ventilation to enhance air circulation and dissipate heat.
- c. Expand Vegetative and Water Elements:
- Use trees and vertical gardens strategically to provide shade in open areas.
 - Integrate water features to promote evaporative cooling and reduce ambient temperatures.
- d. Assess Visitor Thermal Comfort:
- Conduct visitor-focused surveys and physiological studies to understand the thermal performance of spaces from a user perspective.

Broader Implications for Thermal Comfort Design

- a. Integrated Solutions: Combining shading, vegetation, water features, and thermal-responsive materials can significantly improve the overall thermal environment of the Grand Outlet.
- b. Dynamic Design Considerations: Adaptable designs, such as retractable canopies or responsive water features, can offer flexibility to address varying thermal conditions throughout the day.
- c. Sustainability Focus: Incorporating natural cooling elements such as vegetation and water not only improves comfort but also aligns with sustainable design practices, reducing reliance on mechanical cooling

Summary

Environmental Monitoring Setup:

Comprehensive data collection was achieved through strategically placed instruments, including Ambient Weather WS-2000 stations on two rooftops and various devices inside the facility (WBGT meters, anemometers, data loggers).

Switching weather stations (Ambient Weather 1 and 2) between rooftops optimized signal reliability for outdoor data collection.

Parameter Analysis:

Key parameters such as air temperature, humidity, air velocity, WBGT, solar radiation, and rainfall were monitored to assess thermal comfort and environmental loads impacting the facility's microclimate.

Daily Variability:

Using boxplots and statistical methods, the study revealed significant daily fluctuations and mean trends in WBGT and other environmental conditions, highlighting the variability of thermal environments over the operational period (26 November to 5 December).

Impact of External Conditions:

Bivariate analysis showed that outdoor parameters, such as air temperature, wind speed, and solar radiation (measured by weather stations), had a significant impact on Semi-Outdoor conditions, including WBGT, air velocity, and humidity. However, the data consistently showed a trend where Semi-Outdoor values were lower than the corresponding outdoor parameters, reflecting the influence of the facility's design and microclimatic controls.

Summary of Data Comparison:

The comparison between Semi-Outdoor and outdoor temperature data across all measurement points highlights notable differences in thermal performance, particularly between daytime and nighttime conditions. During the daytime, outdoor temperatures consistently peak higher than

Semi-Outdoor temperatures, with outdoor values ranging between 35°C to 37°C and Semi-Outdoor temperatures typically moderated to 28°C to 34°C. This reduction is attributable to canopy as shading, and ventilation mechanisms within the facility, which effectively mitigate the impact of direct solar radiation and outdoor heat loads.

At nighttime, however, the relationship between Semi-Outdoor and outdoor temperatures shifts slightly. Outdoor temperatures drop significantly, often reaching 19°C to 23°C, while Semi-Outdoor temperatures tend to remain more stable, ranging from 24°C to 26°C. This indicates some level of heat retention Semi-Outdoors due to residual warmth stored within the building materials and limited ventilation during the cooler hours.

The difference between Semi-Outdoor and outdoor temperatures is more pronounced during the day, highlighting the effectiveness of passive cooling strategies such as shading and ventilation. At night, the smaller temperature difference suggests that improved airflow or nighttime cooling strategies may be needed to prevent heat buildup and ensure thermal comfort during cooler periods. This analysis underscores the importance of addressing both daytime and nighttime conditions when optimizing the thermal performance of Semi-Outdoor spaces in response to external environmental loads.

Challenges Encountered:

Operational challenges included electrical shortages due to high power demand during December events, thunderstorms requiring temporary evacuation of rooftop equipment, and prolonged equipment usage leading to recalibration needs.

Thermal Comfort Insights:

Outdoor measurements complemented Semi-Outdoor data, providing a holistic understanding of environmental conditions. Key findings emphasized the importance of balancing external environmental loads to maintain Semi-Outdoor thermal comfort.