

AMRC North West

Analysing the energy usage of Boeings Flight Simulation Centers for Low Carbon Review

Mohammad Nadeem Ahangar- Software Engineer
Zohaib Farhat- Theme Lead (Digital)

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**TOMORROW.
DONE BETTER.**

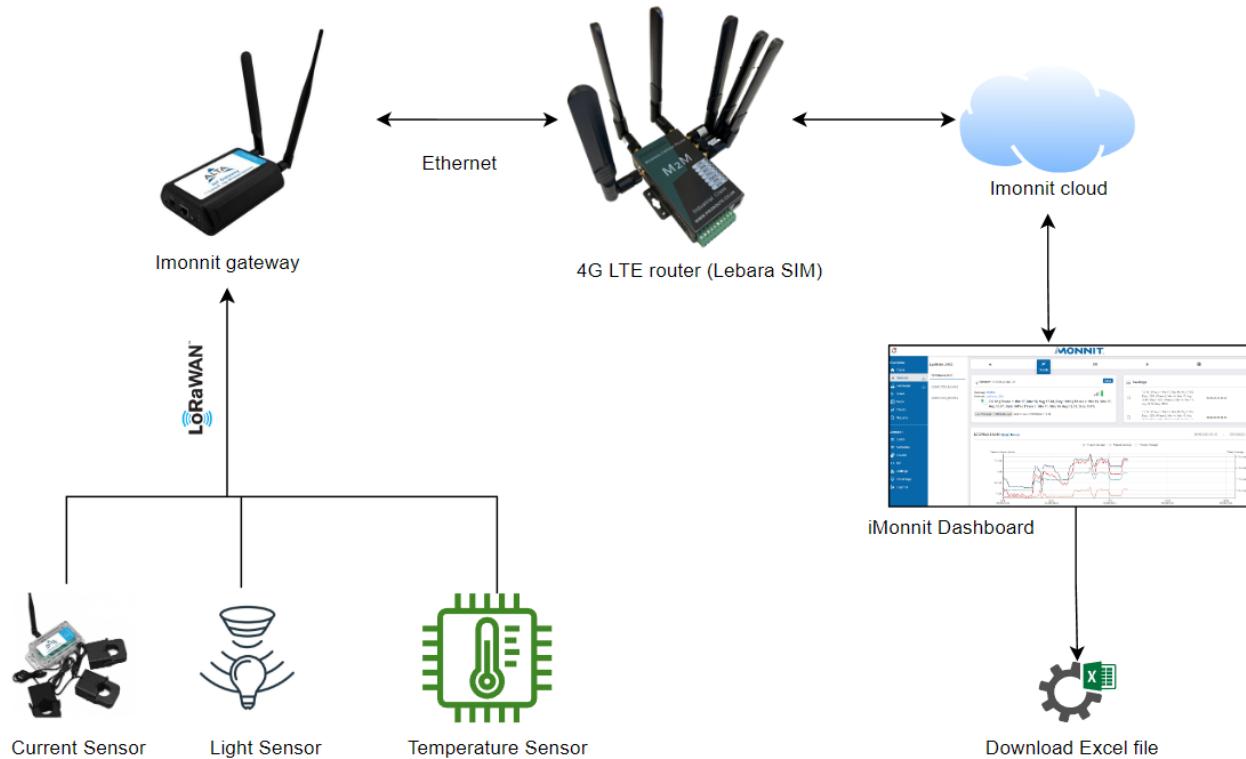
Introduction

In recent years, there has been an increasing focus on reducing carbon emissions across various industries, including aviation. Flight simulation centres play a crucial role in training pilots and improving aviation safety. However, the energy consumption of these centres and their potential environmental impact have received limited attention. This project aims to shed light on the energy usage of Boeing flight simulators and explore opportunities for reducing their carbon footprint.

Objectives

1. Create a comprehensive map of energy usage by utilising the collected data, aiming to identify areas for potential optimization and energy efficiency improvements.
2. Evaluate the feasibility of implementing renewable energy technologies based on the collected data, considering their capacity to offset a specific quantity of test simulations per annum or meet the instantaneous power demand of a test simulator.
3. Identify and assess standard and novel energy generation solutions that align with Boeing's public image and contribute to visual sustainability.
4. Provide informed recommendations and make decisions regarding the adoption of energy generation solutions based on the analysis of available data, effectively balancing the energy requirements of the facility with the sustainability goals.

Methodology

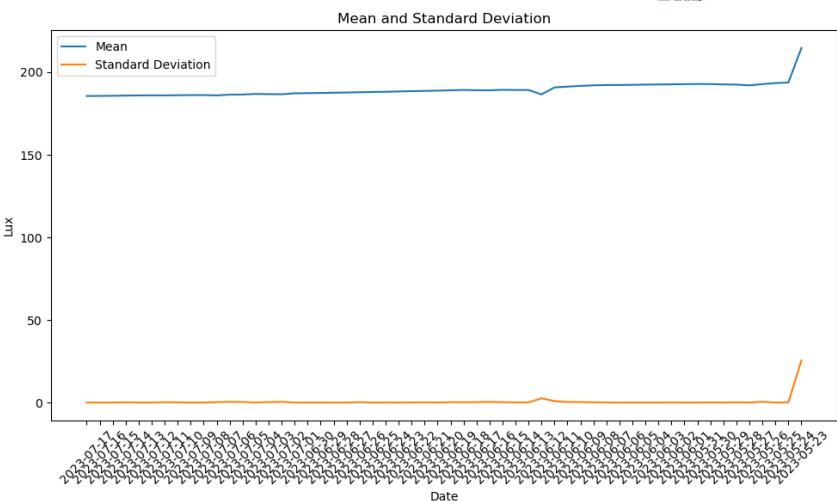
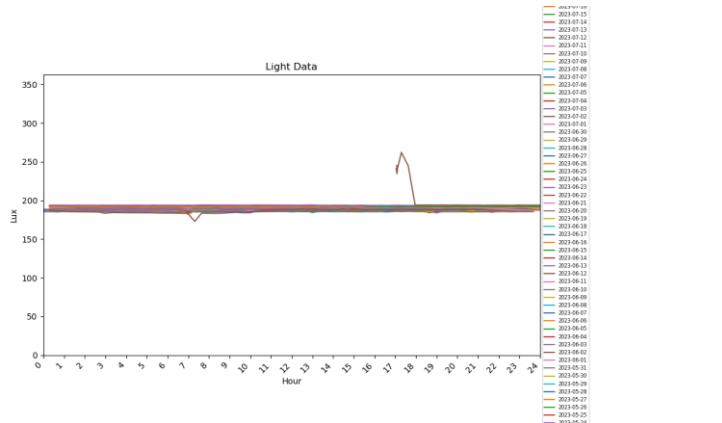
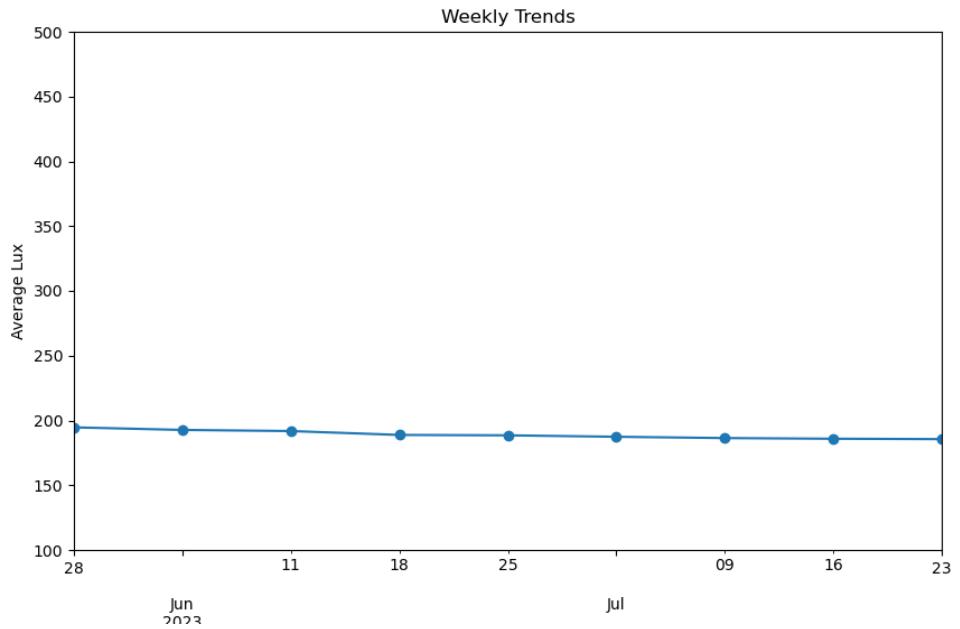


Benefits

- Identify energy-hungry devices.
- peak usage periods.
- Find peak current usage.
- Find patterns of energy usage in all simulators. This can include peak usage hours or recurring consumption patterns throughout the day.
- Analysing the identified patterns can provide insights into potential strategies for reducing energy consumption during repetitive times. For example, we may consider implementing energy-saving measures or adjusting simulator operations during these periods to optimize energy usage.

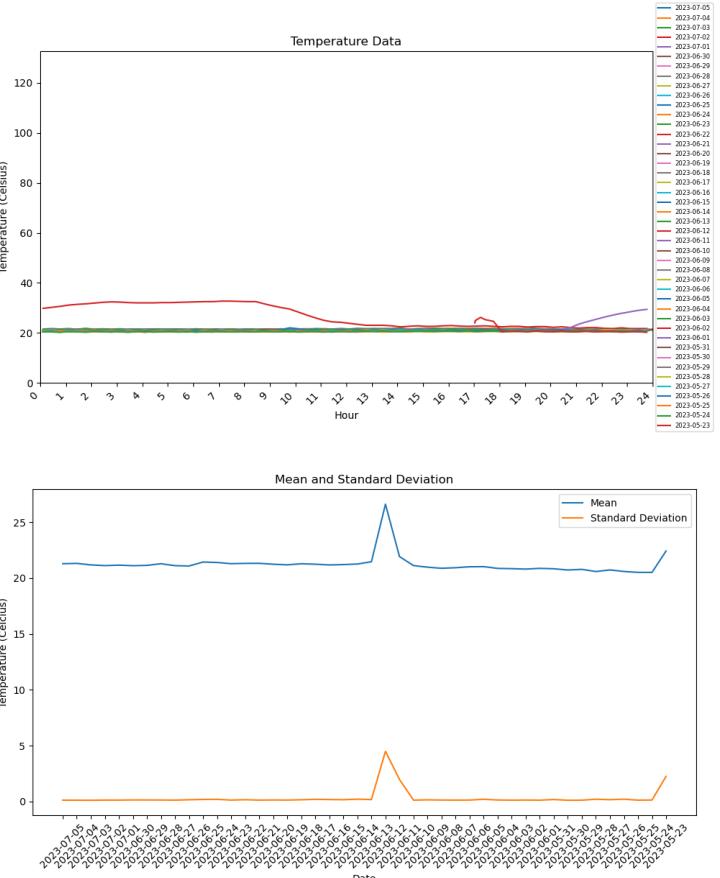
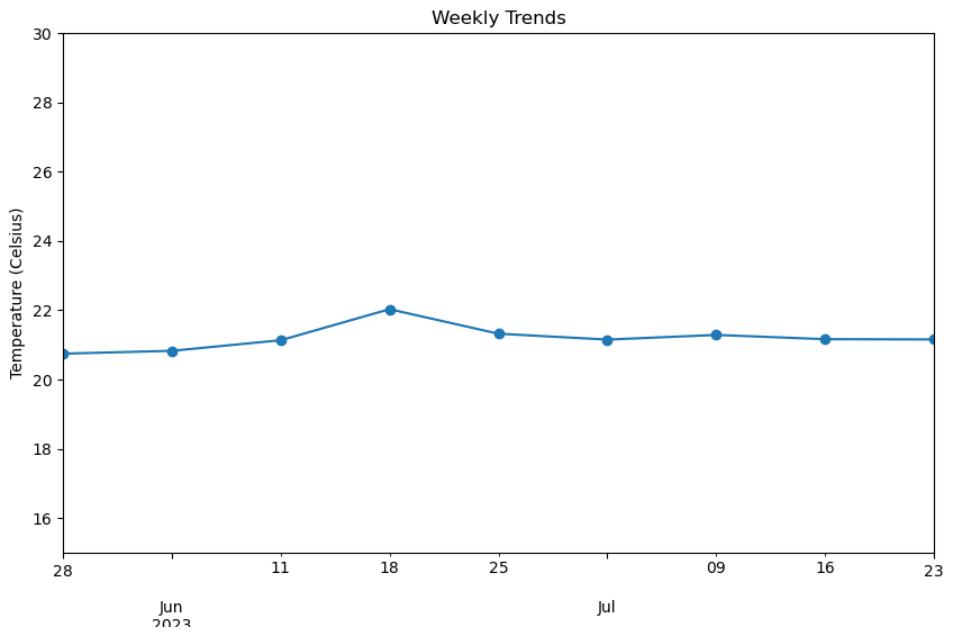
Computer Room Light Sensor

- No change in the light levels.



Computer Room Temperature Sensor

Temperature is very consistent in the server room.



Server Room heat recovery

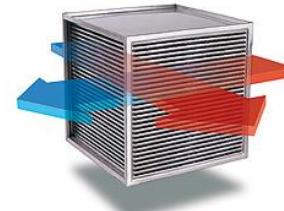
Data centres/server rooms typically generate a significant amount of heat due to the continuous operation of servers and other computing equipment. The cooling systems remove the excess heat from the data centre and release it into the surrounding environment. Instead of releasing this heat outdoors, it can be harnessed for useful purposes, like heating nearby offices, commercial buildings, or even homes. Several methods can be used to transfer the heat from the data centre to the heating destination:

Air-to-air heat exchangers: These systems use fans and heat exchangers to transfer the heat from the data centre air to the building's ventilation system.

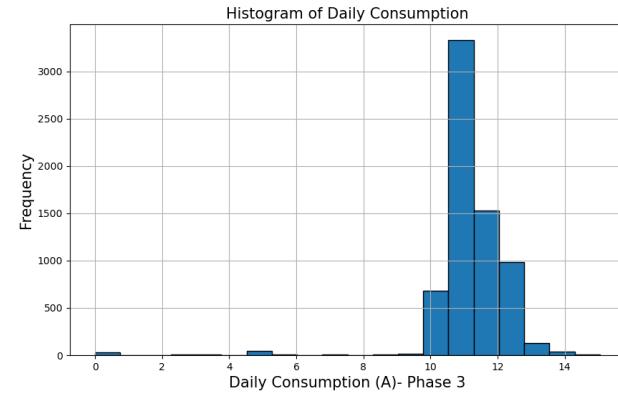
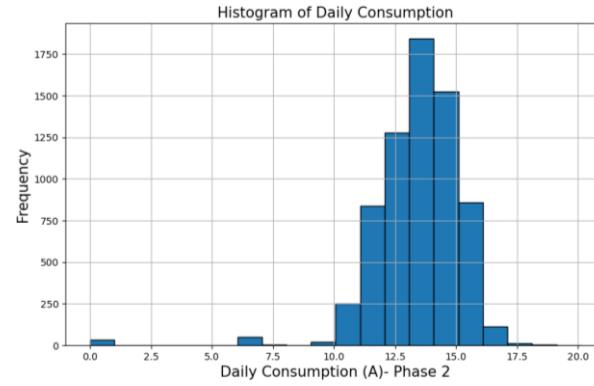
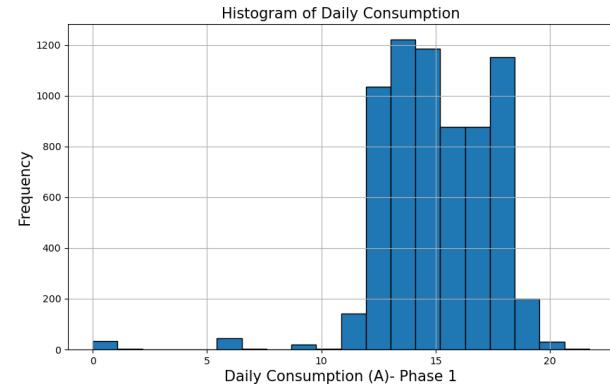
Liquid cooling: Some data centres use liquid cooling methods, which involve circulating coolant through the servers and then transferring the warmed coolant to a heat exchanger, which, in turn, heats water for space heating.

Direct heat distribution: In some cases, the data centre is located close to the heating destination, and the excess heat is directly channelled into the heating system of the building.

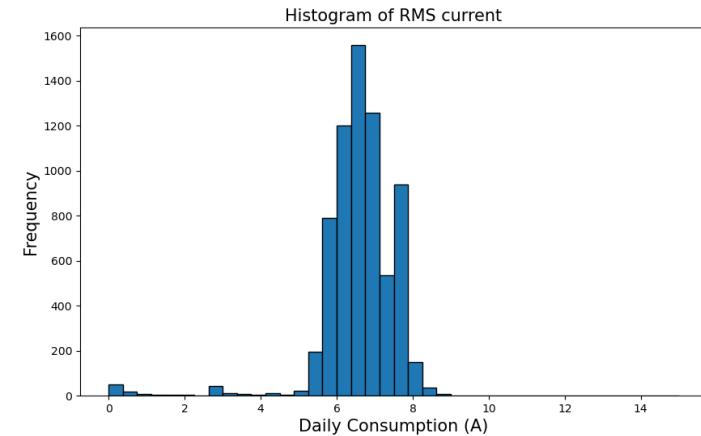
More information: [Alfa Laval](#) , [Airtech](#) , [Daikin](#) , [UK Exchangers LTD](#)



B737MAX-8-M-03

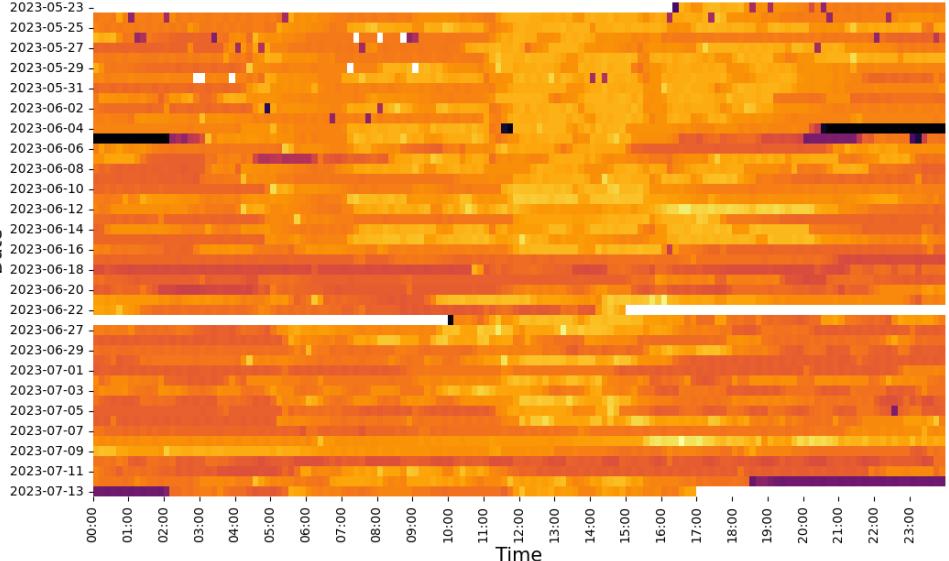


- Phase 1: Frequent current consumption range of 11 A to 19 A.
- Phase 2: Frequent current consumption range of 10 A to 17 A.
- Phase 3: Frequent current consumption range of 10 A to 13 A.
- Total RMS current consumption for all three phases: Mostly in the range of 5 A to 8 A.



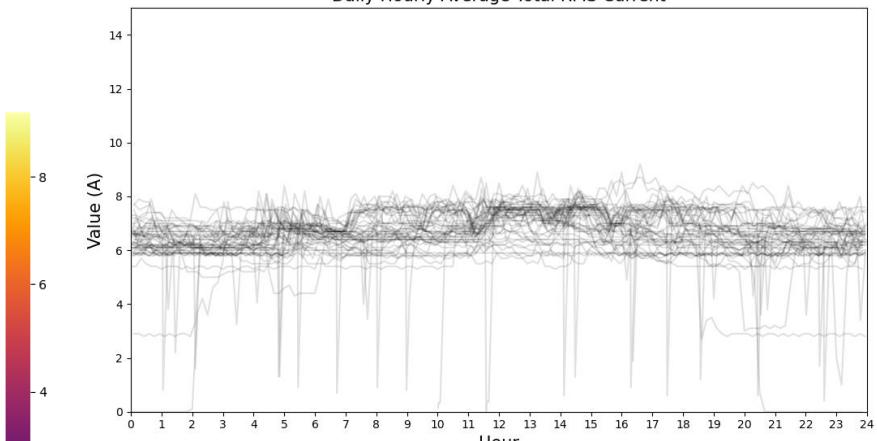
B737MAX-8-M-03

Hourly Current Consumption Heatmap

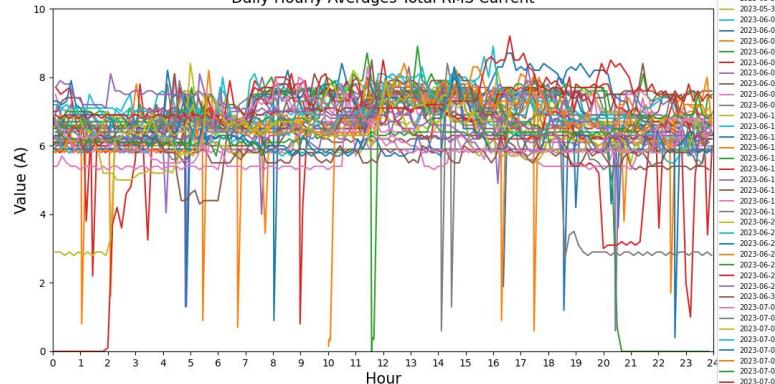


- Daily hourly consumption patterns depicted in the charts/graphs.
- Peak current usage observed between 12:00 to 16:00.
- Irregular drops in current consumption, suggesting random behavior.

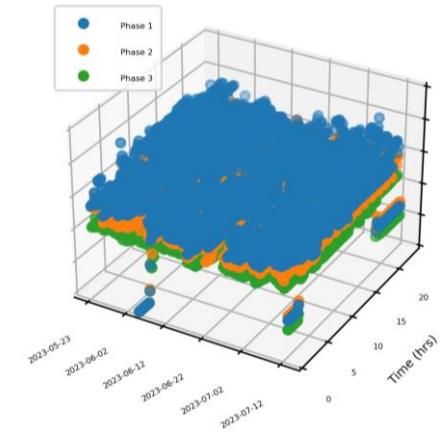
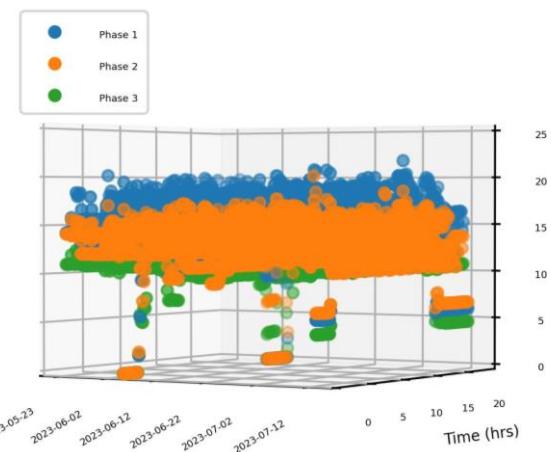
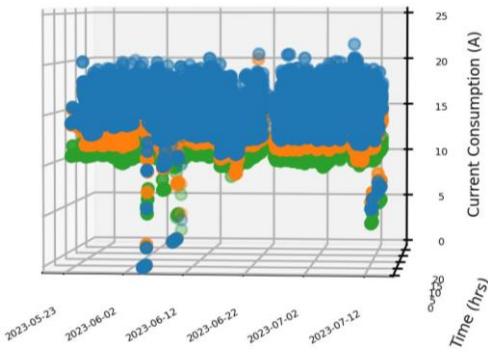
Daily Hourly Average Total RMS Current



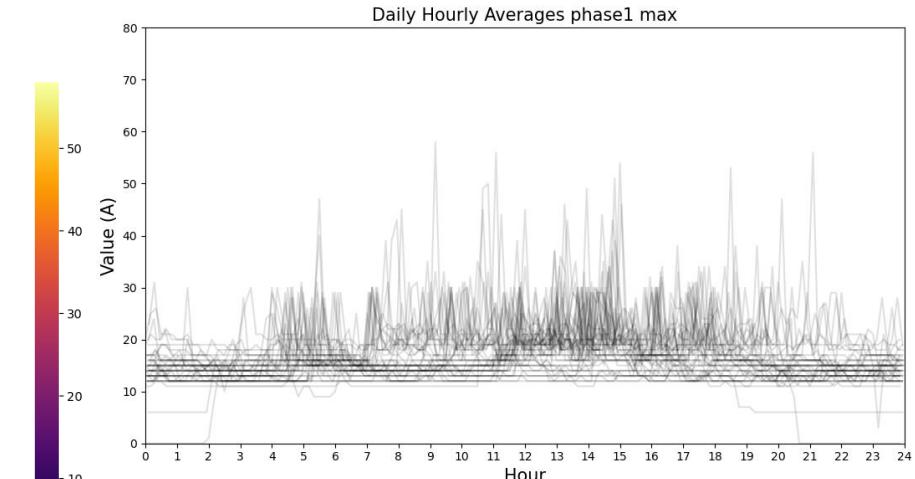
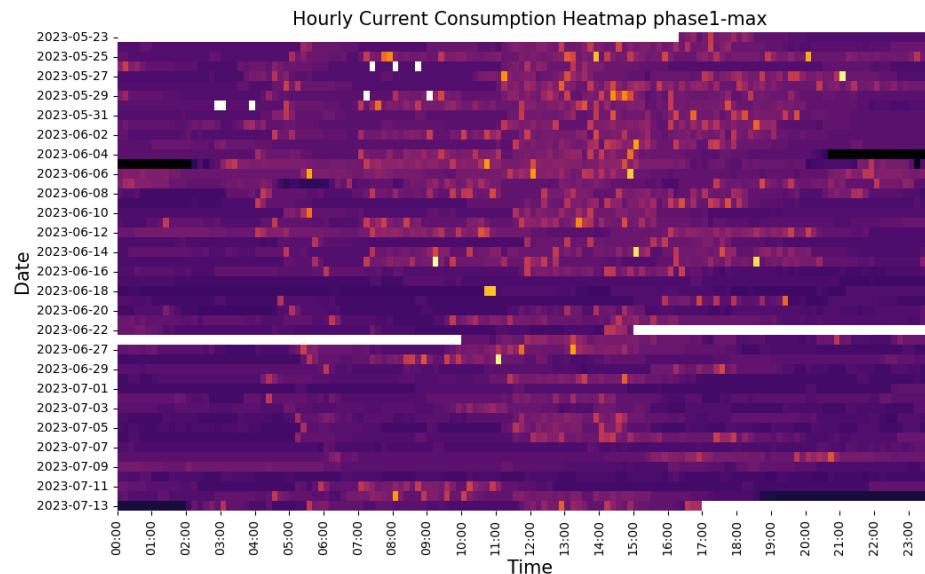
Daily Hourly Averages Total RMS Current



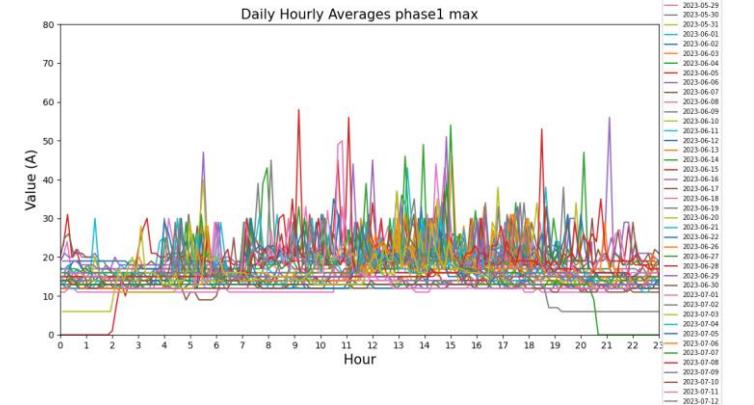
B737MAX-8-M-03



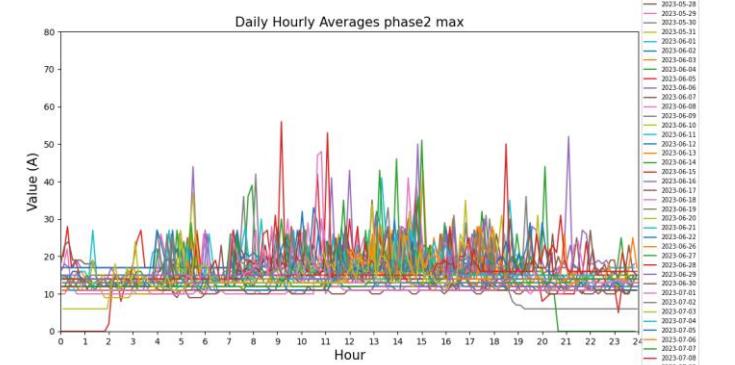
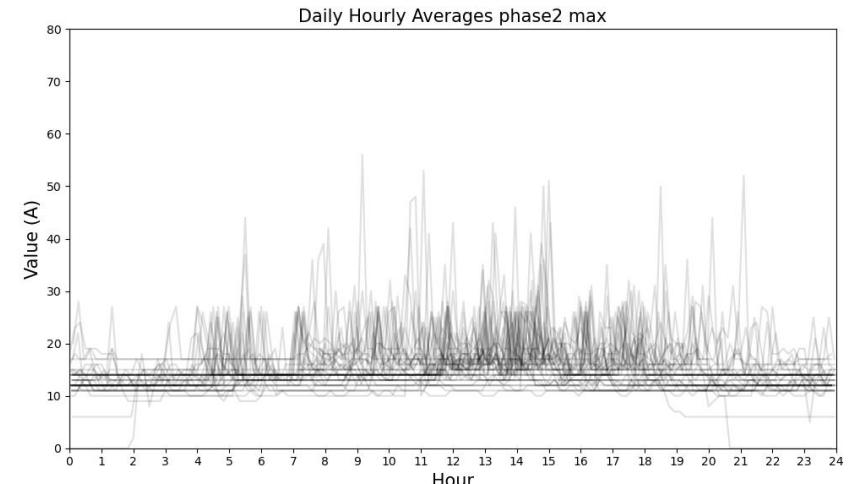
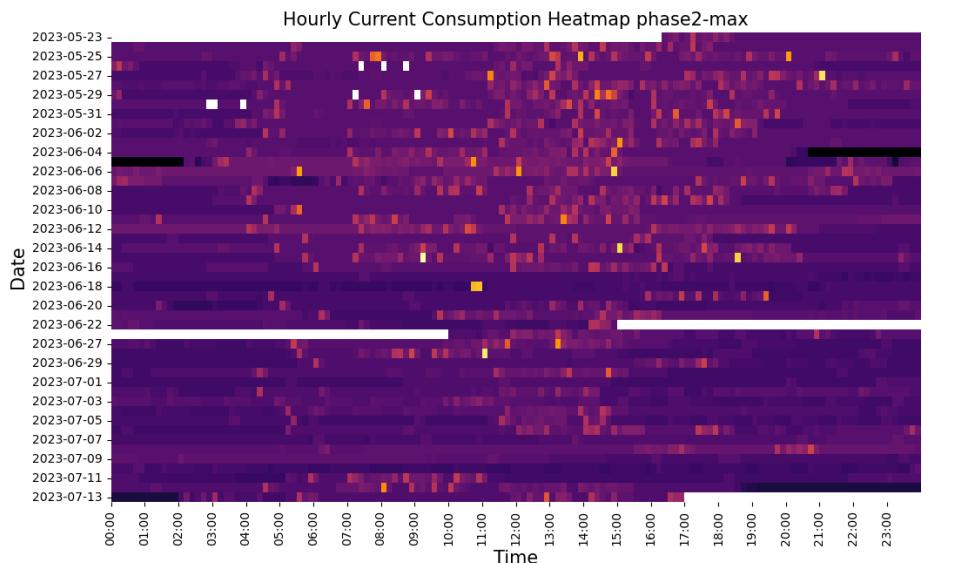
- Average current consumption: 10 A to 20 A across all 3 phases.
- Proximity of the three phases.
- Load imbalance evident from the charts.



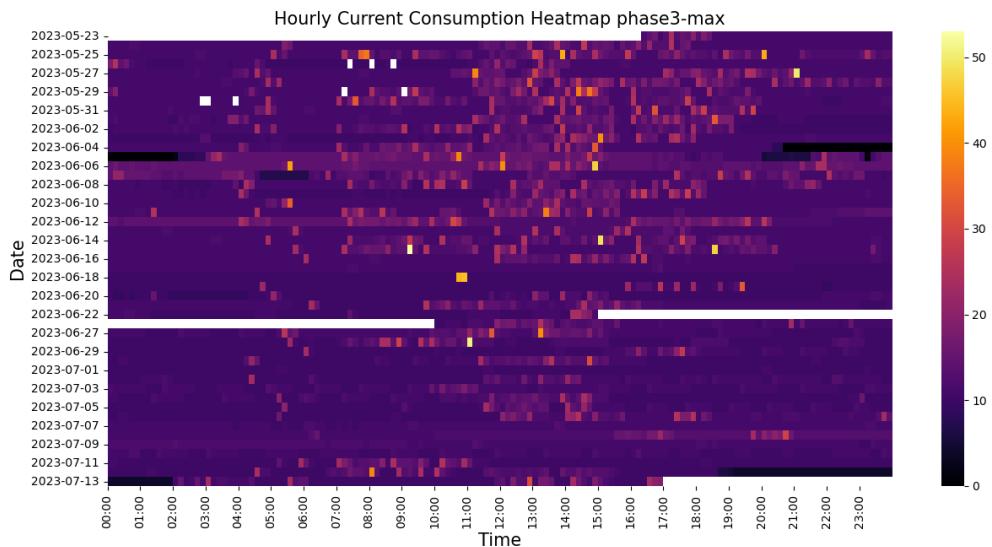
- Top right chart shows a distinct pattern between 12:00 and 16:00.
- Peaks observed in the chart are not repeated.
- Peak current consumption ranges between 50 A and 60 A.



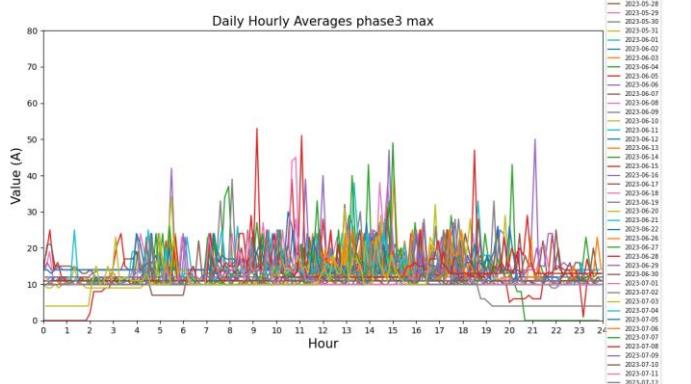
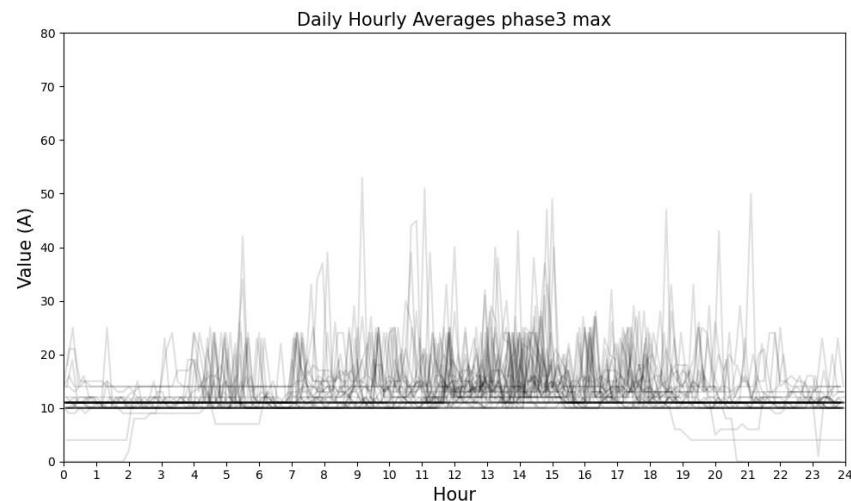
B737MAX-8-M-03 Phase 2 (max)



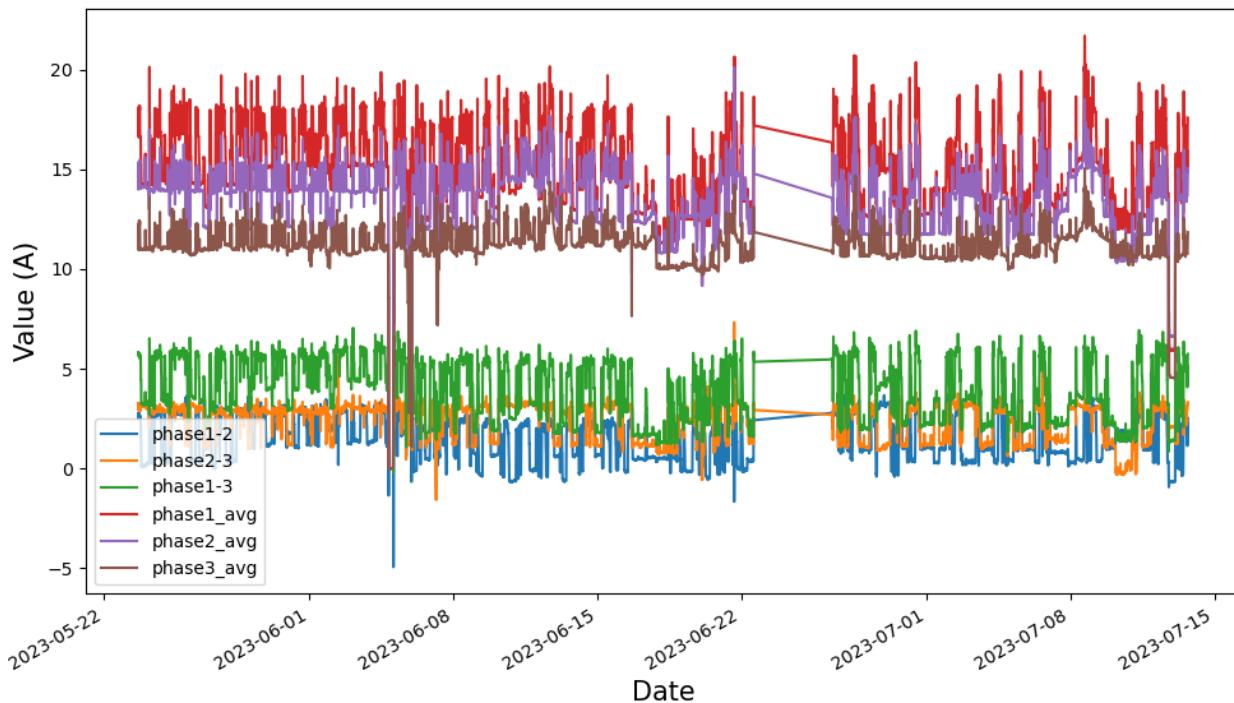
- Top right chart shows a consistent pattern between 12:00 and 16:00.
- Peaks in the chart are not repeated.
- Peak current consumption ranges between 50 A and 60 A.



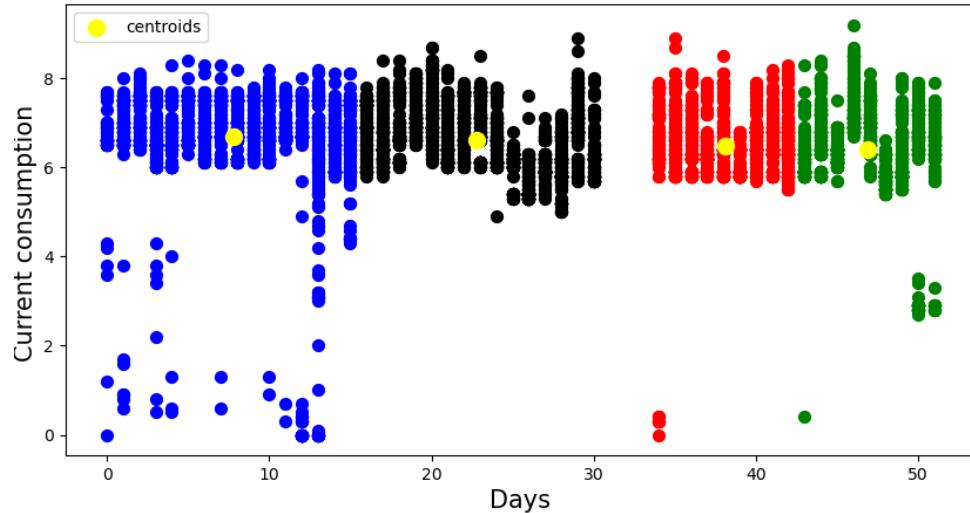
- Top right chart shows a repetitive pattern between 12:00 and 16:00.
- Peaks in the chart are not repeated.
- Peak current consumption falls within the range of 50 A to 60 A.



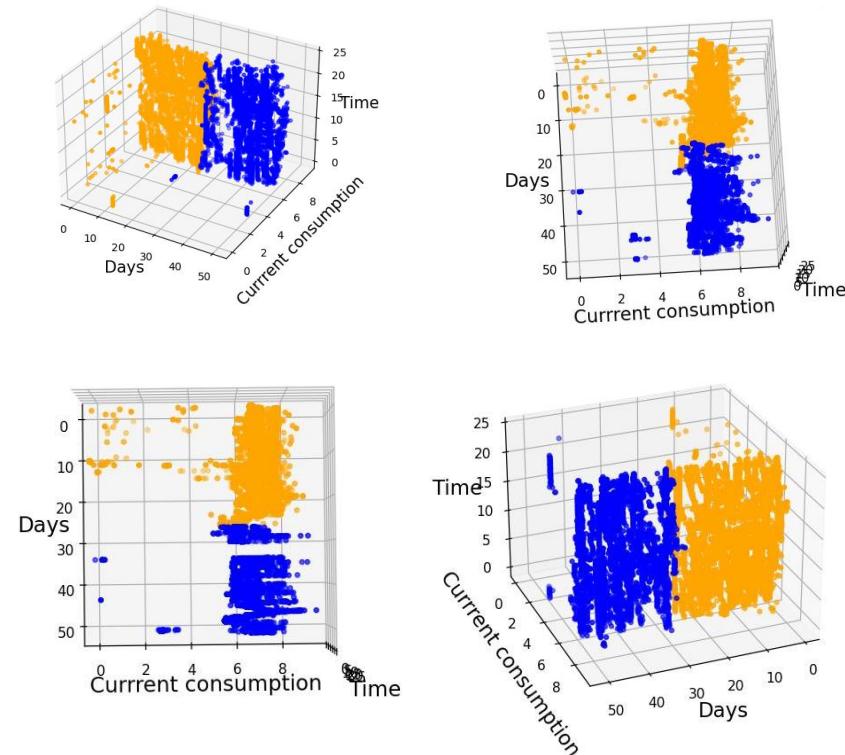
Three Phases



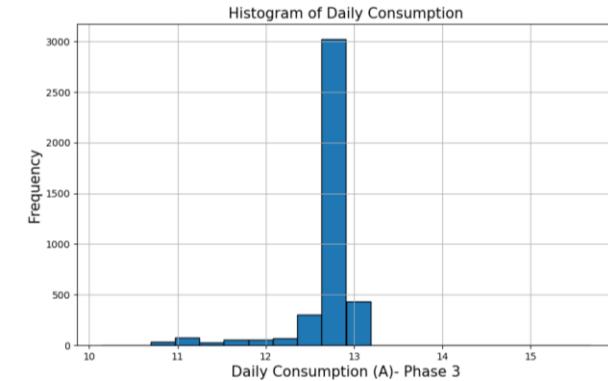
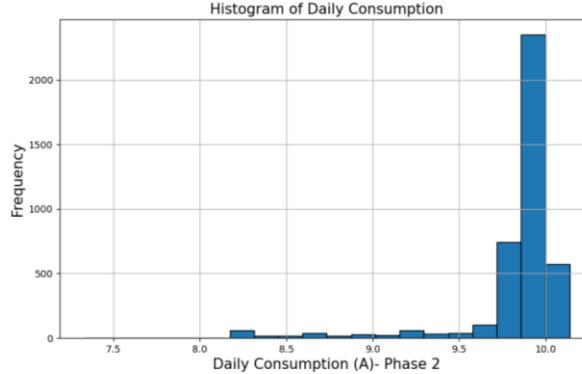
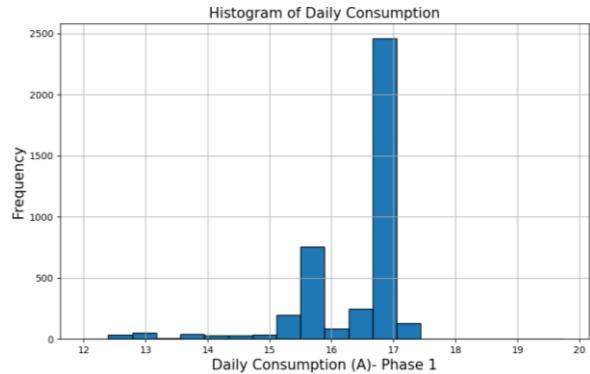
- The phases are synchronized to some extent. However, the load seems unbalanced.
- There is a significant difference between the actual values of each phase, indicating substantial imbalance between them.



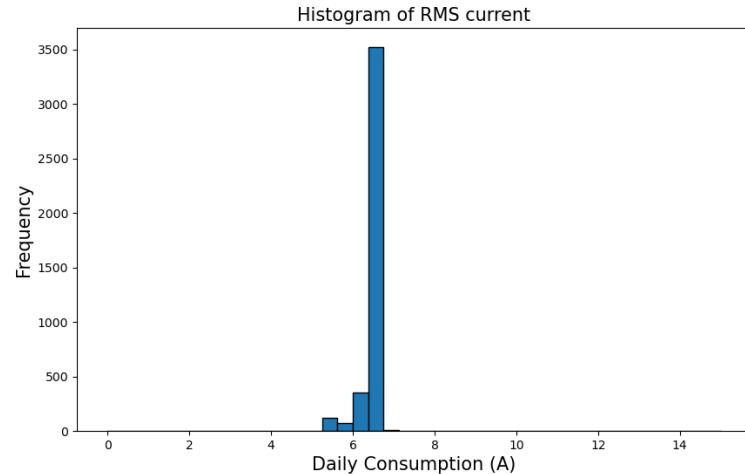
- Clustering is a data analysis technique used to group similar data points together based on their intrinsic characteristics, aiming to maximize intra-group similarity and inter-group dissimilarity.
- Each cluster is denoted by a distinct color.
- No definitive clusters were identified.
- AI is grouping adjacent days as one cluster, suggesting either a lack of discernible patterns or insufficient data for meaningful clustering.



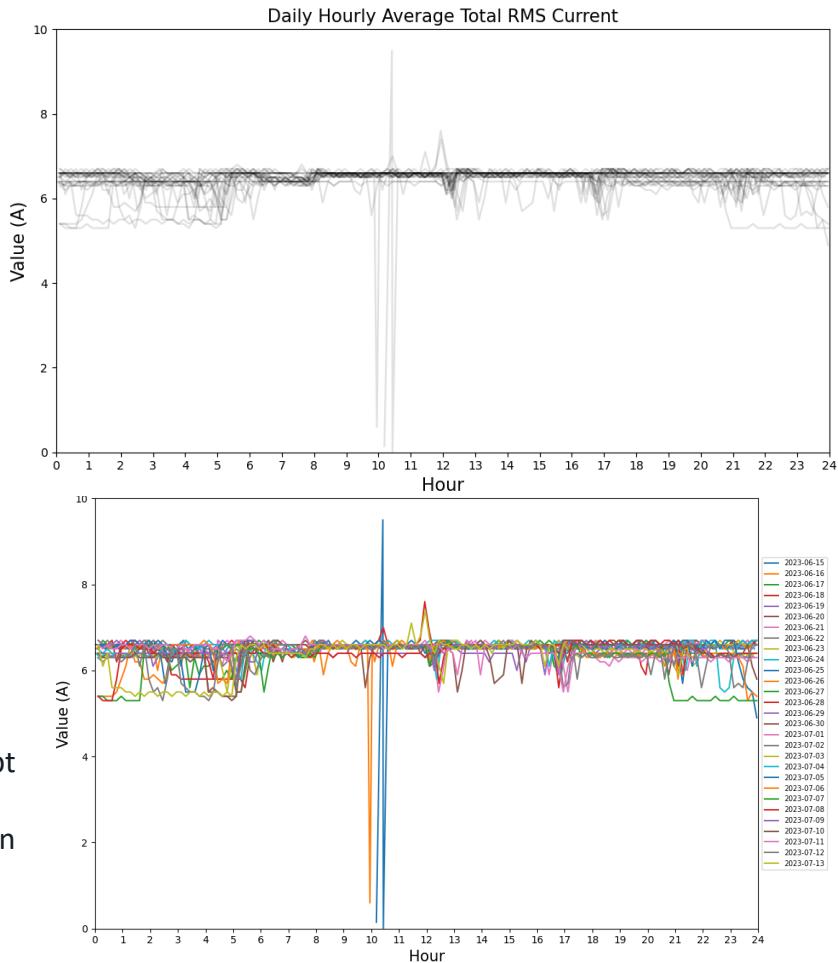
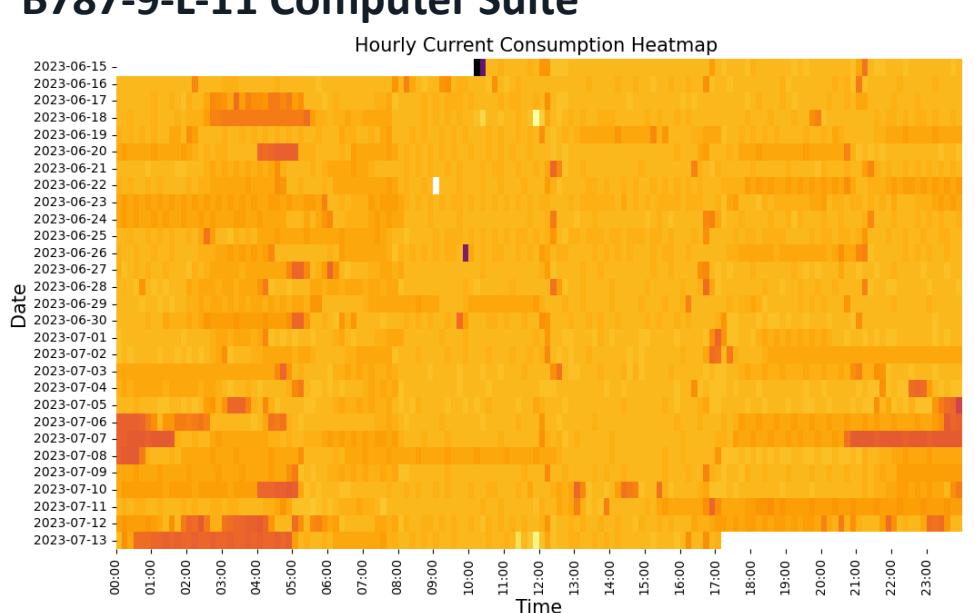
B787-9-L-11 Computer Suite



- Phase 1: Frequent current consumption range of 15 A to 17 A.
- Phase 2: Frequent current consumption range of 9.5 A to 10.5 A.
- Phase 3: Frequent current consumption range of 12 A to 13 A.
- Total RMS current consumption for all three phases: Mostly in the range of 6 A to 7 A.

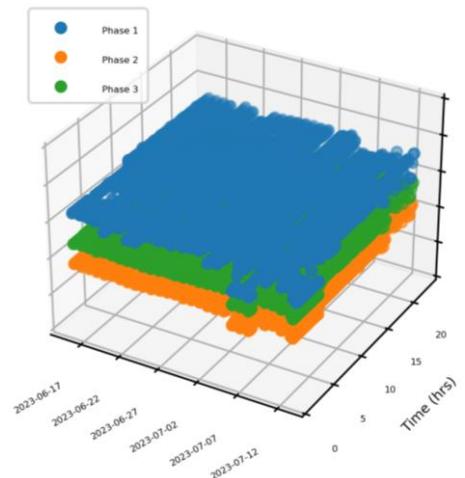
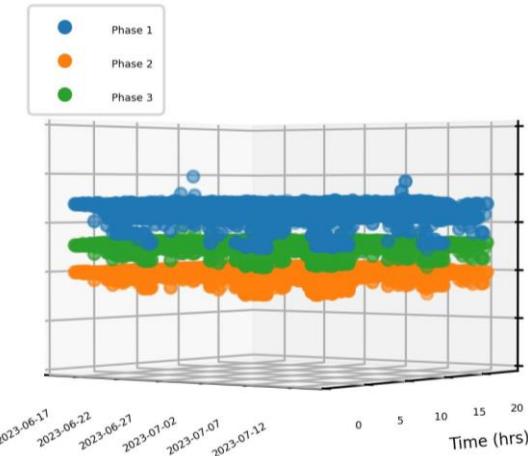
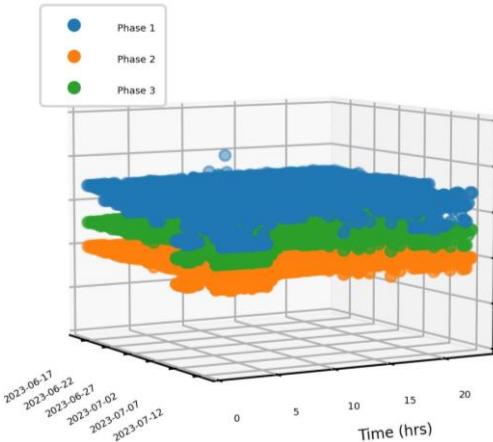


B787-9-L-11 Computer Suite



- Large spikes observed on 15th and 26th of June, around 10:00 and 11:00.
- Peak current consumption during these spikes is approximately 9.5 A. Abrupt turn-offs were also noticed.
- Overall current consumption remains stable, ranging between mainly between 6 A to 7 A.

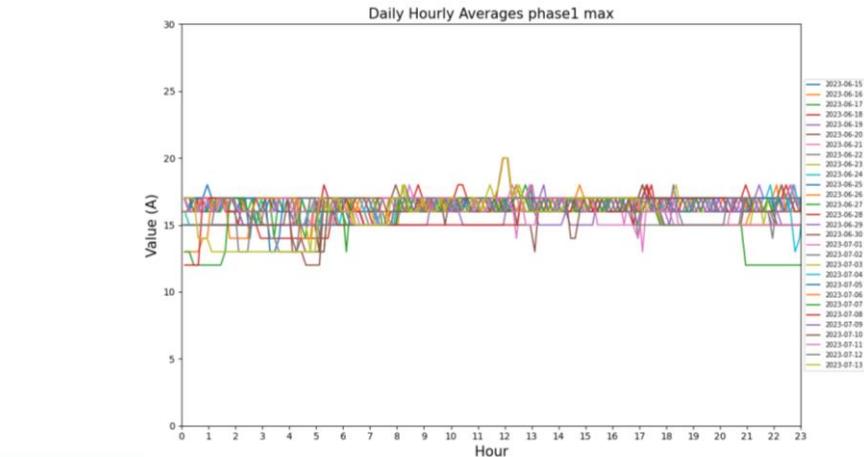
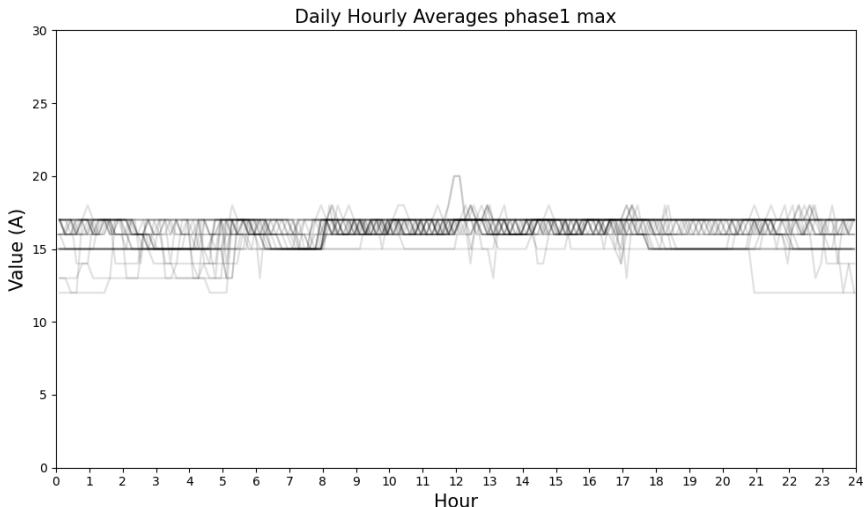
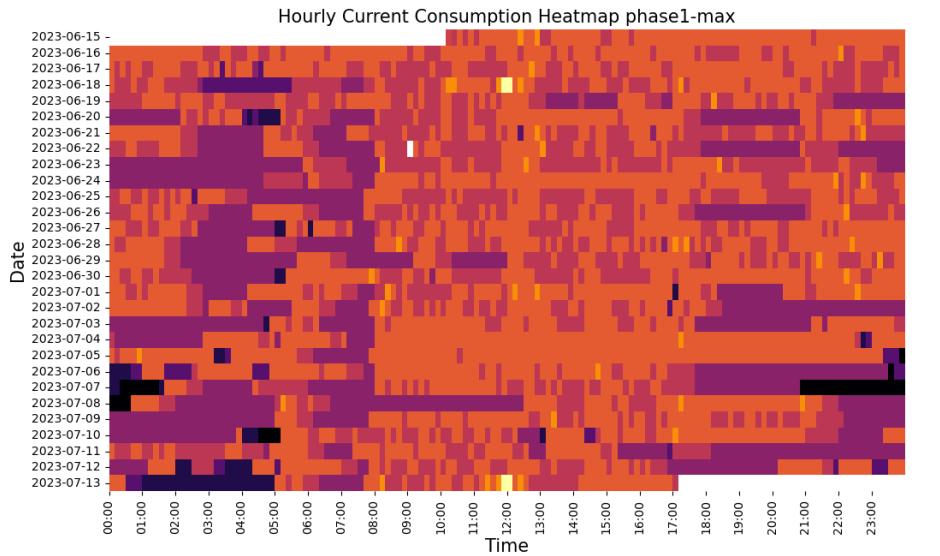
B787-9-L-11 Computer Suite



- All three phases exhibit a consistent gap, suggesting possible synchronisation but with an imbalance load.

B787-9-L-11 Computer Suite

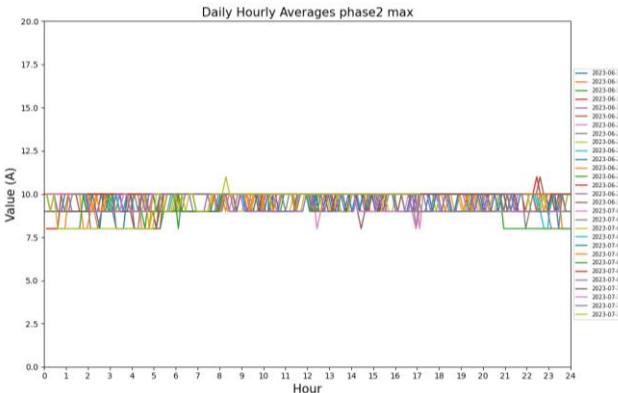
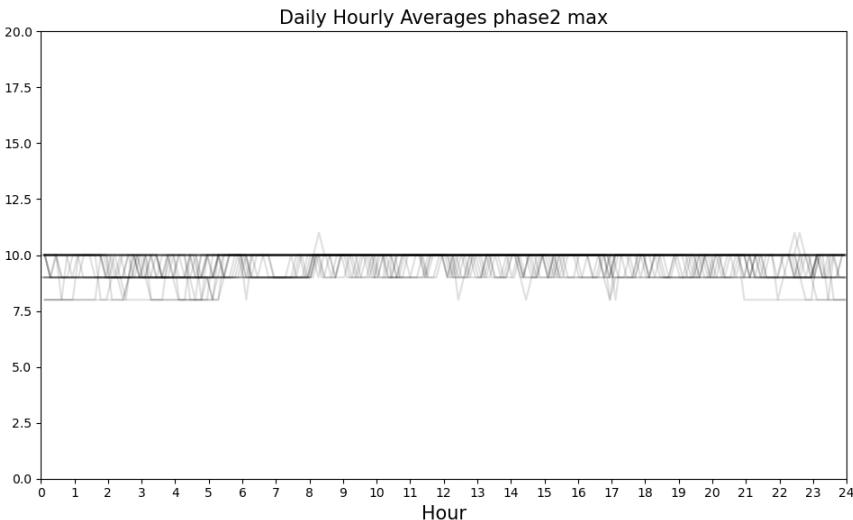
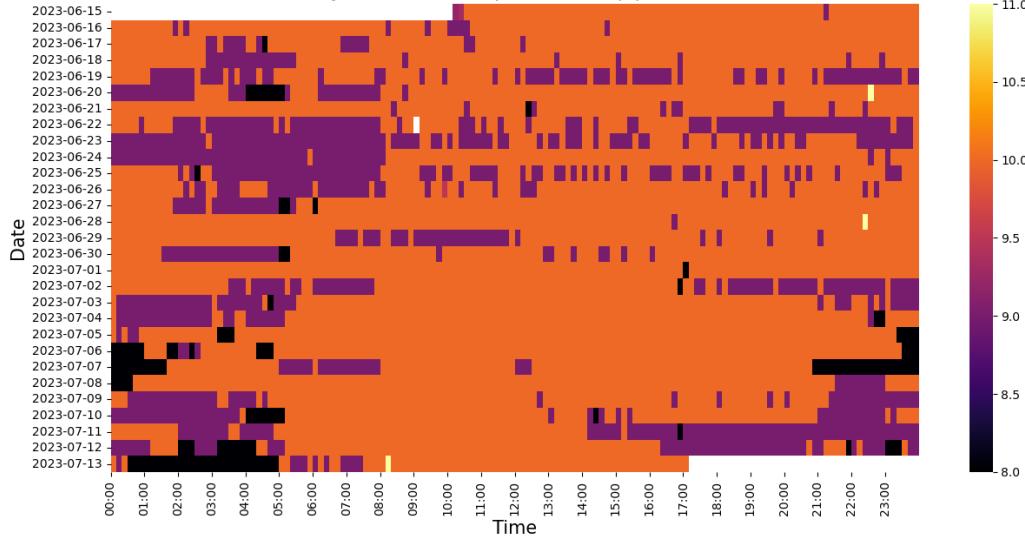
Phase 1 (max)



- Phase 1 (max) consistently maintains a current consumption of around 15 A.

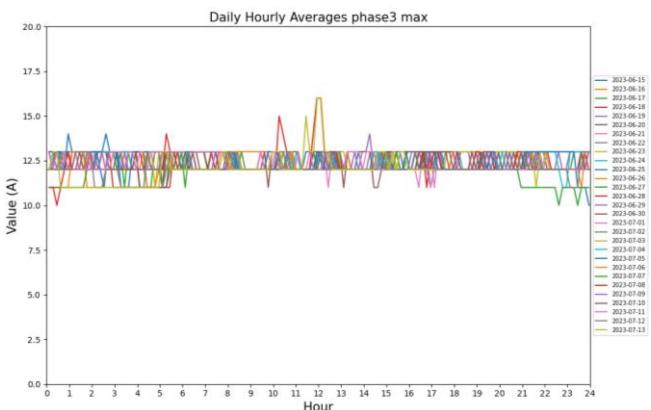
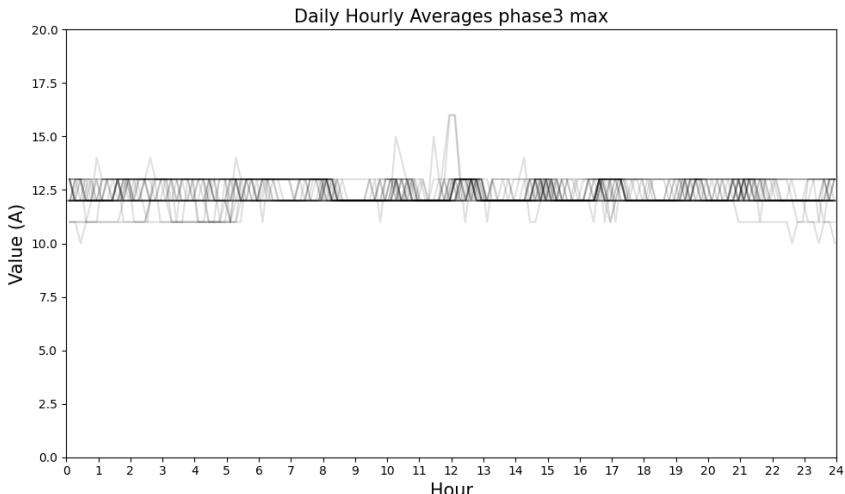
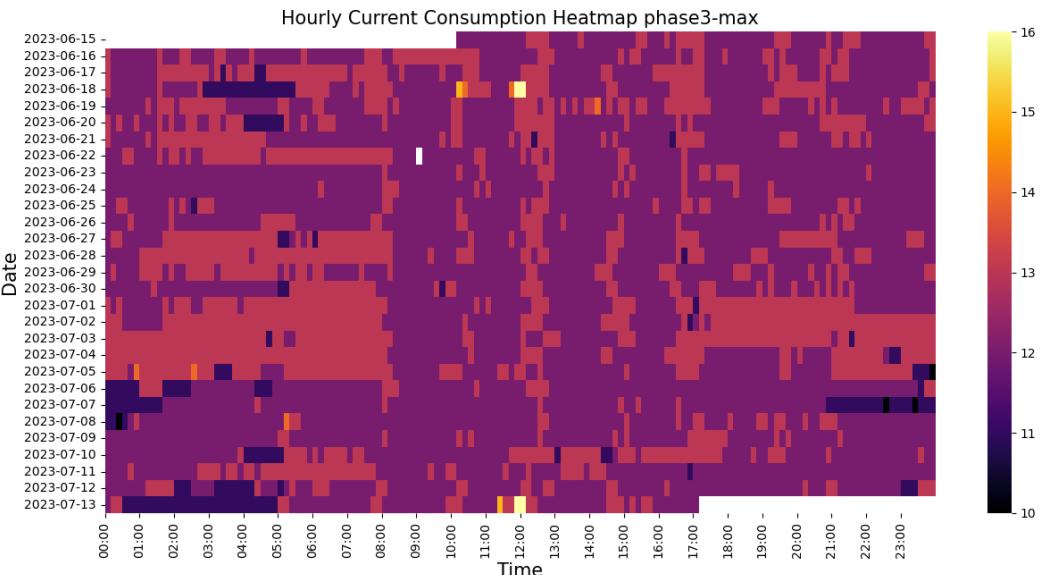
B787-9-L-11 Computer Suite Phase 2 (max)

Hourly Current Consumption Heatmap phase2-max

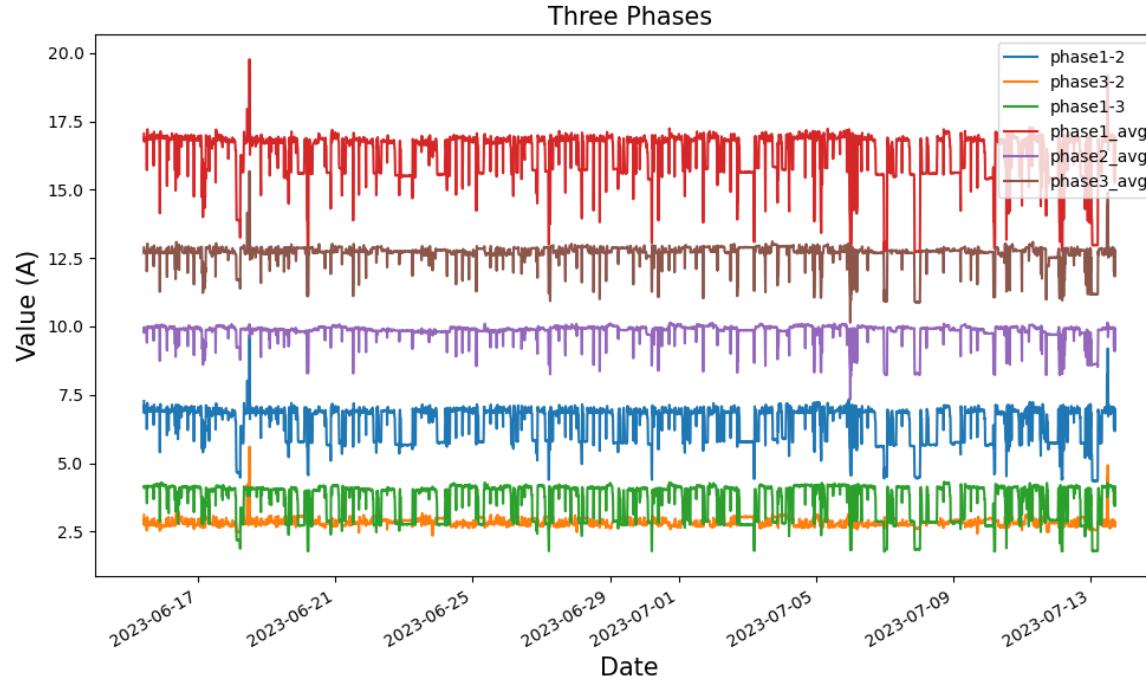


- Phase 2 (max) also shows consistent current consumption, hovering around 10 A.

B787-9-L-11 Computer Suite Phase 3 (max)

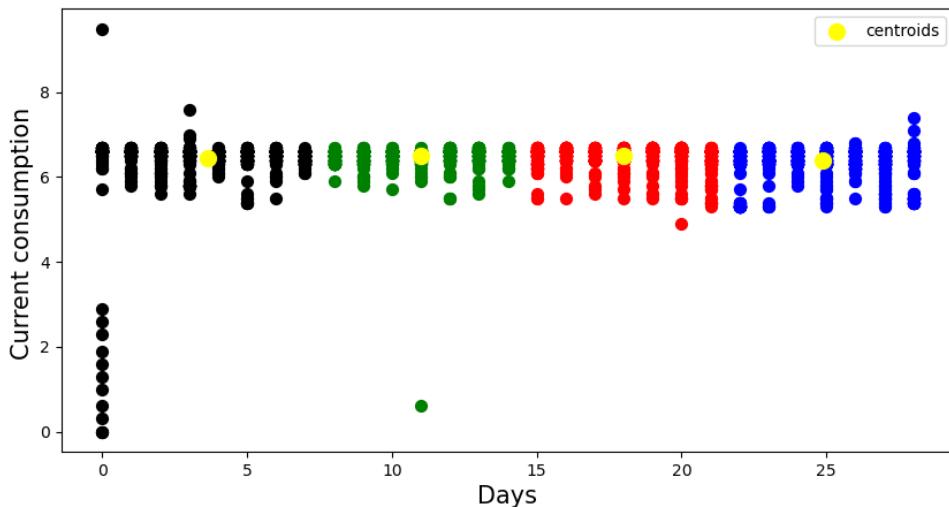


- Similar to phases 1 and 2, phase 3 demonstrates a consistent current consumption of around 12.5 A.

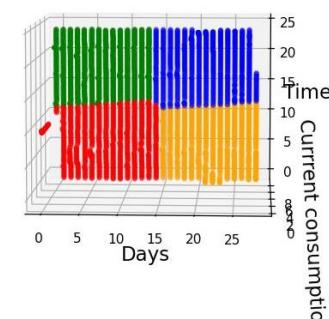
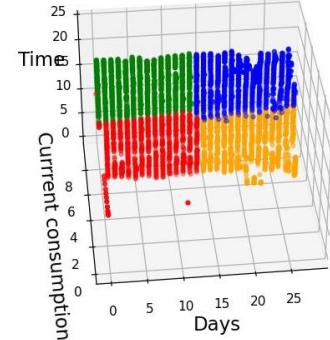
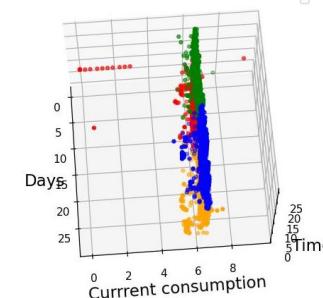
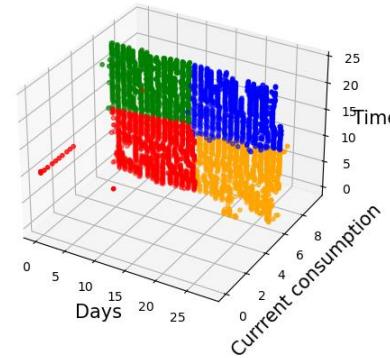


- There is a notable difference between the current consumption patterns of the three phases, as also observed in previous slides.
- When comparing to B737MAX-8-M-03, the phases show some level of synchronization, but the difference between them is more pronounced.

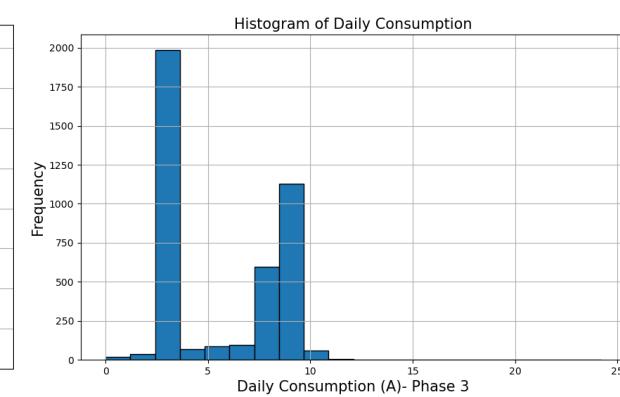
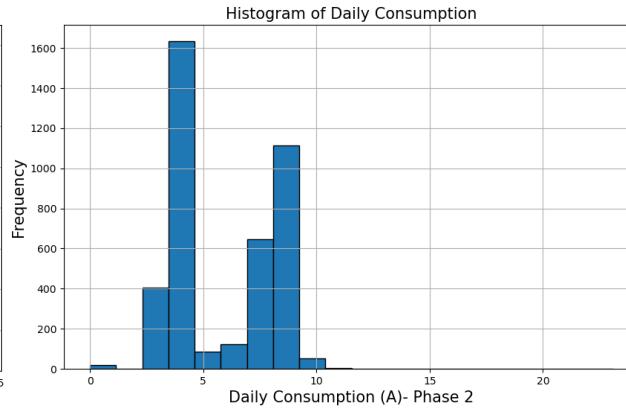
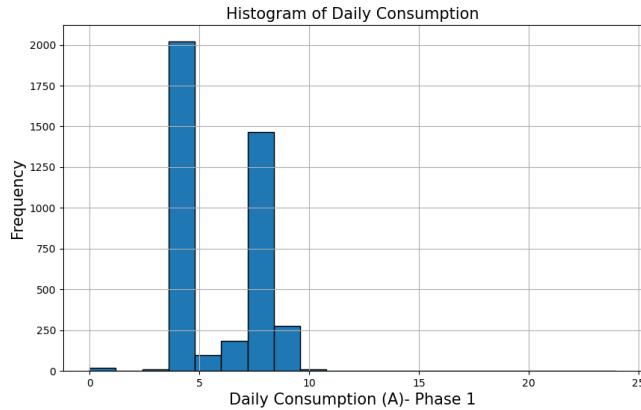
B787-9-L-11 Computer Suite Clustering



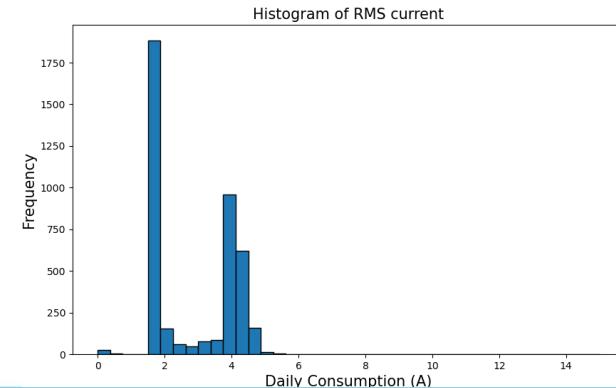
- The top left chart represents 2D clusters, with each cluster assigned a single color.
- No definitive clusters were detected in the 2D clustering.
- AI is grouping adjacent days as one cluster, indicating that either there are no discernible patterns or the available data is insufficient to form meaningful clusters.
- The 3D clusters shown in the charts on the right also did not yield conclusive results.



B787-9-L-11 Motion System

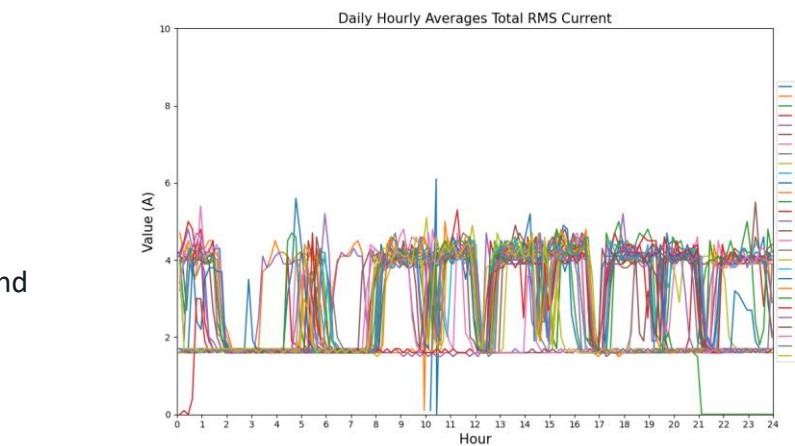
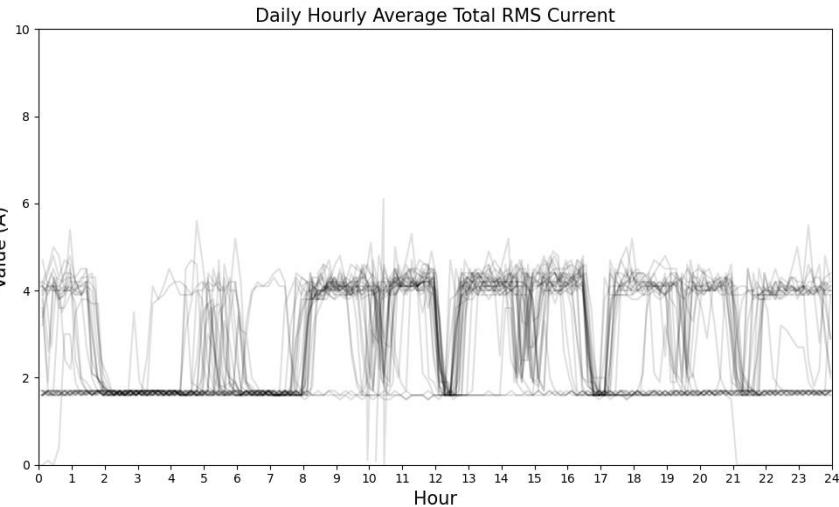
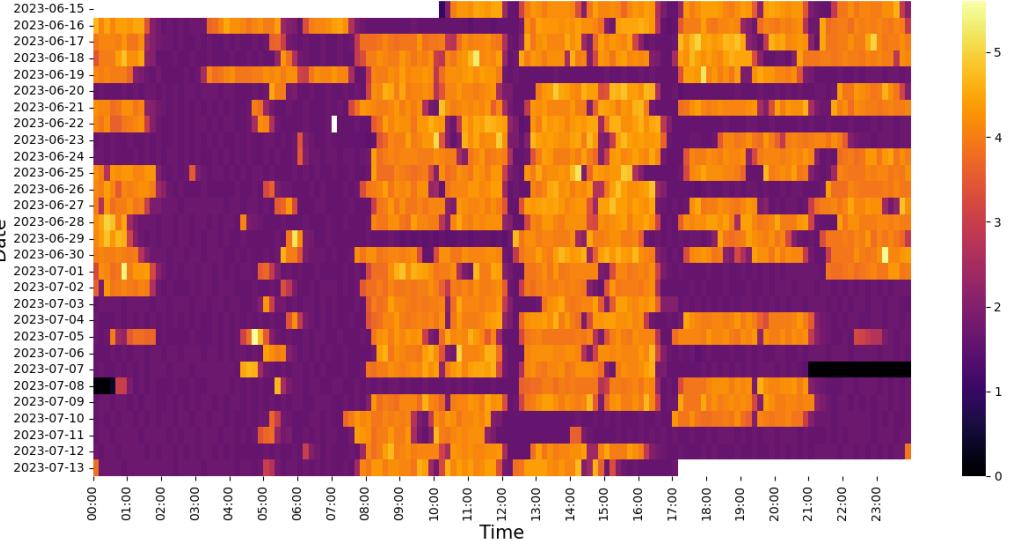


- Phase 1 (average) shows two tall bars, one just under 5 A and the other around 8 A.
- Phase 2 (average) also exhibits two tall bars, one below 5 A and the other around 9 A.
- Phase 3 (average) displays two tall bars, one below 4 A and the other around 9 A.
- In the case of RMS current consumption, multiple distant bars appear in the chart. This contrasts with the patterns observed in B787-9-L-11 Computer Suite and B737MAX-8-M-03, where the bars were likely more uniform or clustered closely together.



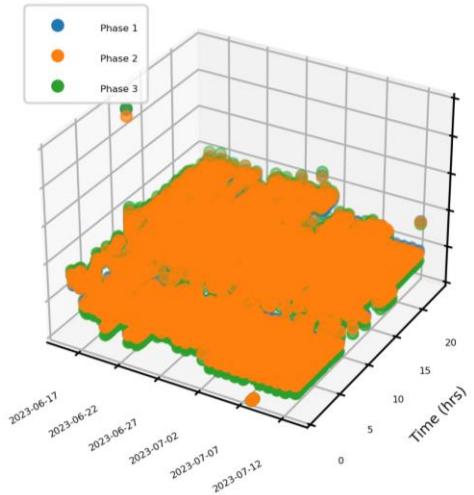
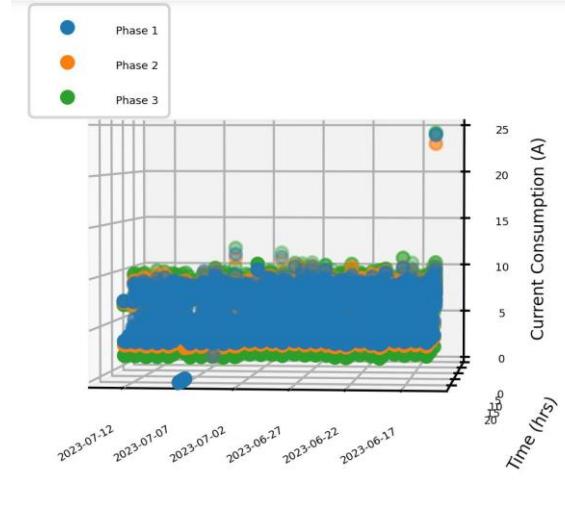
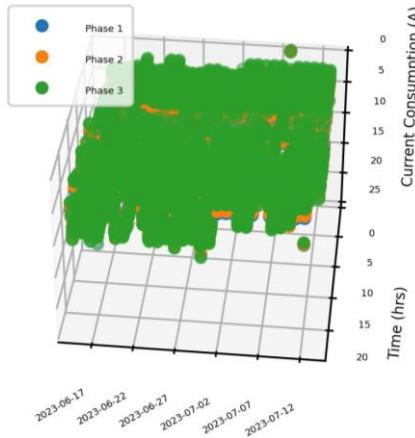
B787-9-L-11 Motion System

Hourly Current Consumption Heatmap



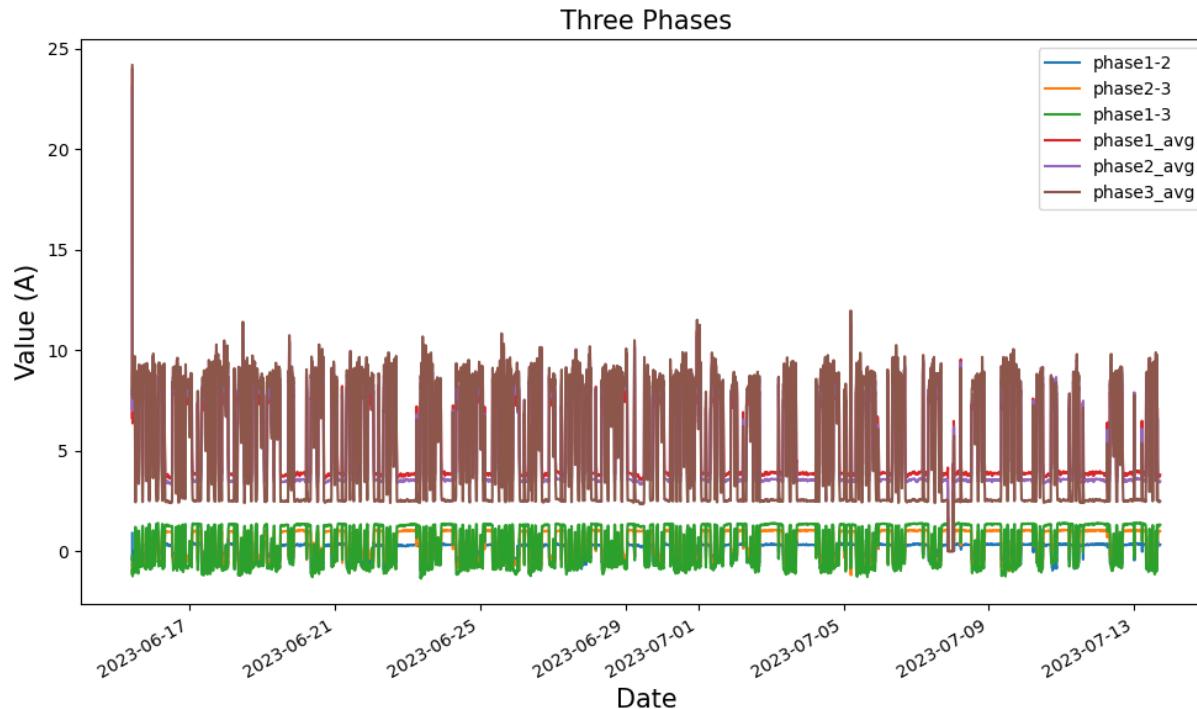
- Clear patterns were identified, showing minimal activity between 02:00 and 08:00.
- Can Boeing move peak hours activities to this slot?

B787-9-L-11 Motion System



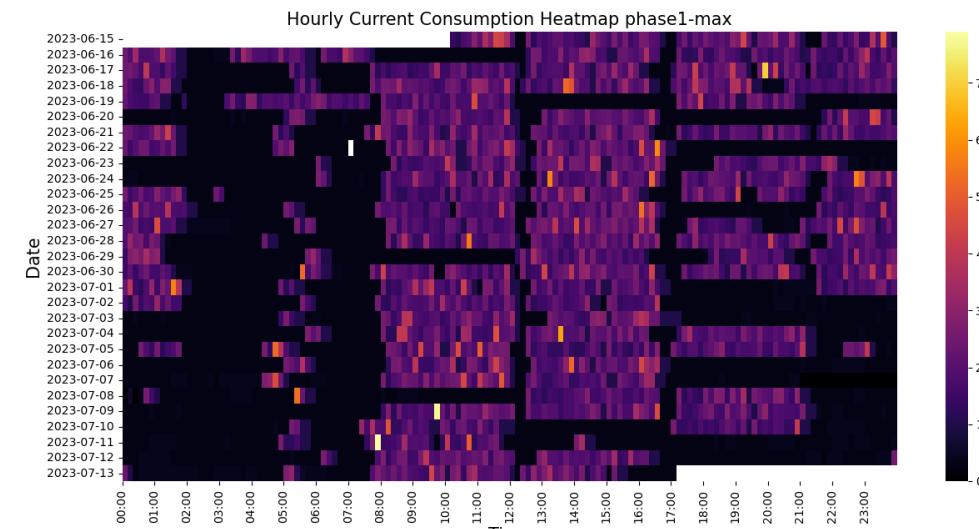
Each phase is positioned close to each other, indicating a smaller gap compared to B787-9-L-11 Computer Suite and B737MAX-8-M-03.

B787-9-L-11 Motion System

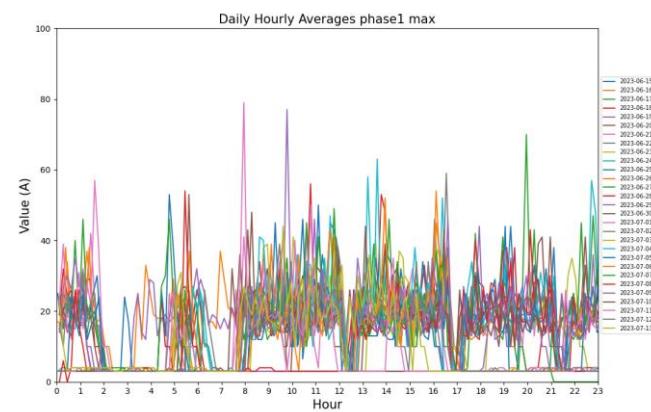
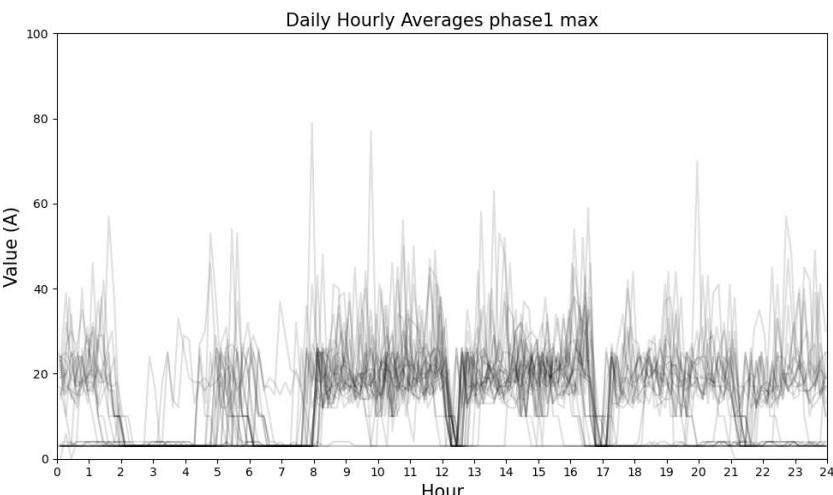


- All the phases indicate the load is balanced.

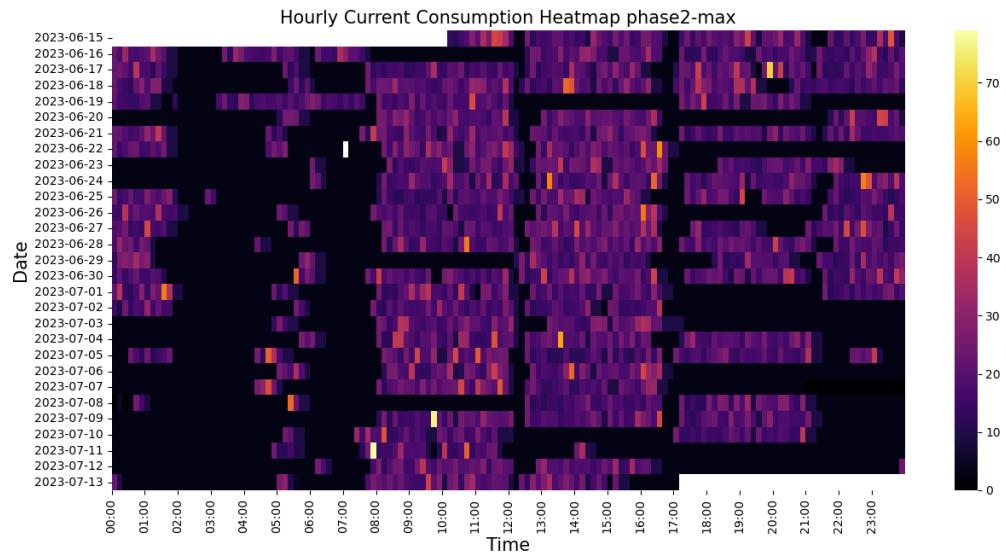
B787-9-L-11 Motion System Phase 1 (max)



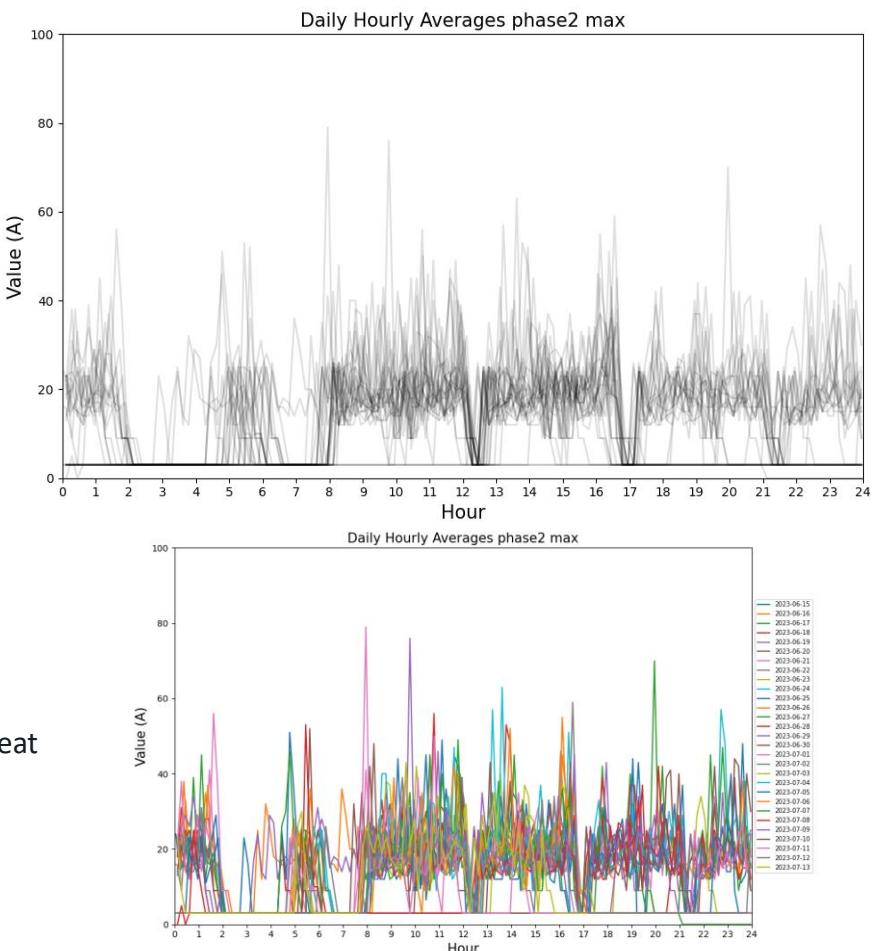
Phase 1 (maximum) exhibits clear patterns that are visible from both the heat map and charts.



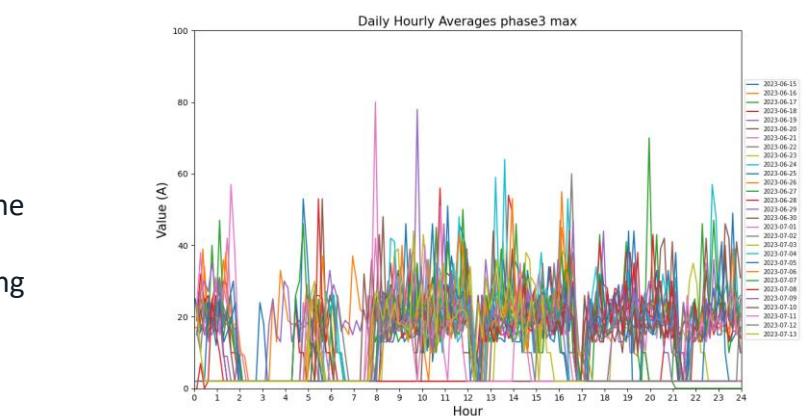
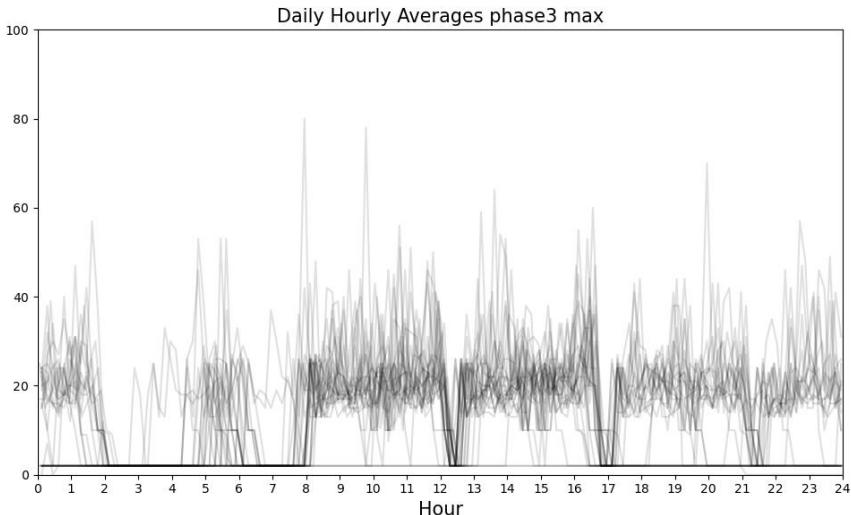
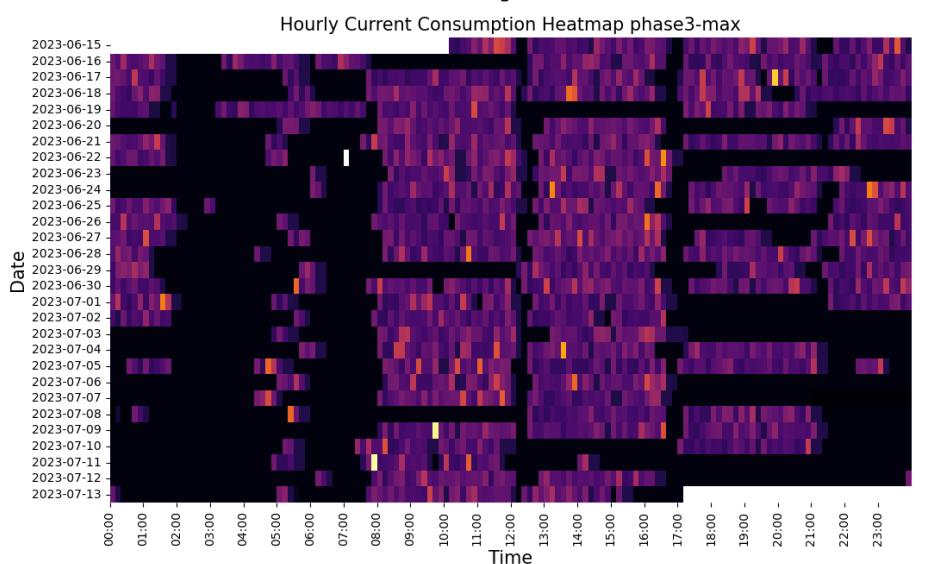
B787-9-L-11 Motion System Phase 2 (max)



Phase 2 (maximum) exhibits clear patterns that are visible from both the heat map and charts.

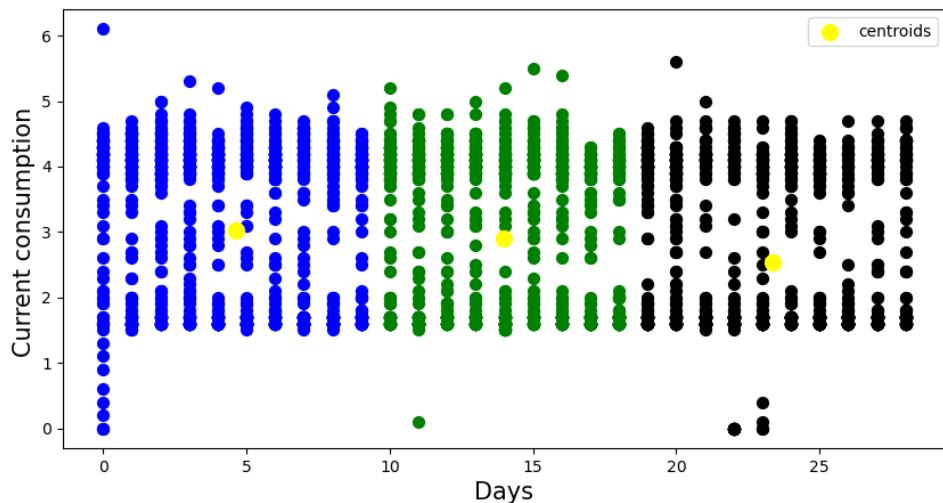


B787-9-L-11 Motion System Phase 3 (max)

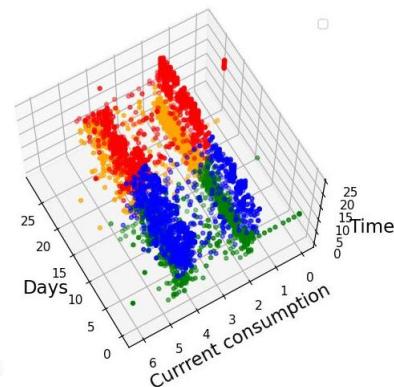
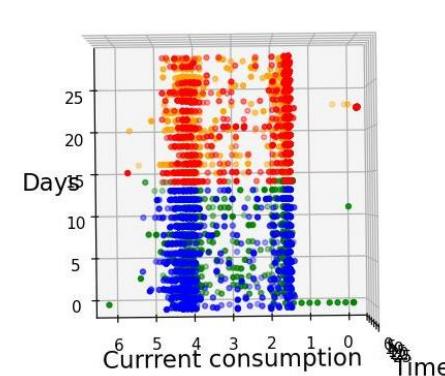
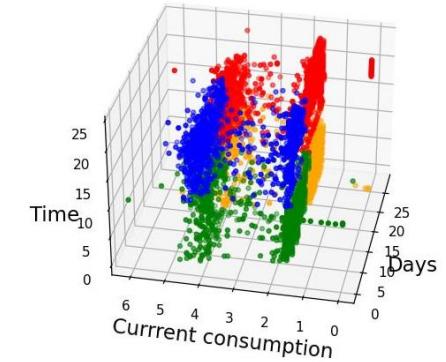
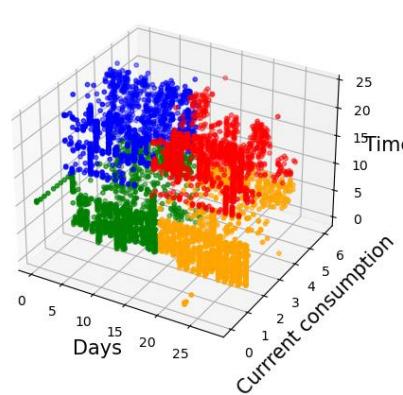


- Phase 1 (maximum) exhibits clear patterns that are visible from both the heat map and charts.
- It must be noted that all three phases are synchronised and indicating balanced load.

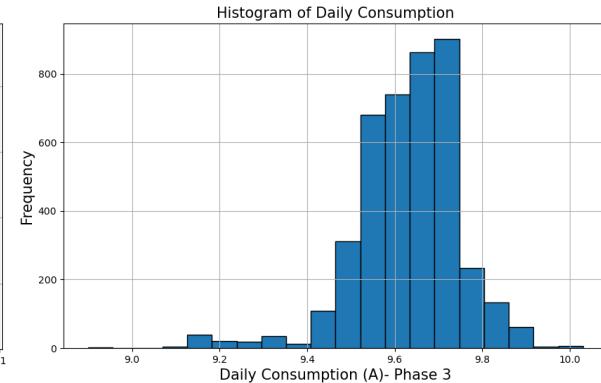
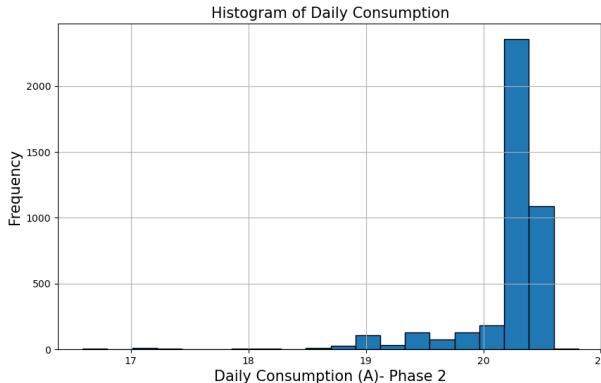
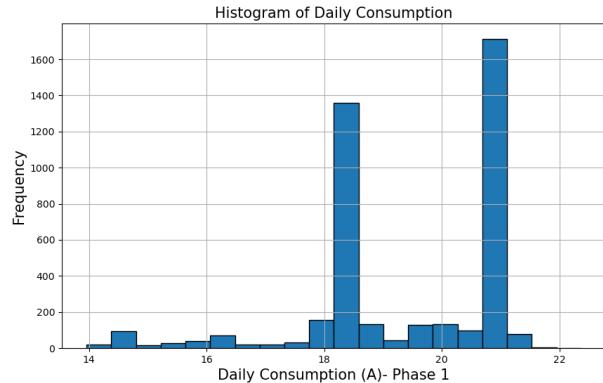
B787-9-L-11 Motion system Clustering



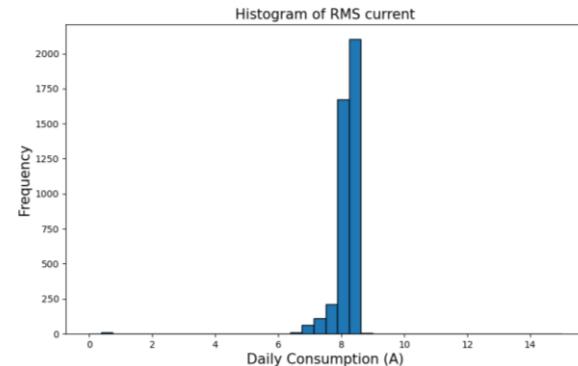
- The top left chart represents 2D clusters, with each cluster assigned a single color.
- No definitive clusters were detected in the 2D clustering process.
- AI is grouping adjacent days as one cluster, indicating that either there are no discernible patterns or the available data is insufficient to form meaningful clusters.
- The 3D clusters shown in the charts on the right also did not yield conclusive results.



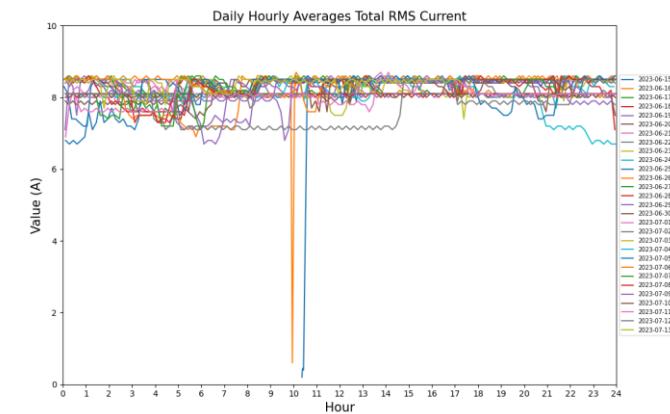
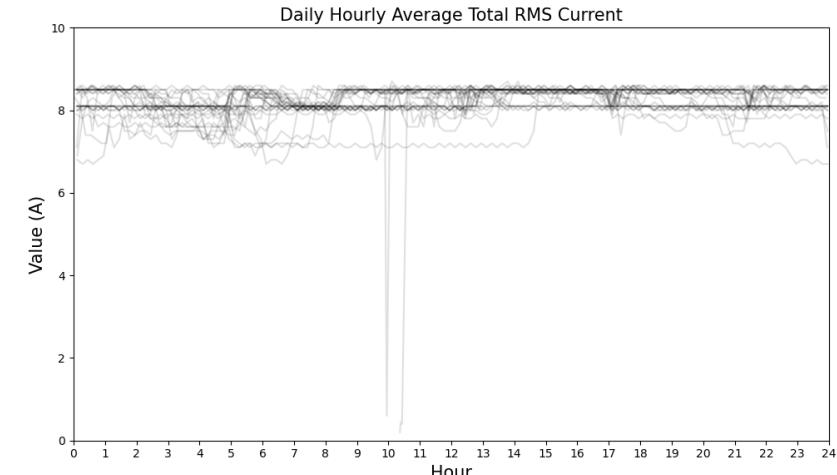
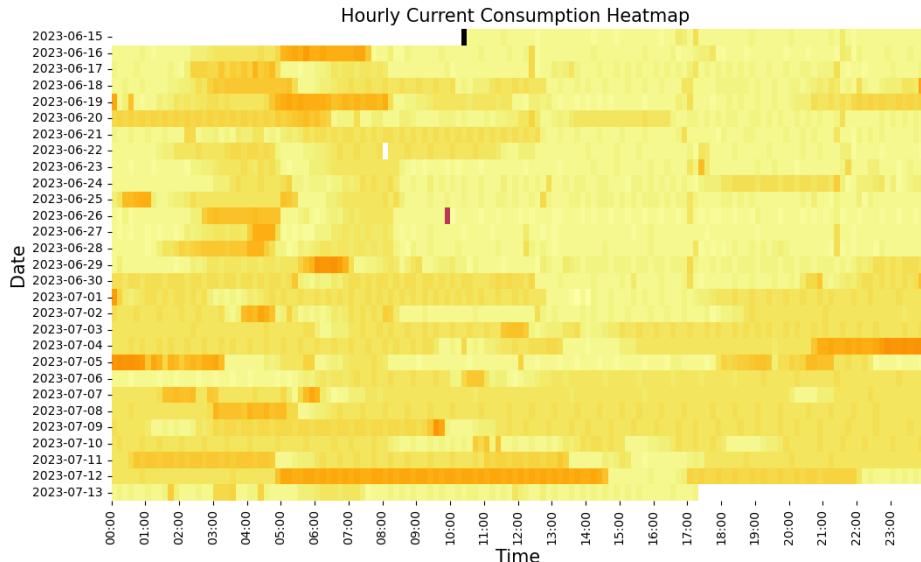
B787-9-L-13 Computer Suite



- Phase 1 (average) shows two tall bars, one just above 18 A and the other around 21 A.
- Phase 2 (average) exhibits two tall bars between 20 A and 22 A.
- Phase 3 (average) demonstrates a different behavior compared to phases 1 and 2.
- In the case of RMS current consumption, there are two adjacent bars around 8 A.

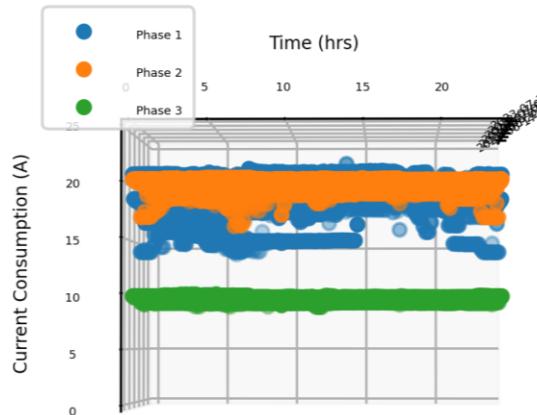
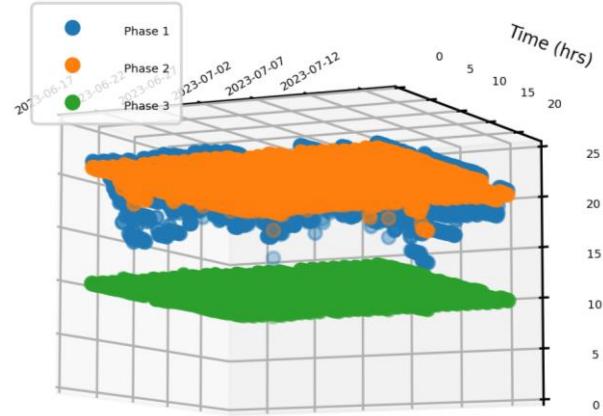
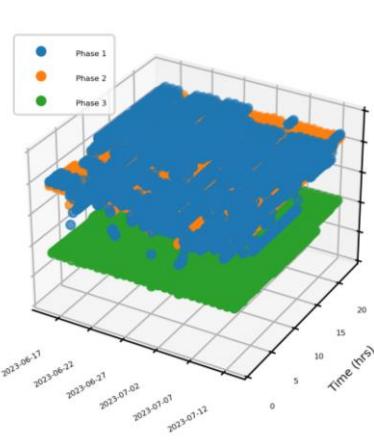


B787-9-L-13 Computer Suite



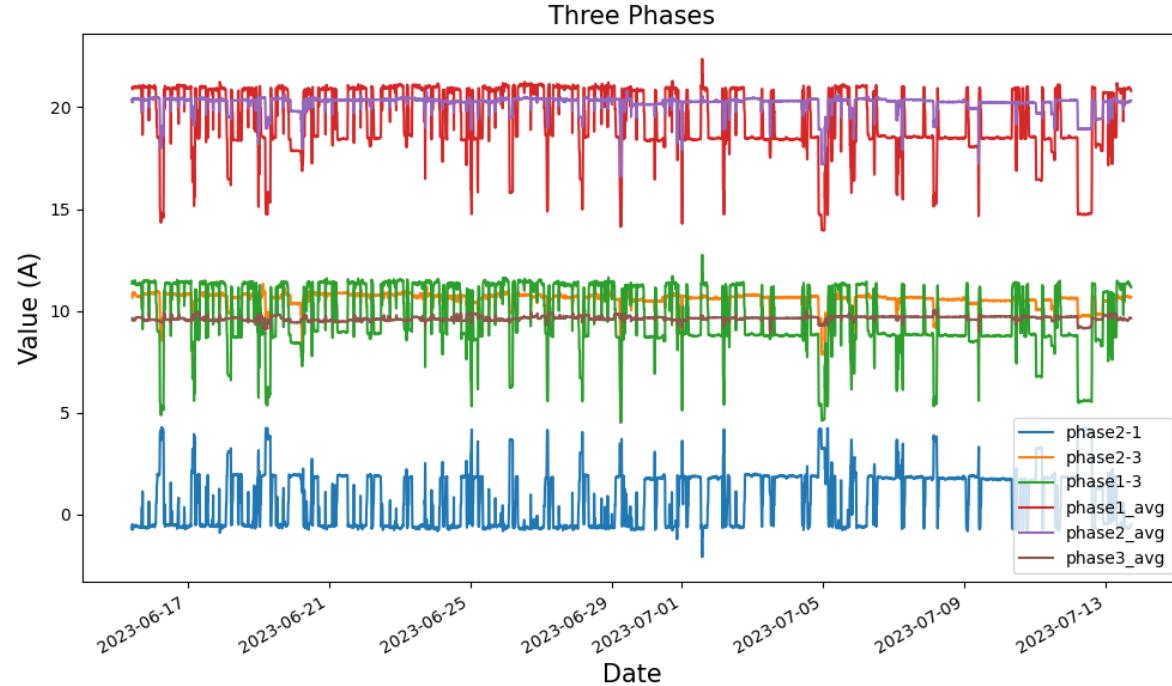
- Abnormal drops were observed on 15th and 26th June, around 10:00 and 11:00.
- Overall current consumption remains stable, ranging between 7 to 8 A.

B787-9-L-13 Computer Suite



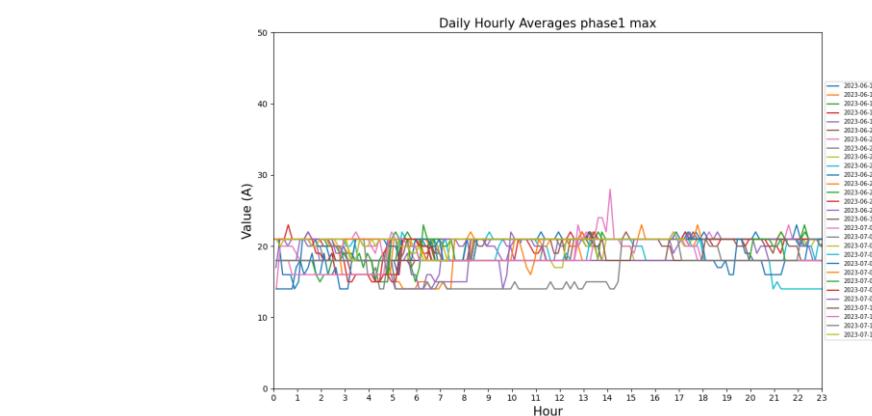
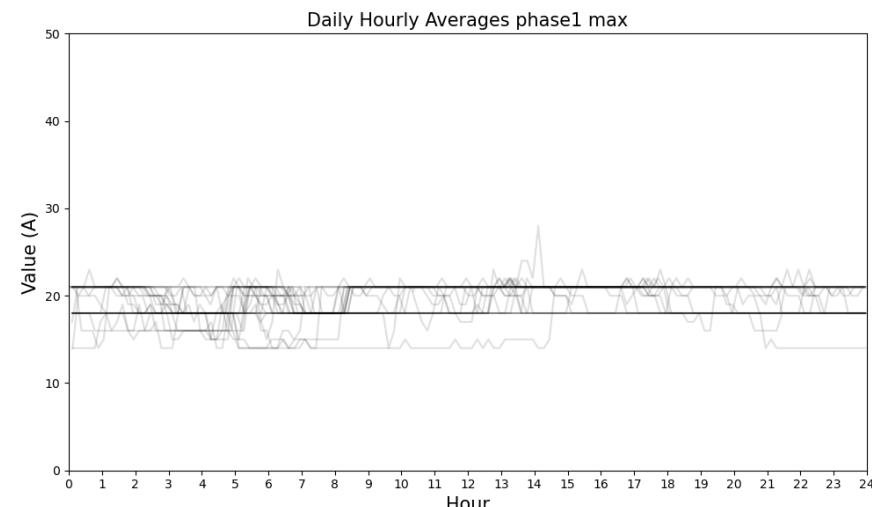
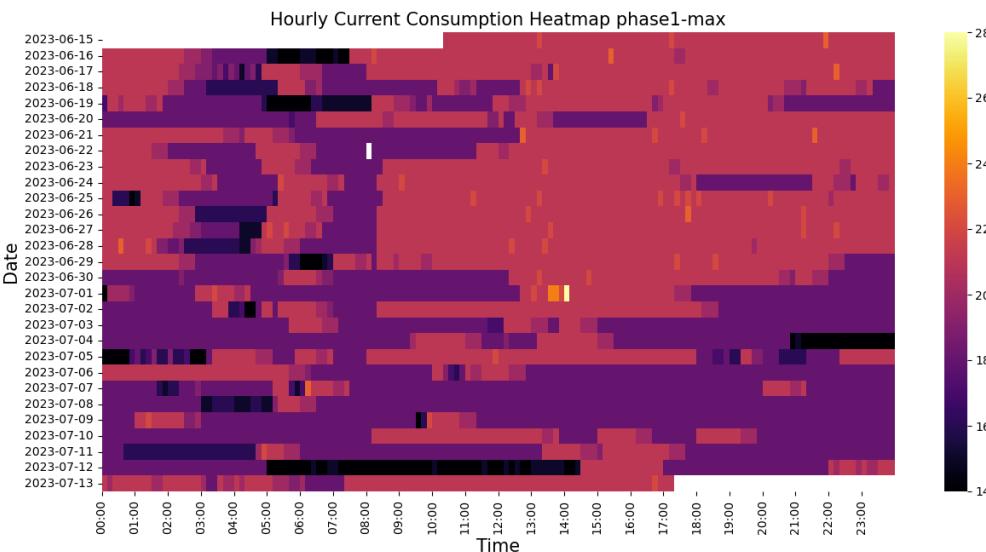
- Phase 1 and Phase 2 exhibit similar current consumption patterns, indicating a resemblance in their behaviours.
- Phase 3 is the outlier as it demonstrates lower current consumption compared to phases 1 and 2.
- A potential reason behind phase 1 and 2 showing similar behaviour could be due to similar load characteristics or connected equipment. On the other hand, phase 3 might have different equipment or load types that lead to its lower current consumption. Other factors such as distribution of loads, circuit design, or specific operational requirements may also contribute to these differences. Further analysis would be needed to determine the exact reasons behind the observed behaviour.

B787-9-L-13 Computer Suite



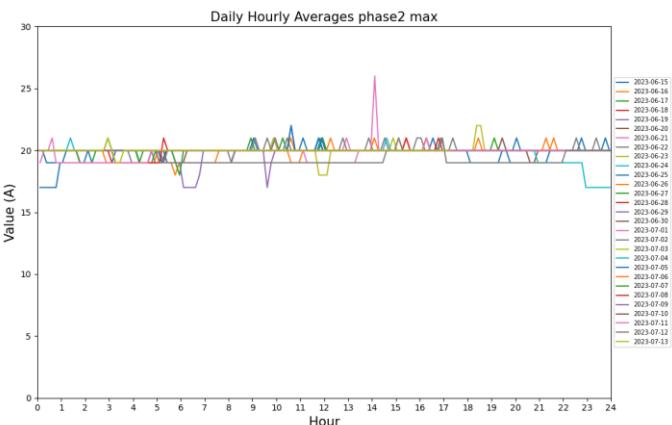
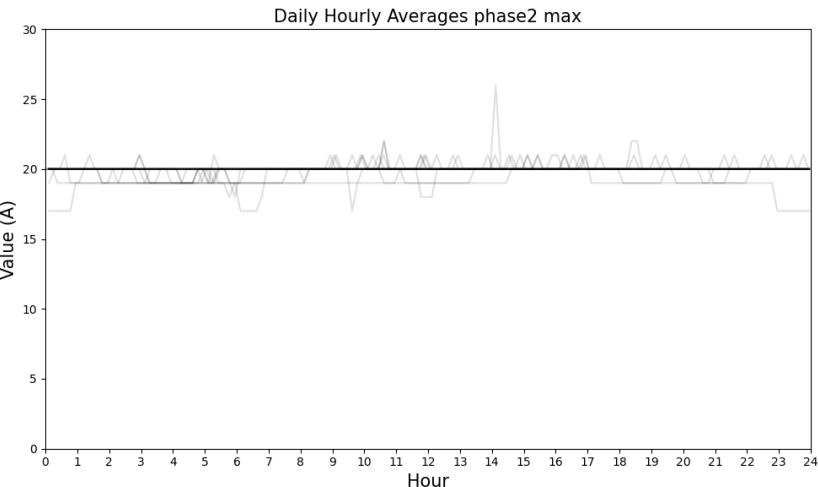
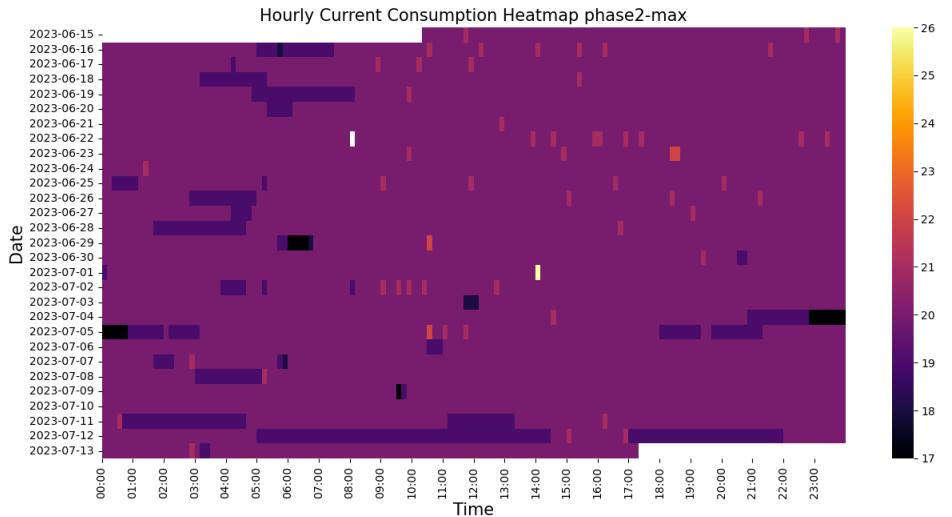
- The overlapping of Phase 1 and Phase 2 charts suggests synchronized operation between these two phases.
- Phase 3's significantly lower current consumption indicates an imbalance among the phases.
- The unbalanced behaviour of the phases is evident from the differences in their current consumption patterns.

B787-9-L-13 Computer Suite Phase 1 (max)



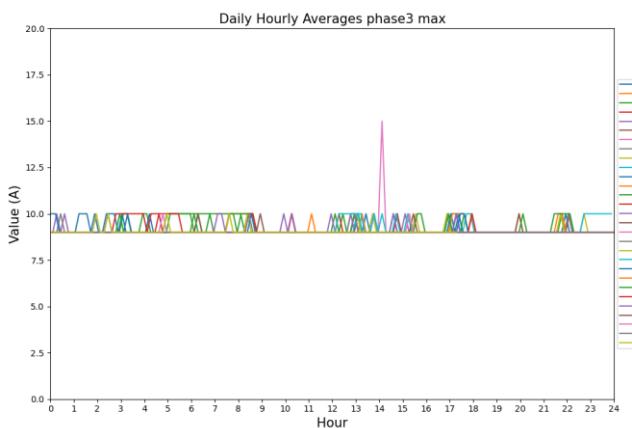
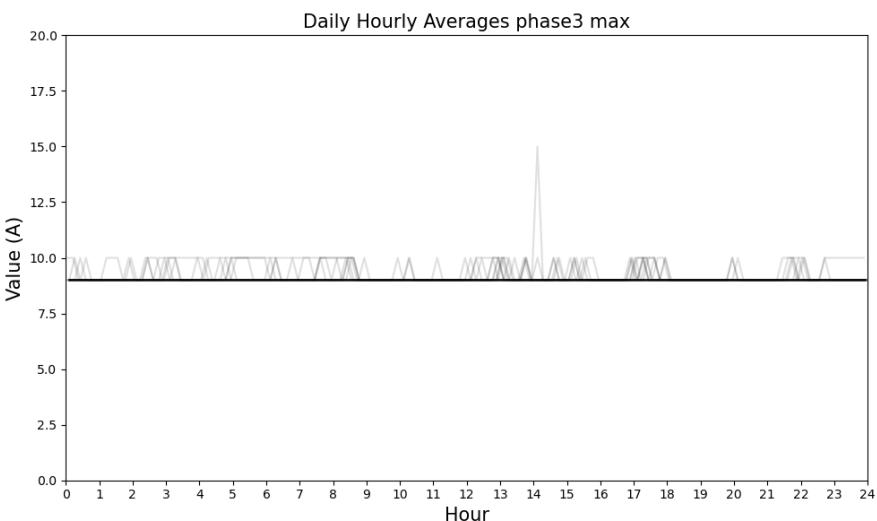
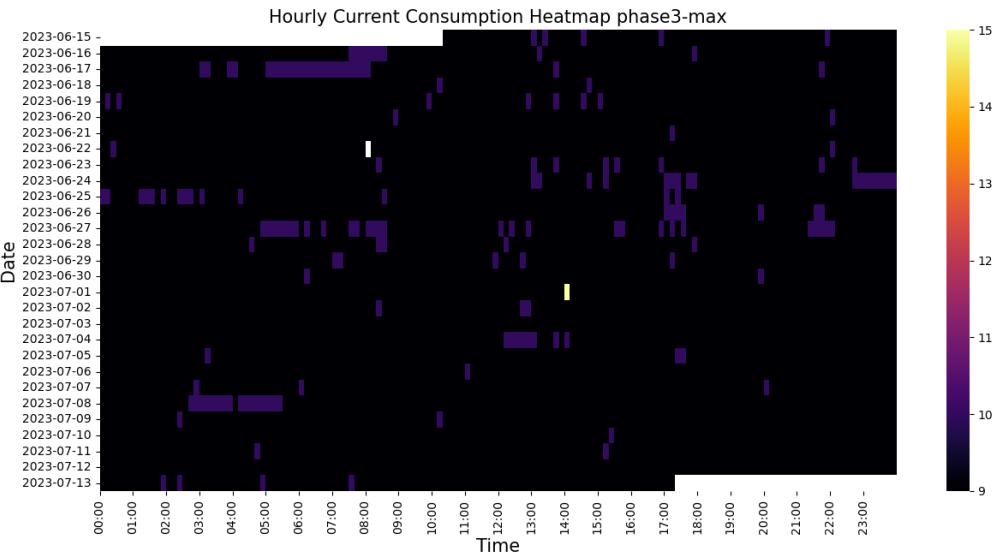
- The maximum phase 1 current consumption ranges between 14 to 20 A.

B787-9-L-13 Computer Suite Phase 2 (max)

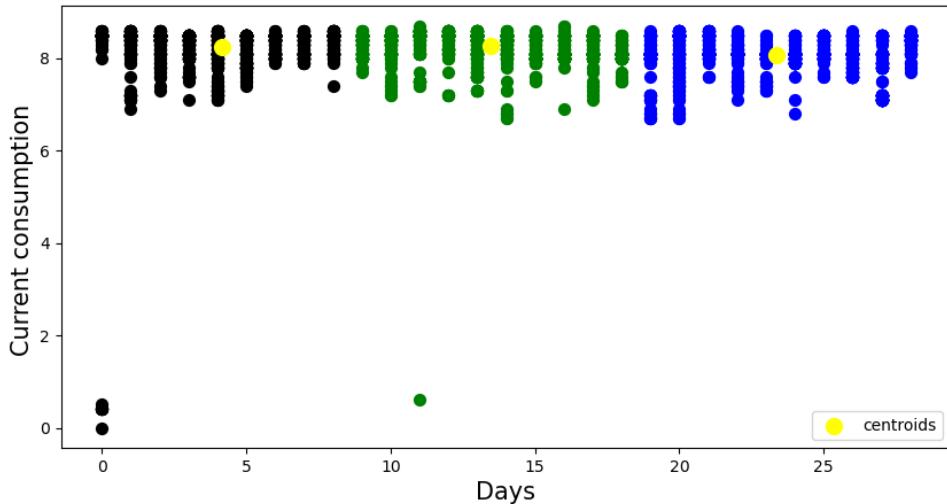


- Phase 2 exhibits a maximum current consumption of 25 A at one instance.
- However, the main fluctuating range for phase 2 lies between 19 to 20 A.
- The heatmap also reflects this information, showing the fluctuations in the current consumption of phase 2.

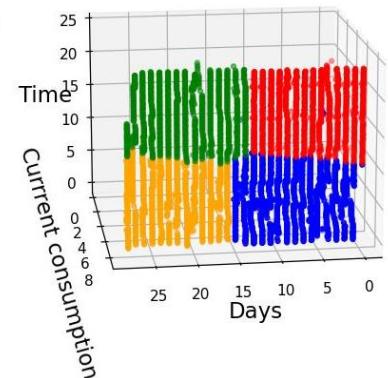
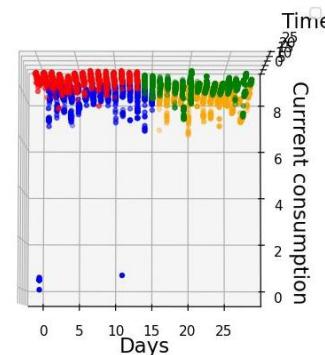
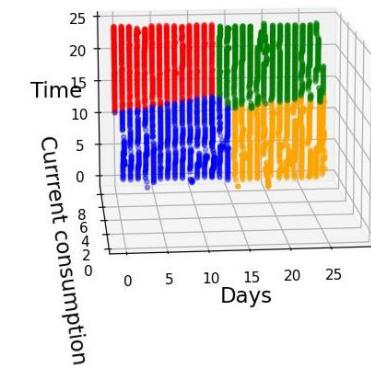
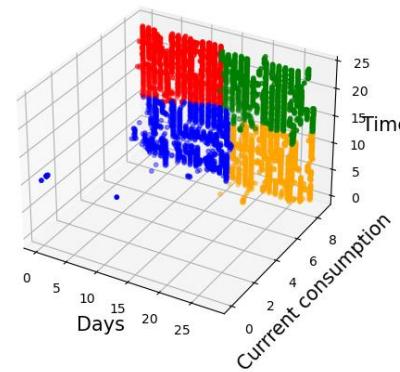
B787-9-L-13 Computer Suite Phase 3 (max)



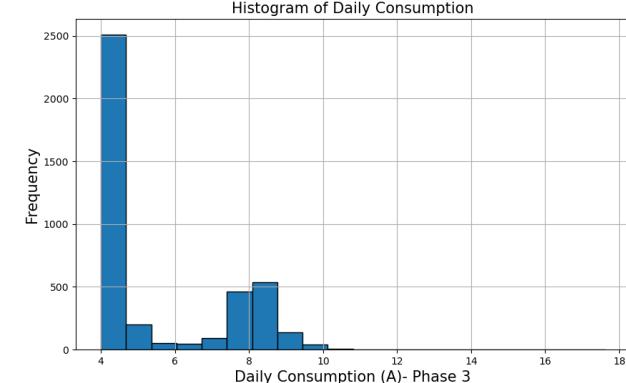
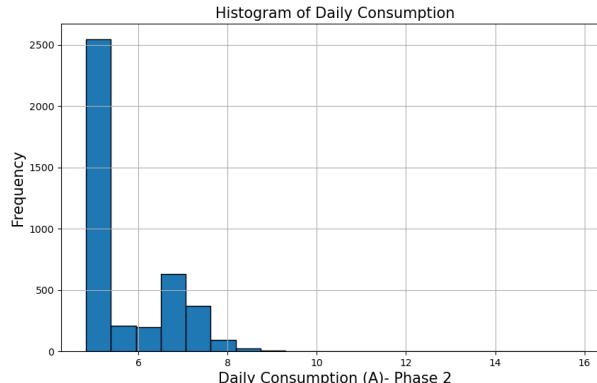
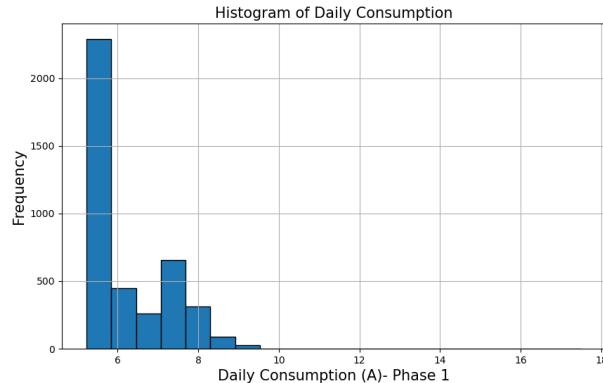
- Phase 3 displays very consistent behaviour compared to other sensors.
- Notably, the current consumption in phase 3 is only half of what is observed in phase 1 and phase 2.
- A single peak is visible reaching to 15 A.



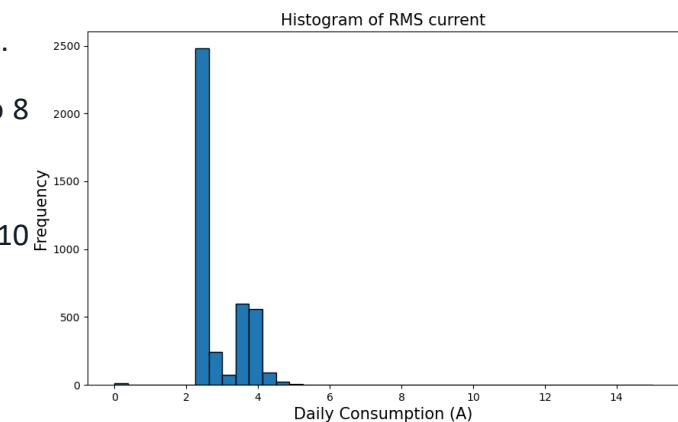
- The top left chart represents 2D clusters, with each cluster represented by a single color.
- No definitive clusters were detected in the 2D clustering process.
- AI is grouping adjacent days as one cluster, indicating that either there are no discernible patterns or the available data is insufficient to form meaningful clusters.
- The 3D clusters shown in the charts on the right also did not yield conclusive results.



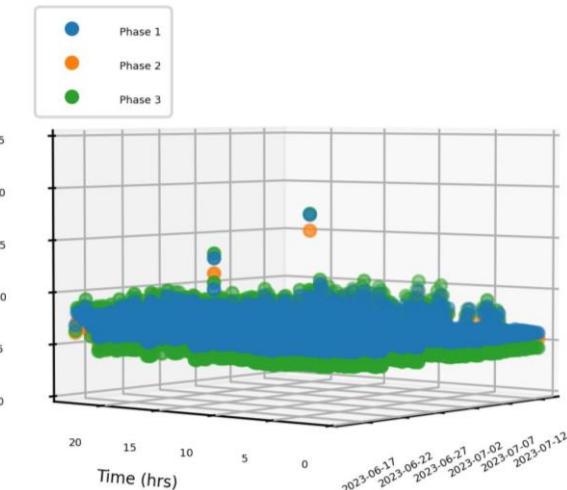
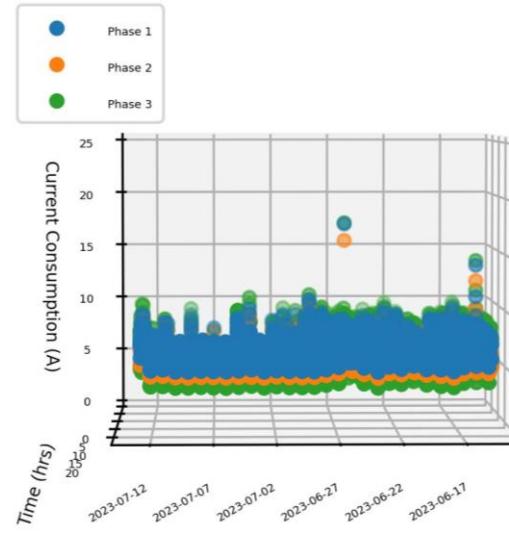
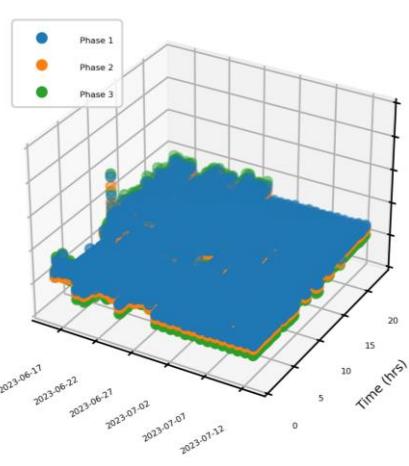
B787-9-L-13 Motion System



- Phase 1 (average) has current consumption just under 6 A, occasionally reaching up to 9 A.
- Phase 2 (average) shows current consumption just under 6 A, occasionally reaching up to 8 A.
- Phase 3 (average) has current consumption just under 6 A, with occasional spikes up to 10 A.
- RMS current consumption is mainly between 2 A and 4 A.

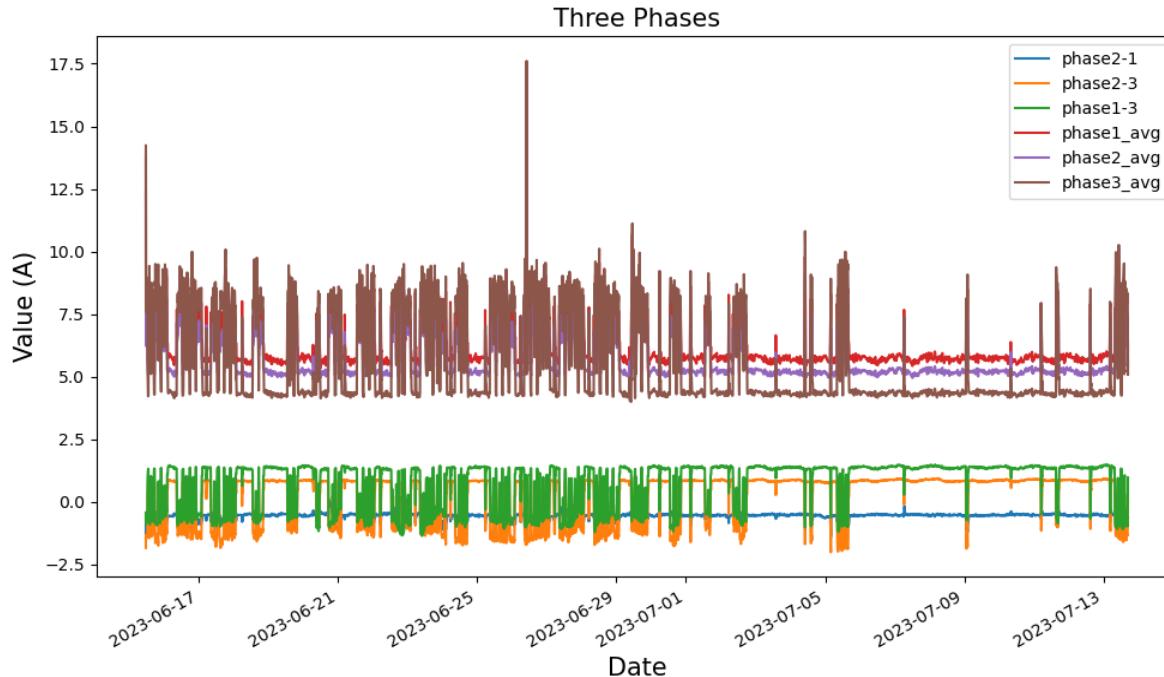


B787-9-L-13 Motion System



- Phase 1, Phase 2, and Phase 3 current consumption are stacked in the graphs.
- The average current consumption for all three phases falls within the range of 5 to 6 A.

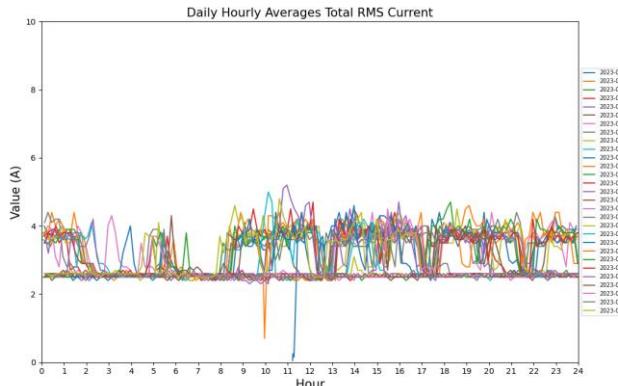
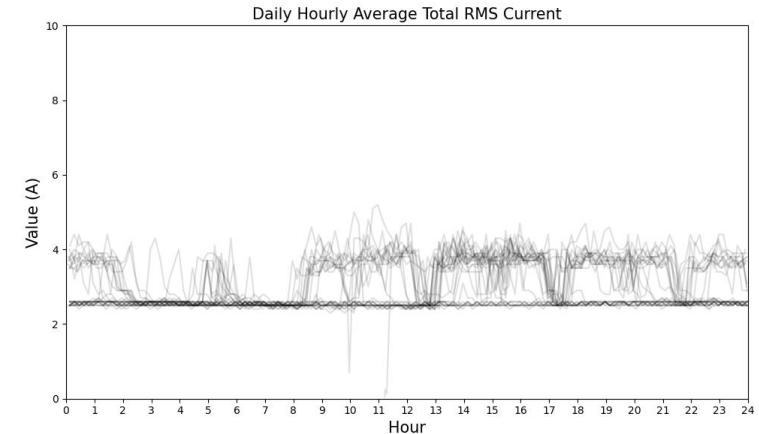
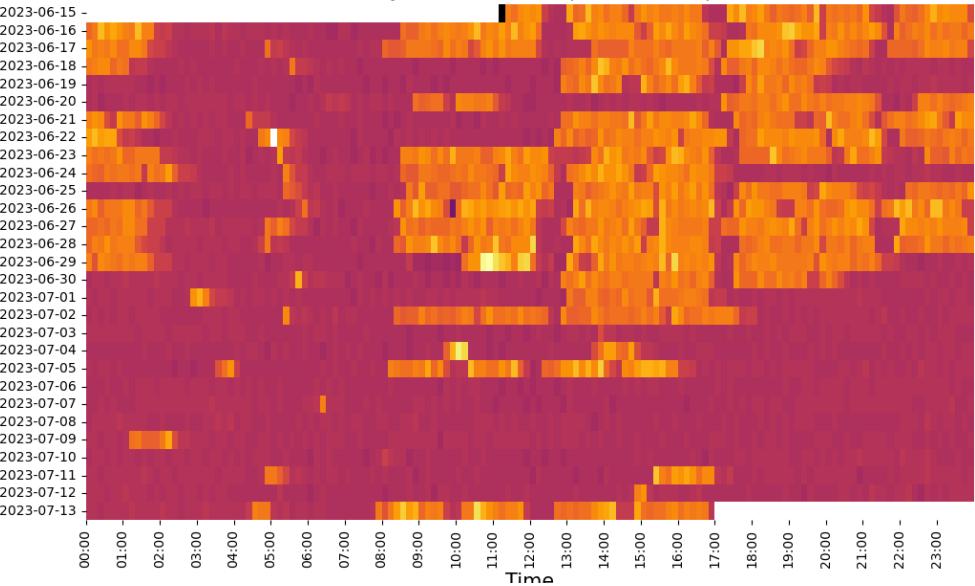
B787-9-L-13 Motion System



- All the charts show synchronized and balanced load.
- The difference in current consumption between the phases is minimal, indicating a well-balanced system.

B787-9-L-13 Motion System

Date

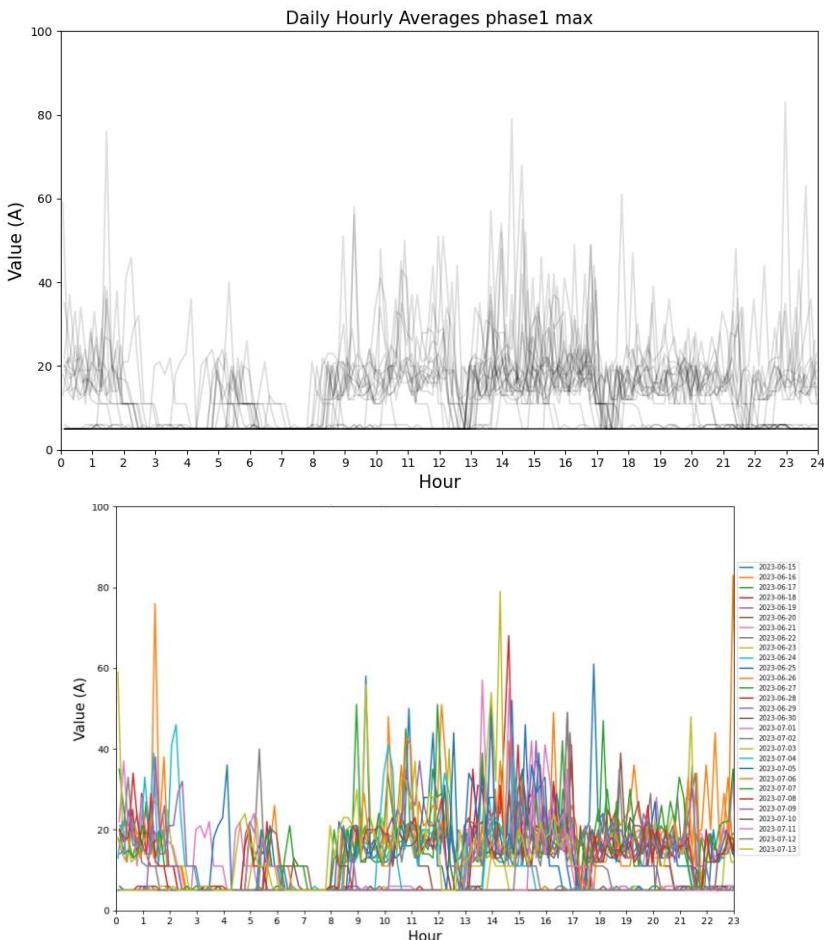


- The overall current consumption ranges between 3 A to 5 A.
- Lesser activity is detected in the early hours of the day.
- Clear patterns are visible in the current consumption data, suggesting some regularity or recurring behaviours.

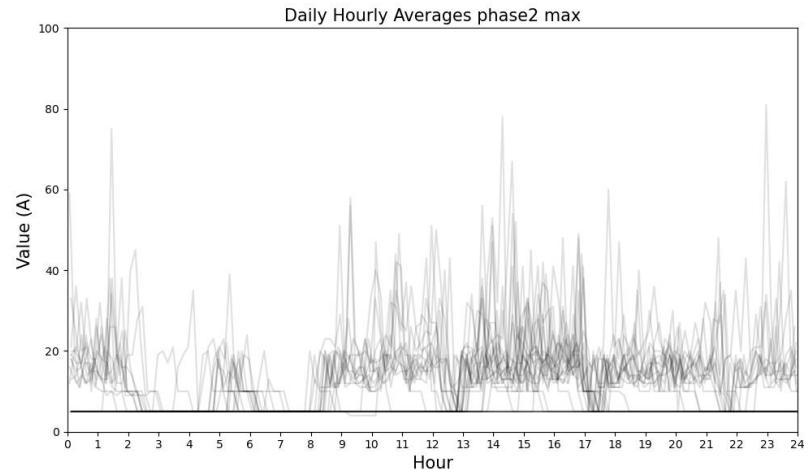
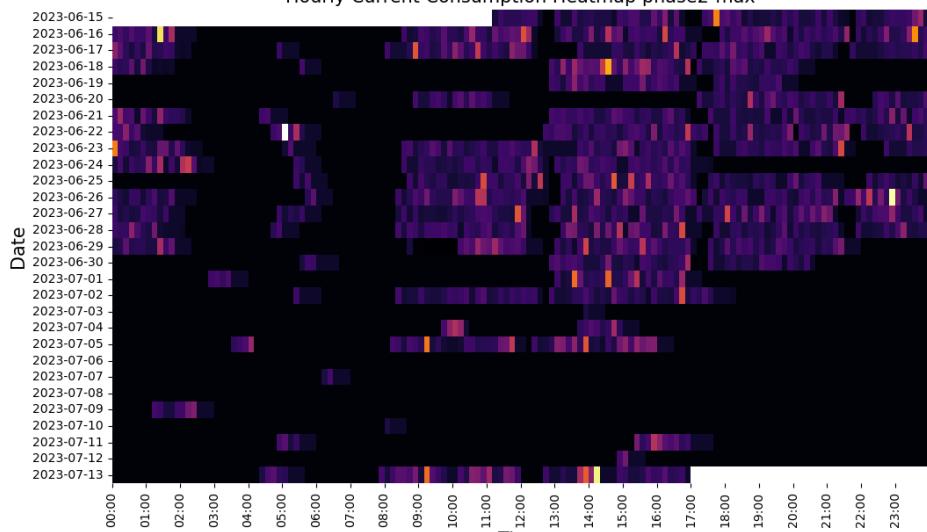
B787-9-L-13 Motion System Phase 1 (max)



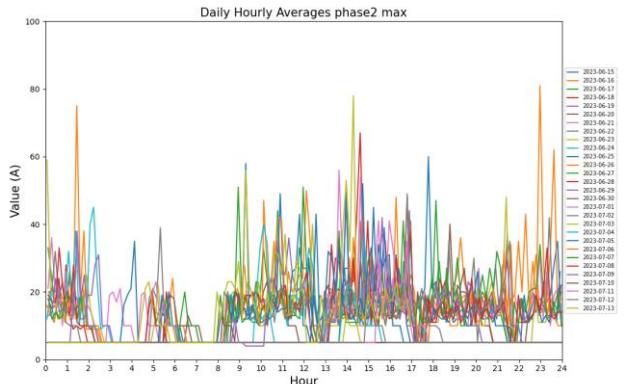
- The maximum phase 1 current consumption ranges between 0 to 80 A.



B787-9-L-13 Motion System Phase 2 (max)

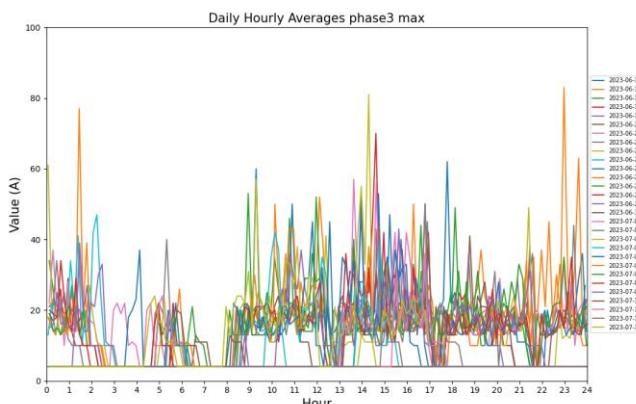
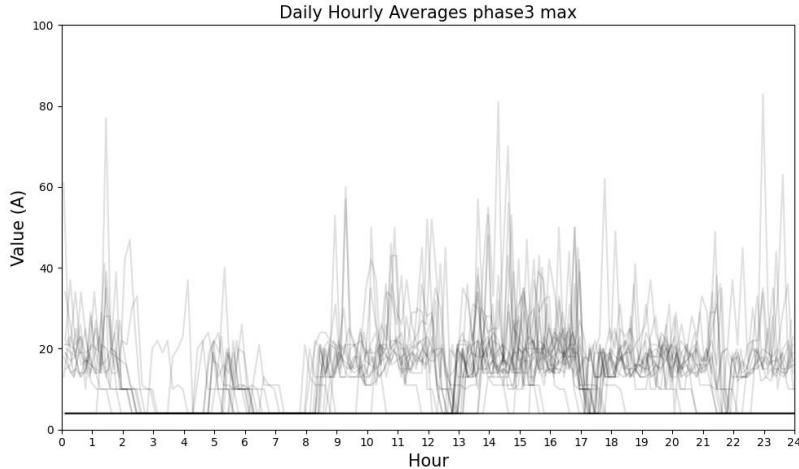
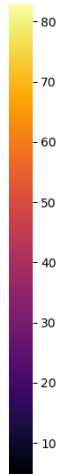
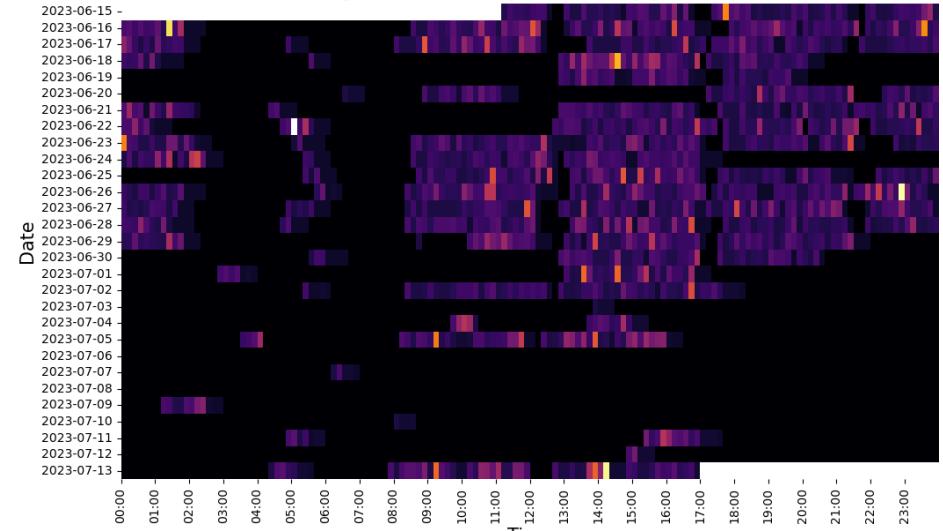


- Phase 2 exhibits a maximum current consumption of 80 Amps at some instances.
- Throughout all days, the current consumption in phase 2 fluctuates between 5 A to 80 A.

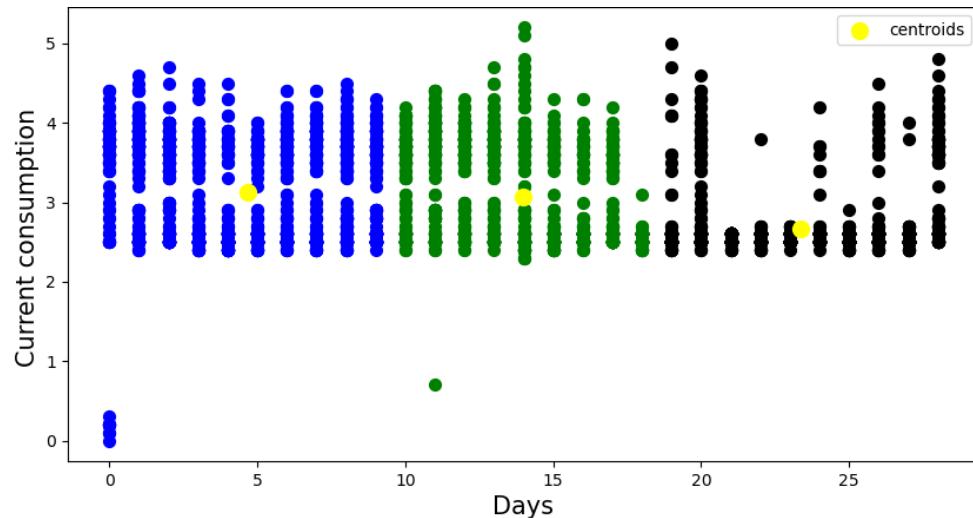


B787-9-L-13 Motion System Phase 3 (max)

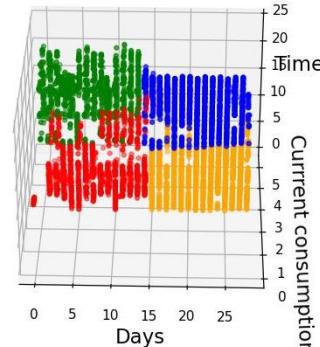
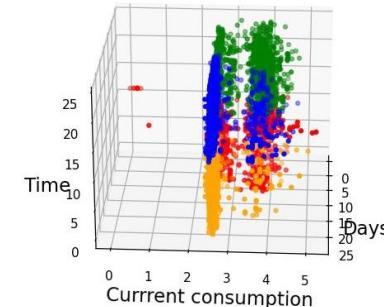
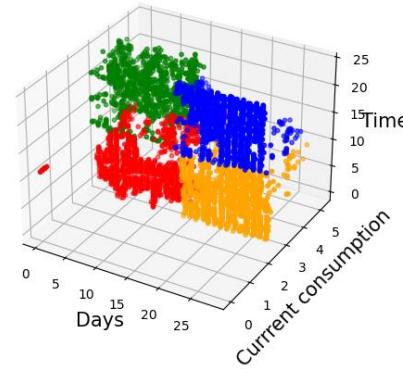
Hourly Current Consumption Heatmap phase3-max



- In all the days, phase 3 current consumption fluctuates between 5 A to 80 A.
- The heatmap validates this observation, showing a distribution mainly between approximately 5 A to 80 A.
- The most frequent current consumption, as indicated by the heatmap, is between 10 A to 20 A.
- Some trends are also detected in certain hours of each day, suggesting recurring patterns in phase 3's current consumption.



- The top left chart represents 2D clusters, with each cluster assigned a distinct colour.
- No definitive clusters were detected in the 2D clustering process.
- AI is grouping adjacent days as one cluster, indicating that either there are no discernible patterns or the available data is insufficient to form meaningful clusters.
- The 3D clusters shown in the charts on the right also did not yield conclusive results.



Monthly Consumption (kWh)

Month	B737MAX-8-M-03	B787-9-L-11 Computer Suite	B787-9-L-11 Motion System	B787-9-L-13 Computer Suite	B787-9-L-13 Motion System
2023-05-31	572	N/A	N/A	N/A	N/A
2023-06-30	1723	956	442	1219	464
2023-07-13	816	817	324	1027	324
Total	3111	1773	766	2246	496

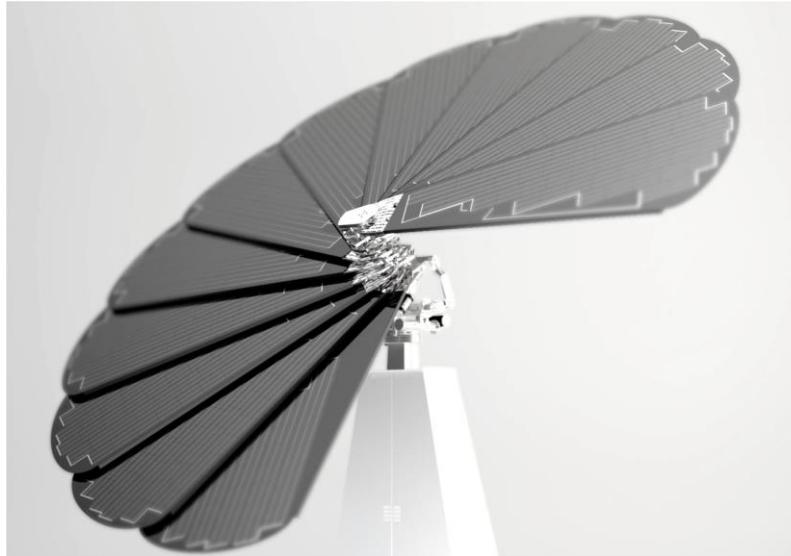
Weekly Consumption (kWh)

Week	B737MAX-8-M-03	B787-9-L-11 Computer Suite	B787-9-L-11 Motion System	B787-9-L-13 Computer Suite	B787-9-L-13 Motion System
2023-05-28	366	N/A	N/A	N/A	N/A
2023-06-04	474	N/A	N/A	N/A	N/A
2023-06-11	465	N/A	N/A	N/A	N/A
2023-06-18	461	178	88	227	89
2023-06-25	229	452	203	577	203
2023-07-02	428	455	205	578	204
2023-07-09	464	450	181	564	181
2023-07-16	226	227	88	300	88

Sustainable options

Solar smart-flowers: Using solar energy to power simulators can meet energy needs and generate environmentally friendly electricity. This sustainable option offers a viable approach to achieve the concept of net zero by minimizing carbon emissions.

Technical Specifications:



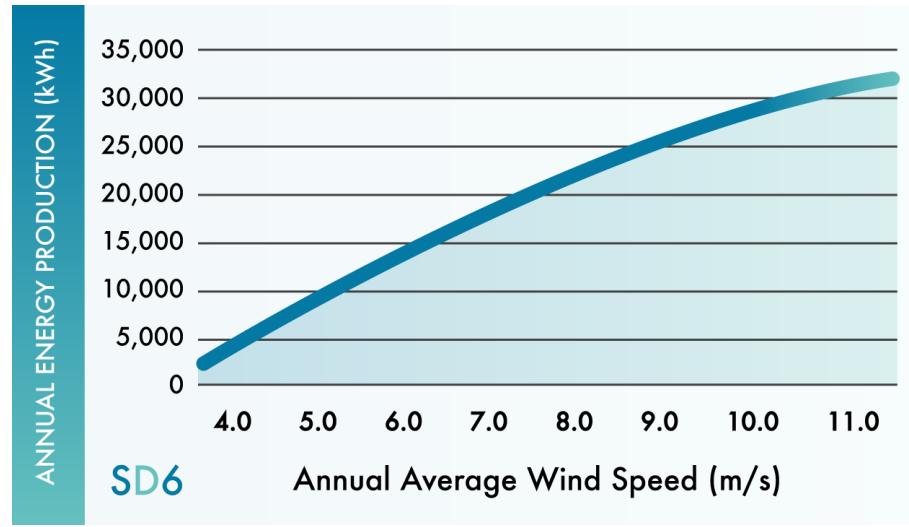
Technical Specs	Description
Nominal Output	2.50kWp
Annual Output	4,000 – 6,200kWh/annum
Installation	4 fastening points earth screws or concrete foundation
Clear Space	~16ft3
weight	~1,690lbs
Temperature Range	-13 F° — 122° F / -25°C – 50°C
Wind speed before automatically entering two safety positions	1: >30 miles per hour 2: >40 miles per hour
System warranty	2 years
Module performance warranty	25 years

Note: The data above is obtained from the official site of smart flowers.

Please follow the [link](#) to find more information about it.

Sustainable options

SD6 Wind turbine: The SD6 wind turbine is a compact and efficient wind energy system designed for distributed applications. It harnesses the power of the wind to generate clean electricity, making it an ideal solution for residential, commercial, and industrial settings. With advanced technology and optimized performance, the SD6 turbine contributes to a sustainable and renewable energy future.



Note: The data above is obtained from the official site of SD6 wind energy. Please follow the [link](#) to find more information about it.

Sustainable options

Technical Specifications (SD6 Wind turbine)

Technical Specs	Description
Peak Power	6KW
Applications	Rural Domestic, Small Holdings, Commercial, Telecoms, Public Sector, Remote Islands
Solutions	Grid Tied & Battery Charge, 48V, 120V, 300V
Rotor	5.6m Diameter (maximum 200 RPM)
Tower Options	9m / 15m / 20m Taperfit Monopole - Hydraulic
Foundation Options	Pad / Root / Rock Anchor
Cut In Speed	2.5m/s
Survival Wind Speed	Designed to Class 1 (70m/s)
Warranty	5-Years

Note: The data above is obtained from the official site of smart flowers. Please follow the [link](#) to find more information about it.

Conclusion

Visualisations and graphs have effectively showcased the consumption patterns, enabling a better understanding of when energy is being consumed.

By examining the weekly and monthly consumption data, it becomes possible to identify recurring patterns and peak load periods. This information can guide decision-making processes and facilitate the implementation of strategies to optimize energy usage. Load-shifting techniques, such as adjusting operations or scheduling energy-intensive activities during off-peak hours, can help reduce consumption and potentially lower costs.

Furthermore, the identification of consumption patterns opens up opportunities for utilizing renewable energy sources to power the simulators. Integrating renewable energy into the operations can contribute to environmental sustainability by reducing reliance on fossil fuels and minimizing greenhouse gas emissions. The analysis provides a foundation for exploring and implementing renewable energy solutions, taking advantage of their benefits such as cost competitiveness, energy security, and reduced environmental impact.

Overall, by gaining insights into current consumption patterns, exploring renewable energy options, and implementing energy optimization strategies, it is possible to enhance sustainability, reduce costs, and improve energy efficiency in operating the simulators.

Lastly, AMRC recommends employing PIR sensors for lighting control in server rooms. Additionally, they propose using heat exchanges to reuse server-generated heat during winters and vice versa. This approach optimizes energy usage and enhances the server room's efficiency.

Thank you.

For further information please contact or visit:

m.n.ahangar@amrc.co.uk

z.farhat@amrc.co.uk

amrc.co.uk



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