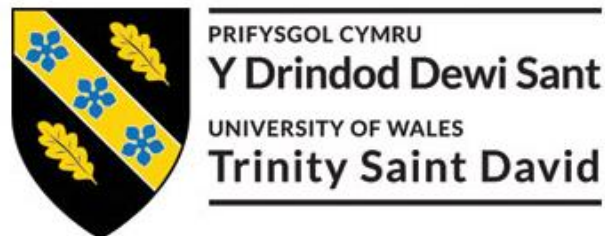


An investigation into the design and integration of a chilled thermoelectric compartment
into an aircraft cabin.

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BEng Honours in Mechanical & Manufacturing Engineering



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Abbreviations and Acronyms

Acronyms	
SSGB	Safran Seats GB
R&T	Research and Technology
AIX2024	Aircraft Interior Exhibition 2024
dBA	Decibel
V	Volts
W	Watts
AC	Alternating Current
DC	Direct Current
Hz	Hertz
POC	Proof of Concept
ECU	Engine Control Unit
TRL	Technology Readiness Level
FST	Fire, Smoke & Toxicity
ACT	Advanced Concepts Team
CMF	Colour, Materials and Finish
R&D	Research and Development
NDA	Non-Disclosure Agreement
CAD	Computer Aided Design
BOM	Bill of Material
Ft	Feet
ρ	Rho (Density)
Kg	Kilogram
Kg/m³	Kilogram Per Meter Cubed
m³	Meter Cubed
°C	Degrees Celsius
J	Joules
J/Kg°C	Joules per Kilogram Degrees Celsius
g	Grams
mm	Millimetre
CFD	Computational Fluid Dynamics

Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: MORGAN WHEELER

Date: 18/05/2024



Abstract:

Enhancing the passenger experience has been the goal of many commercial aircraft cabin designers. One approach that is being investigated to achieve this, is to provide a chilled compartment for the passenger.

Initiated by Safran Seats GB (SSGB), this potential solution addresses the growing demand for improving the passenger experience, particularly within business and first-class suites. Providing a chilled compartment, within the proximity to passengers, has emerged as a desirable feature. This will provide convenient access to cooled beverages while maintaining optimal cabin temperatures.

Through rigorous research, analysis, and testing, this study aspires to pave the way for the adoption of thermoelectric cooling technologies as a viable and eco-friendly means to create chilled compartments within commercial aircraft cabins. The project aims to show how the chilled compartment may be integrated into SSGB's technology demonstrator for presentation at Aircraft Interior Exhibition 2024 (AIX24), thereby differentiating SSGB from competitors and establishing a strong rapport with airlines.

Key objectives of the project include achieving target internal temperatures for the chilled compartment, ensuring efficient circulation and cooling within a confined space and minimising noise levels to enhance passenger comfort. Tests conducted on the thermoelectric cooling system provided valuable insights into its performance under various conditions, highlighting the efficacy of insulation materials and ventilation strategies in maintaining desired temperatures. Further refinement based on these findings, will enhance the system's performance and contribute to advancing air travel comfort and sustainability.

To systematically evaluate and optimise the thermoelectric cooling system, a meticulous approach was undertaken, incorporating Design of Experiments (DoE) methodology. Through controlled experiments, variables such as ambient temperature, insulation thickness, thermoelectric device placement, and container materials were scrutinised to ascertain their impact on system performance.

Findings from these tests underscored the critical role of insulation in temperature retention within the compartment, with Plastezote foam emerging as the preferred material with an optimal thickness of 10mm. Moreover, investigations into container materials revealed minimal differences in cooling rates, emphasising the significance of insulation to maintain 'cold' temperatures for long durations.

1. [Introduction](#)

The aviation world is continuously evolving. Enhancing passenger comfort and experience is regarded as key to attracting the discerning customer. Commercial aircraft cabin environments, traditionally engineered for safety and functionality, are increasingly being scrutinised for their capacity to provide optimal features for the comfort of passengers. Amongst these various factors cabin features play a significant role, especially in long-haul flights.

Safran Seats GB is a French subsidiary company based in South Wales with approximately one-thousand employees. They design, manufacture, assemble and retrofit business class, premium business class and bespoke first-class suites for aircraft of various types.

On some airlines such as Emirates, there is a 'minibar' where drinks can be stored but not cooled. These drinks however are stored at ambient temperature and are not desirable to some passengers who would prefer their drinks to be chilled. This feature has been the focus of sales bid requests from many airlines such as British Airways, Emirates and Etihad, who would like to see future projects such as a 'chilled compartment' or 'minibar' being made available to passengers. However, there are certain limitations for such a system on an aircraft, as normal domestic appliances are cooled by refrigerants. These refrigerants are banned on aircraft due to their behaviour under rapid decompression, as they can be explosive.

The demand for more sophisticated cooling solutions within aircraft cabins has led to exploration the use of more innovative technologies. One promising approach has been the integration of thermoelectric devices to create the chilled compartments within the cabin. Thermoelectric cooling, leveraging the Peltier effect, offers a compact and energy-efficient alternative to traditional compressor-based systems. By harnessing the temperature differential between two conductive materials when an electric current passes through them, thermoelectric modules can generate a cooling effect for the application required.

When a passenger travels in a business class or first-class suite, they expect impeccable standards which have a high perceived quality. The price of a business class ticket can cost anywhere from £3,000 to £6,000 and the first-class tickets can range from £7,000 up to a staggering £50,000 as Alpen Air (2023) states. It is vital for Safran Seats GB (SSGB) to be continuously innovating and showcasing new technologies that can be sold to airlines to enhance the passenger's experience.

Undeterred by challenges, SSGB uses the airline insights to fuel the Research and Technology (R&T) department's efforts to produce concepts and prototype cutting-edge solutions. With sights set on the prestigious Aircraft Interior Exhibition 2024 (AIX24), SSGB aims to showcase not just a concept but a tangible, high-quality solution that redefines in-flight luxury.

Ultimately, through rigorous research, analysis and testing, this study aspires to pave the way for the adoption of thermoelectric cooling technologies as a viable and eco-friendly means to create chilled compartments within commercial aircraft cabins, thus advancing air travel comfort and sustainability.

2. [Acknowledgement](#)

I would like to say a special thank you to some key stakeholders that have been involved in the project, who helped to make it more enjoyable and would motivate me to carry out the best work possible.

Thomas and Claire - The expertise and insights from industrial design have played a crucial role in shaping the conceptualisation and aesthetics of the thermoelectric device integration within the aircraft cabin. Their creative input has been invaluable in ensuring both functionality and elegance in the design.

Mike North, Ciaran Doherty, and Julian Guy: The expertise in mechanical design and topic knowledge has been indispensable in creating conceptual designs into practical and functional solutions. Their attention to detail and dedication to produce innovative products have greatly contributed to the development and optimisation of the thermoelectric cooling system.

Robert Goodson and Emma Davies: The knowledge and feedback I have received from both Rob and Emma have helped to keep me on track and focused on carrying out a good project. They have provided plenty of support and spare time on helping me which I'm very grateful for.

European Thermodynamics and Micronel: I extend my gratitude to both European Thermodynamics and Micronel for their collaboration and support as suppliers of critical components for the thermoelectric cooling system. Their commitment to quality and reliability has been essential in ensuring the performance and effectiveness of the cooling system.

Ogle Models: A special acknowledgment to the team at Ogle Models for their expertise and craftsmanship in building the mock-up of the cooled compartment. Their precision and attention to detail have provided valuable insights into the physical realisation of the design concept, and have enhanced the overall quality of the finished concept.

3. Aims and objectives of the project.

As previously mentioned, the main objective of the project is to have a high quality concept, integrated into R&T's technology demonstrator ready for AIX24. As AIX24 is held at the end of May, the project objective will be to get a concept which can be shown to stakeholders and customers. Production solutions were also investigated however, only concept prototypes will be available for the show. There were various performance targets set by airline customers which needed to be achieved, to ensure the hardware performed correctly to achieve desired results. As stated by airlines, they would expect the internal temperature of the chilled minibar to be between five to eight degrees. The ideal internal temperature for a domestic fridge is between one and three degrees as stated by O'Meara (2023). A reason for this is due to 'the danger zone' which is when food is defrosted at temperatures between eight and sixty-three degrees Celsius, bacteria grows which can make the consumer ill (Food Standard Agency, 2020). For this reason, only drinks should be stored in the cooled compartment within the suite.

When the door is opened, the cold internal air will escape from the cooled compartment. The target time for the internal temperature to reach seven to ten degrees once closing the door again is ten minutes. This will allow the air to circulate through the thermoelectric device and allow the Peltier effect to cool the air. It will be important for the fans to stop when the door is open, as it will prevent any unnecessary energy being used and it can also extend the lifespan of the hardware which is being used. M.Durgut (2023) describes that considering the average lifespan of an aircraft is between twenty to thirty years, it is important that hardware can be turned off when not required, to save on electrical power and to extend the life period of the hardware for as long as possible.

Due to the location of where the system will be integrated, it will be close to the passenger's head which means that the fans will need to be as quiet as possible when running. This will be able to be tested in SSGB's aircraft simulator which consists of over 80 speakers and exciters to mimic the real sound and vibration of an A350. An aircraft on ground with air conditioning is 61dBA so 55dBA would be a good target to aim for so that the system is not perceivable by the passenger.



Figure 1 - Aircraft Simulator at SSGB



Figure 2 - Aircraft Simulator at SSGB

An aircraft's power is typically 115VAC 400Hz (Skybrary, 2023). R&T technology bricks are developed with DC power because once the technology bricks are productionised, they will be powered by the seat ECU. The ECU will then transform and filter the aircraft's 115VAC

power to the 28VDC required to power the system. The power supply and system will need to be robust enough to handle up to 32V for any peaks that might occur. This could result in reduced efficiency and shorten the lifespan of the system. The target power consumption for the system is going to be 30W with a maximum of 55W, this is so that any power spikes are accounted for and the power supply will be able to cope with any excess power requirements.

During this project it was imperative to gather data, information, knowledge and evidence to input into the different stages of the Technology Readiness Levels (TRL). Levels one to six are within the remit of R&T, and no technology can be offered or integrated onto a programme unless it has reached TRL six. When each level has been achieved, a TRL review is required with a group of experts and stakeholders within Safran, who can identify that the technology adheres to air framers certification requirements and to ensure all testing and safety requirements are met.

Levels one and two are usually research and case studies which can be undertaken by universities. TRL 3 is where a Proof of Concept (POC) is produced to be able to test. TRL four is to be able to test that the performance of the concept is suitable for what is required. TRL five and six are integrating the technology into a representative environment and demonstrating its targeted application. These are usually integrated into R&T's integration test suite within the aircraft simulator, for an aircraft representative environment.

EXPLORATION & VALIDATION			VERIFICATION & INTEGRATION		
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6
Basic principles observed and described.	Technological concept & applications ID	Proof of Concept in Targeted Applications.	Lab-based Validation & Verification	Integrated into Assembly & Verified in Representative Enviro	Representative Demonstration for Targeted Application

Figure 3 - Technology Readiness Level Process

Once the technology has reached TRL six, it will then be passed onto an architect to find possible programmes which they can be implemented on.

The compartment should also be easy to clean and maintain as this will help airlines be able to keep the compartment looking and functioning to a good standard. This can be done by using radiuses on the internal corners instead of sharp corners. This will help any dust build-up be easily cleaned with a cloth. Fan guards must also be installed and kept in good condition as it is a safety feature, so nothing small e.g. fingers, pens and other small items can be inserted into the fan while it is rotating which can damage the hardware.

4. [Timing plan](#)

The Gantt chart which was followed throughout this project can be found in Appendix 1. The second solution testing dates were adjusted to after AIX, as there were so many tests to undertake, the time scale would have been too compact to conduct them all.

The other dates which were not met on the Gantt chart are related to the insulation testing. Due to long lead times on the 20mm thick insulation, this part of the testing had to be skipped however, from testing other thicknesses such as 5mm, 10, and 15mm, the 20mm insulation would not have been beneficial to test.

Otherwise, the Gantt chart was updated and checked frequently to ensure the work was being completed successfully and on track.

5. [Research/literature survey](#)

As part of this dissertation, research had been carried out on multiple solutions to determine what way the project should be steered. To start with, the use of refrigerant was investigated as it is the most common way to create a 'fridge-like' environment. Discovering that refrigerants can be very flammable, toxic and volatile when compressed, it would not make sense to use these types of fluids and gases within an aircraft cabin, as if the aircraft underwent a rapid decompression, this can cause the refrigerant to become explosive within the cabin (Delta , 2024). After finding out this information, a system containing refrigerant could be disregarded as a feasible option and an air cooled solution would be best suited to the application.

Thermoelectric cooling devices are a small, compact, lightweight and reliable piece of hardware. Dongliang Zhao (2014) narrates that they have no mechanical moving parts as they work by using direct current being passed through the thermoelectric device. A thermoelectric device is made up of soldered junctions of two different semiconductor materials (usually copper and bismuth), and two electrical insulator plates which are ceramic. This allows the temperature to be increased when the current passes from copper to bismuth which will create a temperature difference.

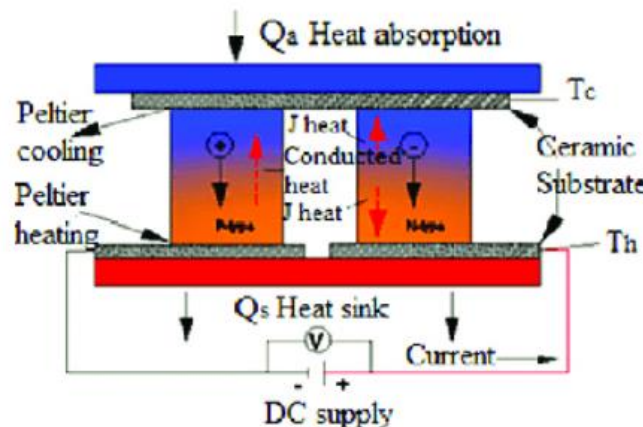


Figure 4 - Diagram of Heat Transfer Between Junctions - (Zheng, 2014)

Likewise, the temperature will decrease when passing from bismuth to copper which will create a 'hot side' and 'cold side' (Zebarjadi, 2015). This effect created by the device is called the 'Peltier effect'. This effect creates the temperature difference and chemical potential between the two materials to cause a cooling effect. The reverse effect of this which is used for heating is called the 'seebeck effect'. This is where heated electrons flow to the cold side (Terasaki, 2016). The hot side can reach temperatures of up to two-hundred degrees in some

instances and the cold side can reach temperatures as low as minus forty-five degrees, which are very dangerous temperatures. For the thermoelectric devices to be useful and more efficient, heatsinks are necessary on the hot side to significantly decrease the temperature from the hot side of the thermoelectric device. This will help extend the lifespan of the component and increase the efficiency of the system. It also stops the component from malfunction or causing extensive damage to itself. Heatsinks are usually made from Aluminium as they're great thermal conductors and they can be easily machined into certain shapes and sizes for different applications (Advanced Thermal Solutions Inc., 2018). As the heatsink withdraws the heat from the device, there must be a fan or blower to remove that heat from the heatsink so the system can be efficient as possible. This required a study to be carried out on where the hot air should be exhausted to. The seat ECU is stored underneath the seat and can get to temperatures of up to thirty-four degrees Celsius when all peripherals of the suite are connected to it. As the temperature from the exhaust was lower than that temperature of the ECU underneath the seat, it could potentially act as a cooling air flow by decreasing the temperature underneath the seat.

The drinks at a cooled temperature will be affected by convection, this is where the transfer of heat occurs through the movement of fluids. When a cooled drink is left in an ambient temperature surrounding, the air around the drink will warm up as heat always flows from the warmer body to the colder body, it then becomes less dense and rises. The continuous circulation of warm air around the bottle will facilitate the heat transfer, making the drink temperature increase to the ambient temperature.

5.1 [Previous Solutions](#)

SSGB have previously investigated integrating a thermoelectric device for a cooled compartment for an airline in 2022 however, the time limit was too short to come up with a substantial solution.

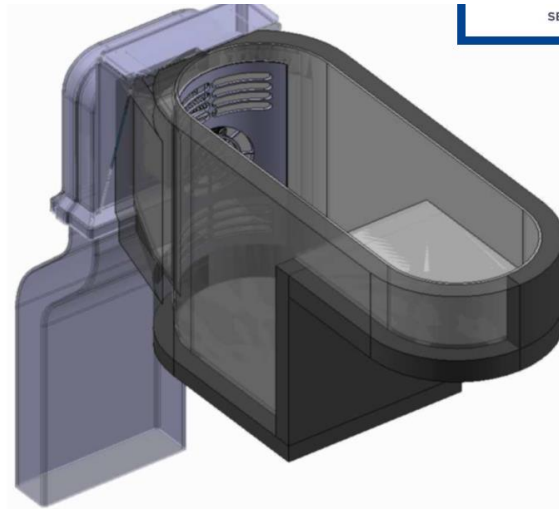


Figure 5 - Previous Concept of Cooled Compartment

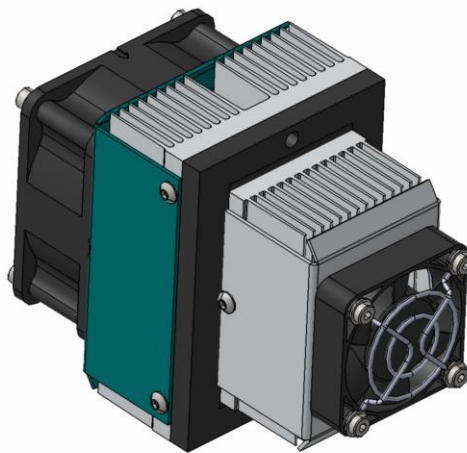


Figure 6 – Previous Concept Thermoelectric Device Stack-up

As seen in Figure 6, there are fans attached to both heat sinks that push the cold air into the compartment where drinks are stored, and the other fan will extract the hot air from the hot side of the thermoelectric device.

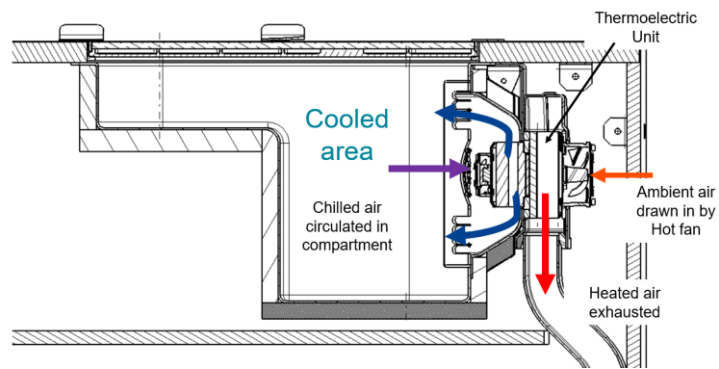


Figure 7 - Cooling Compartment System

As seen in Figure 7, the ambient air is drawn in from the rear of the compartment, then subjected to the Peltier effect where the cold air will go through the cold heat sink and into the compartment. This was a good system to draw knowledge from for the updated cooled compartment.

5.2 Competitors Solutions

Safran Seats GB's main competitor is Collins Aerospace, they are based in Newry and also produce first class and business class seating for airlines. They had also started to look at transforming a normal cubby stowage into a cooled compartment where drinks can be cooled and stored. Their version of this is called 'space chiller' which was demonstrated at AIX2022. There has been no productionised system released, so SSGB are still able to be the first to market with this solution. SSGB's solution is also be a much higher perceived quality system which will be more aesthetically pleasing for airlines.



Figure 8 - Collins Aerospace - Space Chiller Concept - (Collins Aerospace, 2022)

The Collins Aerospace solution has the same bottle capacity of three cans or bottles however, the surrounding area of the bottles is smaller which will make the cooling more efficient as there is less air to cool. This different form factor was worth testing to see how much more efficient it was than the volume SSGB needs to cool.

Collins Aerospace have also filed a patent for the system in Figure 9. This system uses a coolant on the hot side of the thermoelectric device however, an air to air solution which will be more appealing to airlines and customers. The patented solution is very general as it is widely used in the automotive industry.

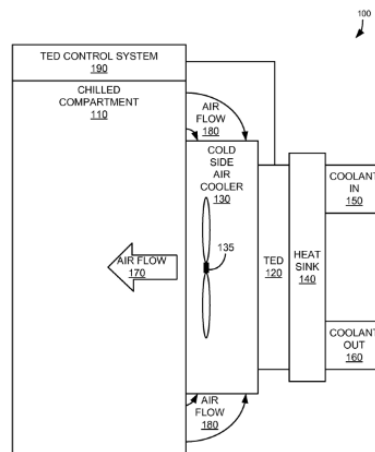


Figure 9 - Collins Aerospace Thermoelectric Device Filed Patent

5.3 Applications of Thermoelectric Devices

While researching different applications of thermoelectric devices, it was interesting to find that they are also used in portable electric cool boxes. They are stored within the lid of the cool box and have a very simple solution. From this already-proven solution, it was decided that a variant different variant should be created. A thermoelectric device in the top of the compartment rather than positioned in the side, could be tested to determine the most efficient location. There would have to be a change in form factor to fit heat sinks, fans and thermoelectric devices in the top however, the circulation of air may be improved due to the heat rising straight up out of the compartment. The thermoelectric devices in these cool boxes can achieve a temperature of up to eighteen degrees below ambient temperature (World of Camping, 2023).

Within first class, it is likely to find a variety of drinks that can be stored within the fridge such as cans of fizzy drinks, plastic bottles of water and even glass bottles of champagne.

SSGB's fridge needed to have the capacity to store a total of three cans, bottles, champagne glasses or a mixture of the three.

FerroTec (2023) describes some other applications where thermoelectric devices are used such as wine cabinets, small power generators, all the way to sophisticated temperature control systems within missiles.

5.4 [Material Research](#)

For the insulation material, there were two main foams which stood out as they were already utilised on aircraft. Meetings were had with Safran galleys, as they use the same material in their cooled compartments in a similar application. The Plastezote and Zotek foams are very similar however, the Zotek foams has better fire retardant properties over Plastezote. The data sheets for both of the foam materials can be found in Appendix 2 and Appendix 3. To ensure that these materials are suitable for the application, various tests between the two were carried out with different thicknesses to see the performance difference.

'Thinsulate' by 3M is also another alternative insulation material. This material is a wool-like insulation, whereas Plastezote and Zotek are both foam insulators. The foam insulation would be easier to cover composite panels as it is a semi-rigid foam, which makes increasing the thickness stack-up easier than using the 3M 'Thinsulate'.

To achieve the tinted mirror finish for the door (as per industrial design requirements), glass or polycarbonate was not a sufficient material as they're transparent. After some research, a company called 'Aviation Glass' was found, who provided glass that had been tested and had passed all aviation certification tests, such as Fire, Smoke and Toxicity (FST) and hardness tests. They were also able to provide different types of finishes and transparencies which could achieved the desired finish. The data sheet for the material can be found in Appendix 4.

For the production solution, it will be important to investigate what thickness and type of composite will be best suited for the application. This activity will take place after AIX24 as the goal is to just have a working prototype for the show to demonstrate the concept to customers and airlines.

5.5 [Fans Research](#)

Due to the amount of various fans that are available on the market, the axial fan best suited the application as they can be purchased in a slim profile, which helped save some space within the suite. The axial fan would pull air from the cold side heat sink and push it into the internal compartment. Radial fans were found to not be as useful due to the exhaust output being at ninety degrees to the inlet. This would make the system build-up much thicker than that of an axial fan. The radial fans are usually louder than axial fans which is a big disadvantage due to the target of 55dBa. Pauls Fan Company (2019) also describes how the axial fans displace more air than radial fans, just at lower pressure, which would be better suited to the larger compartment within the suite.

6. Work carried out

To start this project, it was important to research previous applications and past projects in which knowledge and information can be drawn from. From this, thermoelectric devices were found to be the most appropriate solution that just needed to be matured from previous attempts.

As this project is to be shown at AIX24, it is vital that the cooled compartment has a high level of perceived quality, and it's integrated seamlessly into the suite. Due to this requirement, alignment meetings and workshops were created and attended by SSGB R&T, Advanced Concepts Team (ACT) and the industrial design team. The meetings covered various topics such as different Colour, Materials & Finishes (CMF) and how the thermoelectric device can fit into the suite without making too many modifications for the mock-up builder.

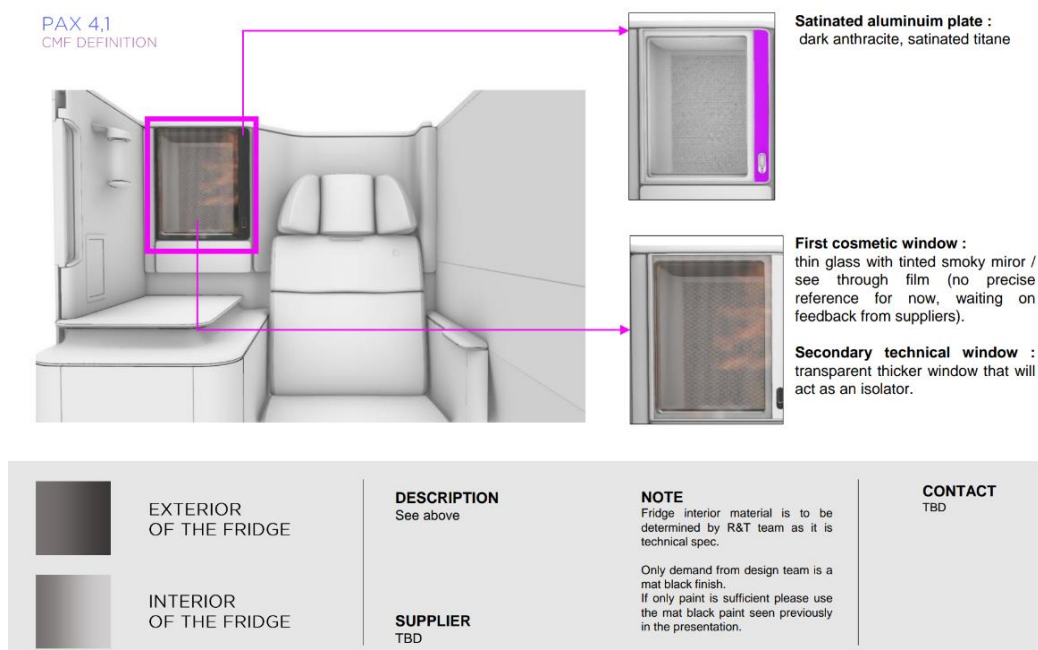


Figure 10 - Colour, Trim and Finish Document (Bourguignon, 2024)

The CMF document is produced by the CMF expert, who is part of the industrial design team. The document is full of mood boards, which is where the inspiration come from. The document is also full of different suppliers which needed to be narrowed down to supply the paints and trims. Pantone references were given so different suppliers can produce the same colour and reduced the changes of having any discrepancies. Any special notes, or actions to be taken are also on each slide, so the CMF document was constantly updated with selected suppliers etc.

From the visuals the industrial design team produced, it was then R&T's job to turn the vision into a reality, and while still ensuring all performance requirements were met.



Figure 11 - Renders of Compartment Integrated Into Suite



Figure 12 - Internal of Cooled Compartment Render

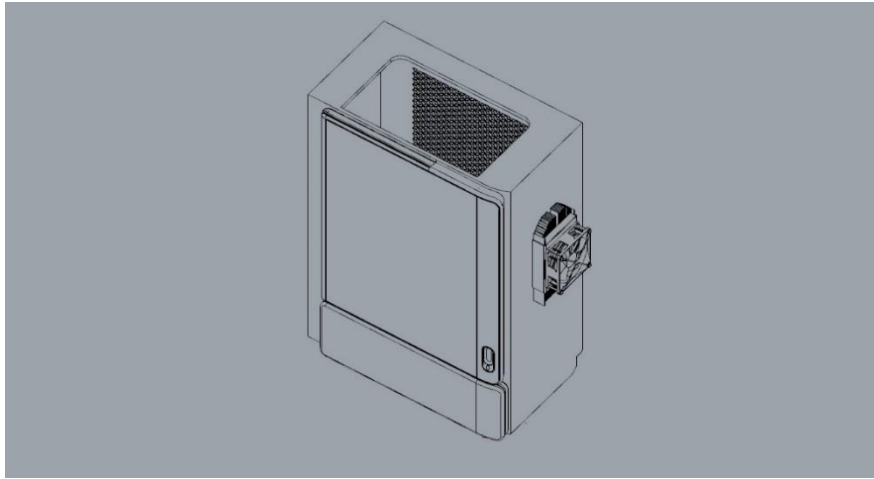


Figure 13 - Location of Thermoelectric Device

Once the final renders were created, the final CAD files were checked over by Thomas Jourdan-Gassin and Michael North and the rest of the SSGB R&T team. This CAD was then sent to Ogle Models to double-check all of the dimensions and tolerances were valid. Ogle Models produce all of R&T's mock-ups and technology demonstrator suites. SSGB requested Ogle Models to produce six of the compartment mock-ups, this is so analysis could be carried out on different solutions and compared against each other. Some were also sent to suppliers so they could undertake their own testing, and could carry out optimisation of the system.

The lead time of creating these compartments was approximately seven weeks. During this time, SSGB engaged in meetings with UK based suppliers, as support is much easier and convenient to obtain than that from an international supplier. The cost of shipping parts back and forth would also be cheaper and more efficient.

For the thermoelectric device, we spoke to European Thermodynamics who are based in Leicestershire and developed a good relationship straight away. They were very accommodating to the requirements and willing to undergo Research and Development (R&D) to make the solution work. SSGB decided to setup a Non-Disclosure Agreement (NDA) which would keep the project and innovations confidential between the two companies (Egan, 2021).

Once the NDA was completed, European Thermodynamics visited SSGB to see the application for themselves.

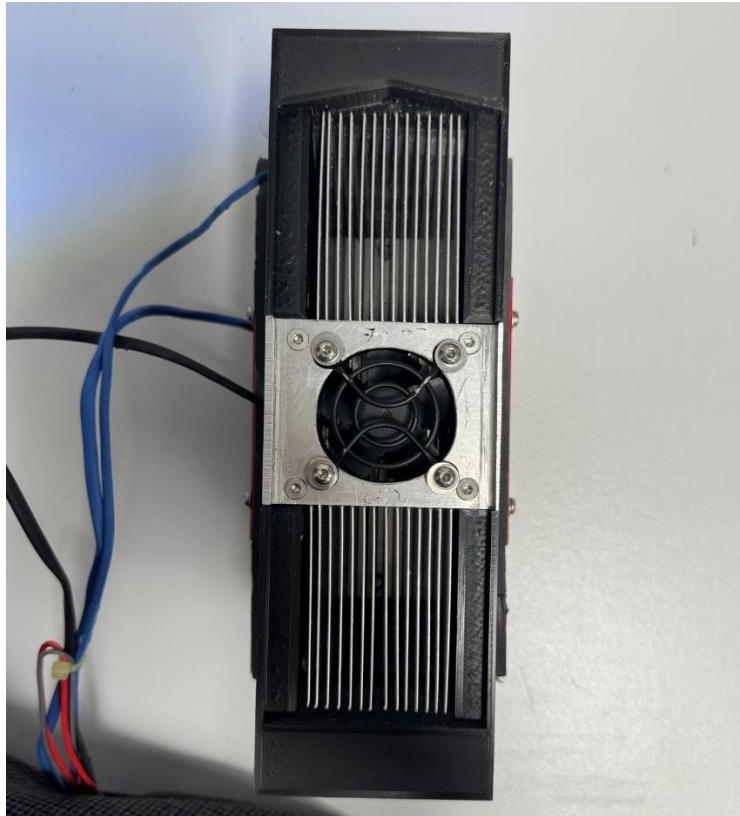


Figure 14 - Front Side of Thermoelectric Device



Figure 15 - Rear Side of Thermoelectric Device

After three weeks, European Thermodynamics came up with a system consisting of a cold side heat sink, hot side heat sink, two fans and a thermoelectric device which would fit within the desired space.

The data sheets for the fans in Figure 14 and 15 can be found in Appendix 5 and Appendix 6.

To be able to mount the thermoelectric device, it was decided to create a 3D printed insert jig. This jig would allow the thermoelectric device to be fixed into place and also provide an 'A' surface finish within the cooled compartment.

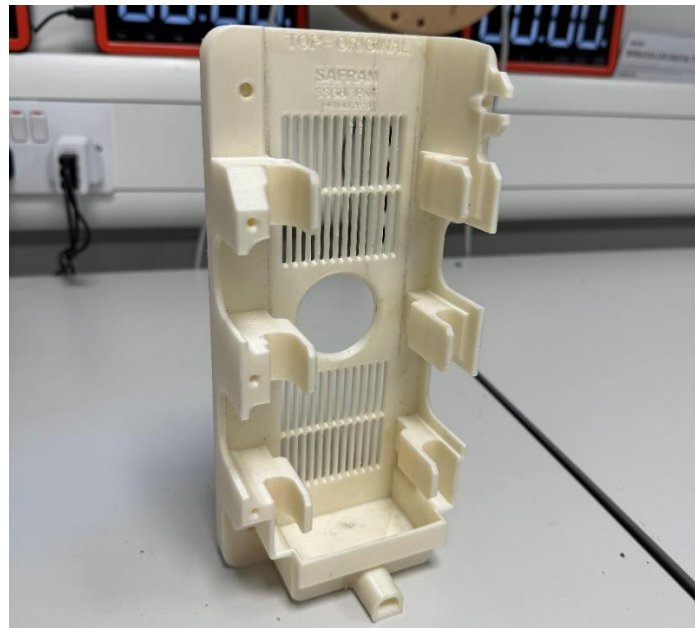


Figure 16 - Test 3D Printed Insert

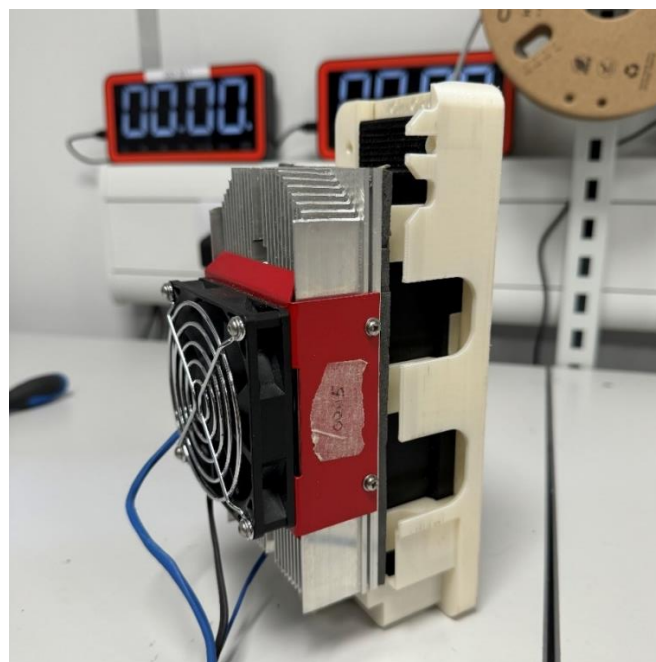


Figure 17 - Thermoelectric Device in Insert

This jig allowed the thermoelectric device to be slid downwards through a channel of the insert which will then be secured from inside of the cooled compartment.

When the demo test units were completed by Ogle models, the thermoelectric device was installed and testing was carried out using a PICO Data Logger. The PICO TC-08 was used to measure temperatures in different locations of the system, it has eight different channels which could record temperatures from -270°C to 1820°C which was more than sufficient for SSGB's application. The data logger also came with a very simple and easy-to-use software application, which can create graphs and record all raw data in an excel spreadsheet format. All of the tests can be found within the 'Testing' section.

This system was installed into one of the test rigs, which was originally built by the prototype builders and tested. This test rig could either be used on a bench or installed into the R&T integration test rig, which allowed different variations to be tested in a representative environment.



Figure 18 - Test Rigs Mid-Build



Figure 19 - R&T Integration Test Suite

Once the testing of the first version thermoelectric system was complete, some modifications were made to introduce another fan to the system, in the hope of providing better air circulation.

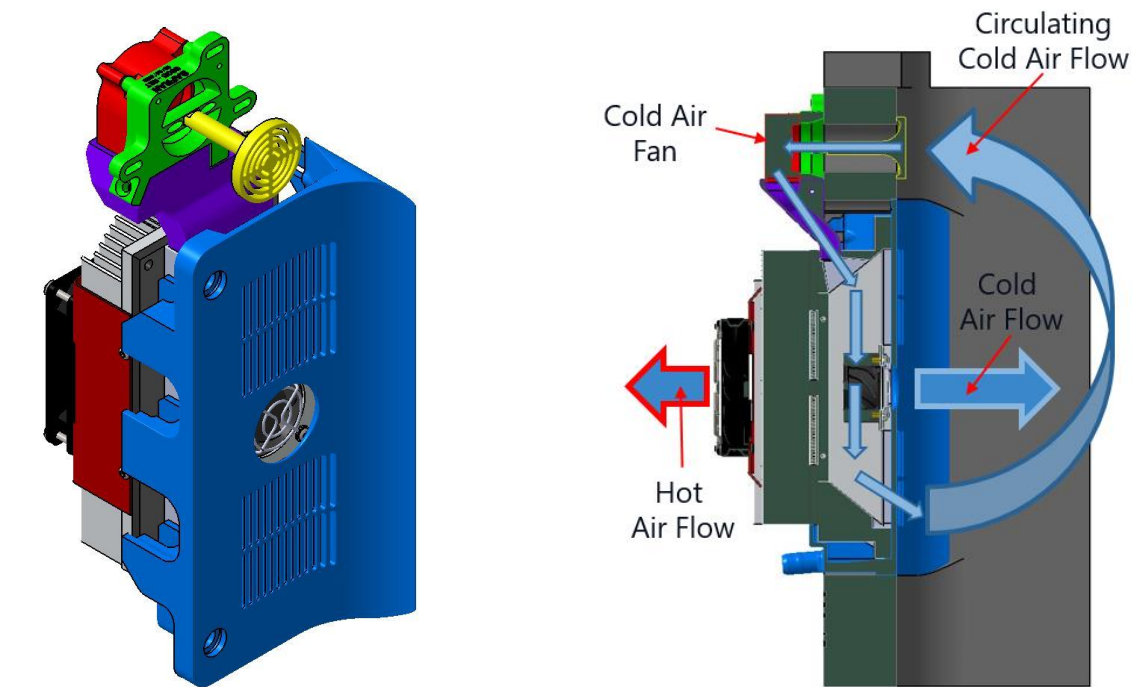


Figure 20 - Second Version of Thermoelectric System with New Fan Installation

From Figure 20, the new fan at the top of the system draws air in from the top of the cooled compartment, then directs the same air back over the cold side heat sink, which the fan will

blow directly back into the compartment. By adding this fan, the cold air was effectively being re-used and cooled again, decreasing the temperature of the air on each circulation of the cooled compartment. To ensure the air was directed back down the cold side heat sink, a 3D printed section was printed to attach to the fan exit, down to the heat sink. The tests were conducted again to see if this modification had any improved effects on the results. The data sheet for the fan can be found in Appendix 7.

Weight is a crucial factor in every section of aerospace as this can increase operating costs significantly, by adding large amounts of weight onto an aircraft.

The weight estimations for the thermoelectric are as per the numbers below however, these will need to be optimised even more for a production solution.

Front piece = 573.7g

Back piece = 500g

Ali spacer = 305g

Thermoelectric device with connectors = 750g

Three bottle shelf = 392g

The weight of the composite structure will depend on the location of the thermoelectric device and other factors such as adhesives and fixings.

After completing all of the tests, a new chiller test rig was created so that the thermoelectric device could be installed in the top of the unit. This decreased the overall internal volume of the compartment, requiring less air to be cooled. This test rig also allowed SSGB to be able to work with a new supplier called Micronel. They are a Swiss company that produce miniature fans and blowers, which can assist in reducing the overall size of the thermoelectric system. Micronel provide a lot of fans and blowers for medical applications, which automatically gave the impression of reputable and reliable products. Some of the new fans which were demonstrated to SSGB provided much a much faster air flow and pressure.

After working with Ciaran Doherty and Michael North, a top mounted design test rig was created utilising Micronel fans. The new design looked completely different to the first version which was side mounted.

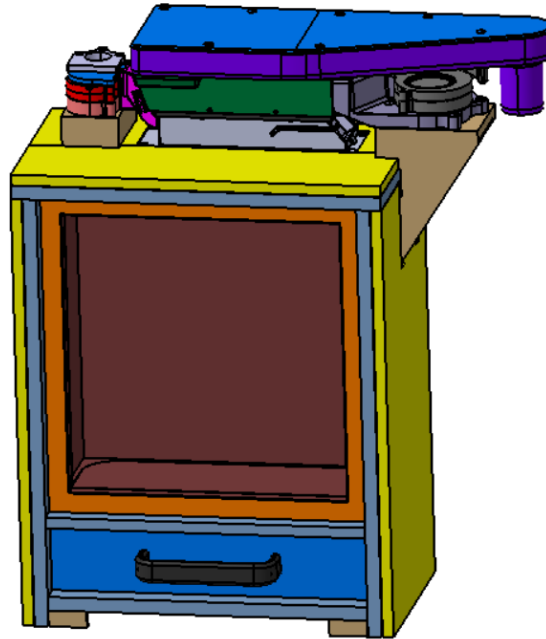


Figure 21 - Top Mounted Cooled Compartment Test Rig

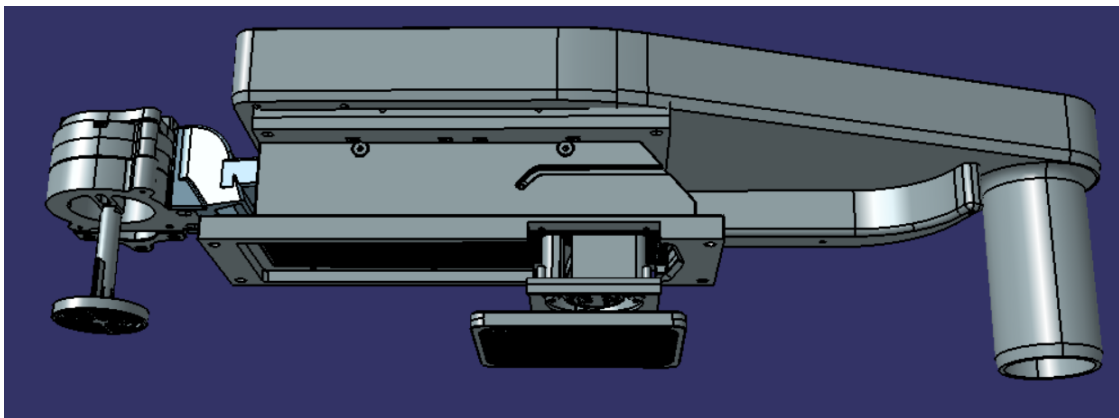
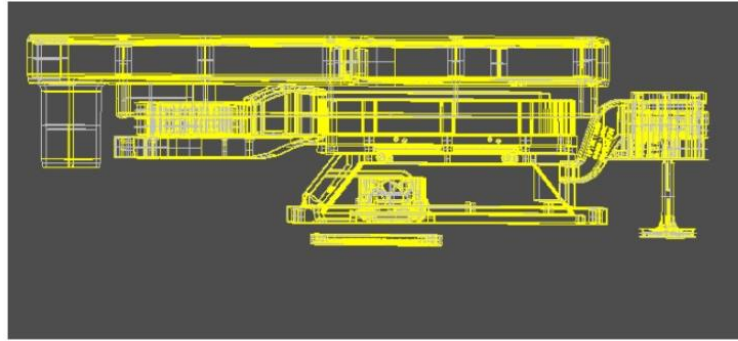


Figure 22 - Top Mounted Cooled Compartment Test Rig

As Figure 21 demonstrates, the internal dimensions have been shrunk to 290.5mm x 145.2mm x 298mm, which was a reduction from the first version, mainly in height. The capacity of three bottles is still the same, but the surrounding area had been reduced to help aid the cooling of the compartment, also reducing the amount of air required to be cooled. The test rig will be manufactured from 0.5 inch composite to further advance the production solution. The yellow surfaces seen in Figure 21 are the Zotek foam sections which retain the cold air within the compartment.

Original



Micronel
suggestion

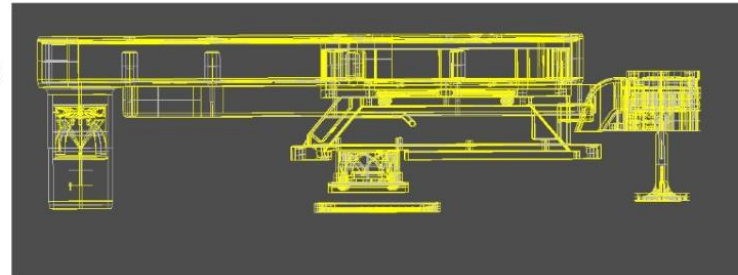


Figure 23 - Micronel Optimisation of SSGB Original Solution

Micronel then took SSGB's suggested design and modified it so that less fans were required. They suggested using a D-line fan which are very powerful. Instead of using a fan to blow hot air over the heatsink, then a fan at the entrance of the exhaust to exit the air, the D-line fan will be able to pull the air over the heatsink then exit the air through the outlet side of the fan. This will help remove one fan from the Bill of Material (BOM) when it comes to production and also helps to reduce the height of the unit, allowing more space for air flow in the top mounted solution.

Due to time constraints, the top-mounted solution was not able to be fully tested to provide full confidence for taking it to AIX24. It was then decided that the side-mounted solution would be implemented into the show suite to demonstrate to customers, then the top-mounted solution could be shown in a more optimised and production ready state for AIX25.

Below are some images of the finished prototype for the top mounted system. Integrated into this is a realistic magnetic seal for the door, this will assist in retaining as much cold air as possible. There are access hatches to install insulation foams, fans and drinks within the compartment. This prototype will be tested after the AIX24 show to develop and mature as a full system.



Figure 24 - Top-mounted Cooled Compartment Prototype



Figure 25 - Space Envelope for Top Mounted Thermoelectric Device System

To prepare the cooled compartment to be show ready, the fridge was painted and installed into the PAX4.0 suite, making the installation look neat and flush to all of the surrounding surfaces. An overlapped mesh background was also implemented to make the compartment aesthetically pleasing and provide a good background for the drinks on show.

The final modifications for the cooled compartment were to install sensors and lighting in the shelf which the drinks stand on. The weight sensors were part of demonstrating more functionality of SSGB's 'connected system', which help cabin crew offer better service by being alerted when the drinks are almost or fully empty.

Small spotlights were installed under the bottles so the light can shine upwards through the glass, resulting in a premium looking setup which would catch customer's attention straight away.

6.1 Calculations

It was important to carry out some calculations to determine some estimated values on how much energy the system would require, to get the cooled compartment from twenty degrees Celsius (which is the average temperature within the cabin) down to eight degrees.

Firstly, the internal volume of the cooled compartment had to be calculated, so the dimensions were taken from the CAD file on CATIA V5.

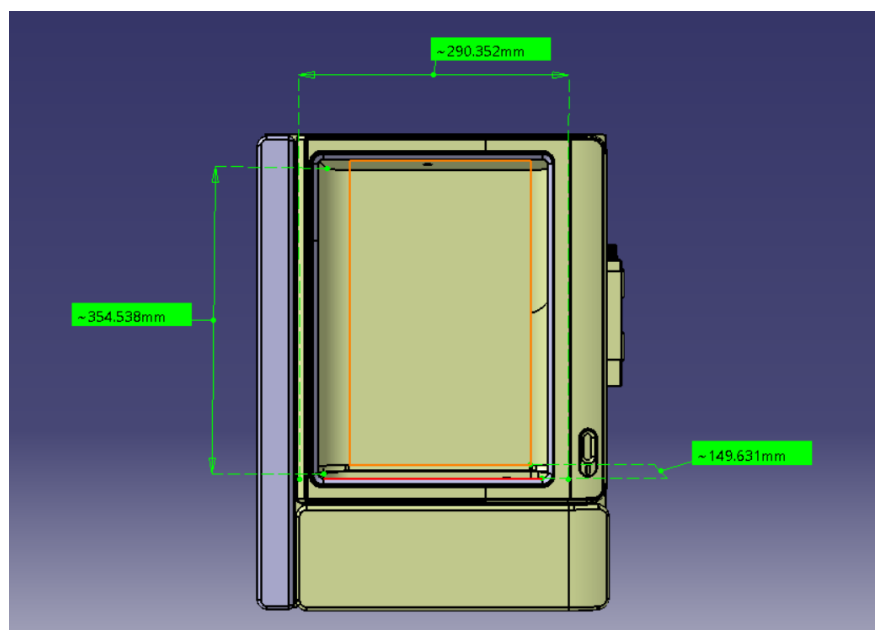


Figure 26 – Internal CAD Dimensions of Cooled Compartment

$$\text{The internal volume of the compartment} = \frac{290.3mm}{1000} \times \frac{149.6mm}{1000} \times \frac{354.5mm}{1000} \approx 0.01567m^3$$

Due to the nature of aircraft, the mass of the air inside the cooled compartment will be more than when it is cruising at 40,000ft. This is because even though aircraft are pressurised to 6,000ft - 8,000ft, the density in the cabin will still be less while the aircraft is cruising, than it will be while on the ground (Monroe Aerospace, 2020). This indicated that the system would require more energy to decrease the temperature, while the aircraft was on the ground. The mass of the air on ground is approximately $\rho=1.293 \text{ kg/m}^3$ (0.0202Kg) as told by UBC ATSC (2019), then while cruising and the cabin is pressurised to 6,000ft, it is approximately $\rho=0.95328 \text{ kg/m}^3$ (0.01493kg).

To calculate the worst case scenario, the plastic water bottles of water needed to be used within the calculation. This is due to the aluminium and glass being better thermal conductors than the plastic. The aluminium and glass bottles also help to keep the contents of the bottle cooler for longer. The mass of a 500ml water bottle is 500g. The specific heat refers to how much heat is required to raise the temperature of a single gram by one degrees (Gregersen, 2023). The specific heat of water is $4182 \text{ J/Kg}^\circ\text{C}$, and the specific heat of air is $1005 \text{ J/Kg}^\circ\text{C}$. These values could then be transferred into the equation to find out the total energy required, for cooling the air on ground, while cruising and cooling a water bottle from 20°C to 8°C .

$$\text{Air in compartment (on ground)} = Q_{ground} = m_{ground} \times c_{ground} \times \Delta T_{ground} = 243\text{J}$$

$$\text{Air in compartment (cruising)} = Q_{cruising} = m_{cruising} \times c_{cruising} \times \Delta T_{cruising} = 180\text{J}$$

$$1x \text{ water bottle} = Q_{water} = m_{water} \times c_{water} \times \Delta T_{water} = 25.14\text{KJ}$$

To calculate the energy required for the smaller top-mounted version, the new internal volume will need to be considered in the calculations.

$$\text{The new internal volume} = \frac{290.5mm}{1000} \times \frac{145.2mm}{1000} \times \frac{298mm}{1000} \approx 0.0125^3$$

Assuming that all other values of the previous calculation stayed the same, the system had an improved efficiency as less air required cooling, as the internal volume of the compartment has decreased. The smaller internal volume also had an advantage of having less surface area for air to escape from the compartment.

7. [Testing](#)

To ensure there was a systematic approach to the testing, also making sure no time was wasted, research was carried out into Design of Experiments (DoE). As More Steam (2023) describes, this method is used to plan, conduct and then analyse controlled experiments, which can then be used to compare and optimise systems. Using DoE was important to identify variables that could be controlled, also have a factor on how the system operates.

Due to only having two prototypes, it was important to ensure that these hardware devices were running at the correct current and voltage so they could be well maintained and not potentially damaging the devices. Running the hardware devices at higher and lower voltages were not the main tests, as these fans and thermoelectric device have all been optimised so they run the most efficient at the stated voltage and current.

From this, a test plan was created to log how the tests should be carried out. The tests involved:

- A. Changing the ambient temperature (Low: 15°C - 19°C), (Medium: 20°C - 24°C)
- B. Changing the insulation thickness stack-up around compartment (5mm, 10mm, 15mm)
- C. Changing the location of the thermoelectric device (Side mounted, top mounted)
- D. Changing the contents of the cooled compartment (Plastic bottles, Glass bottles and Aluminium cans)

These tests were carried out a total of three times each to account for repeatability, verifying that the tests are free from anomalies and errors.

7.1 [Changing Ambient Temperature](#)

For testing the unit in a representative environment, the ambient temperature should be between twenty-two and twenty-five degrees Celsius. To achieve this, the tests were carried out in the aircraft simulator in SSGB where the temperature can be controlled via an air conditioning unit.

The unit was also tested in a colder workshop environment to compare how much colder the compartment got by changing the ambient temperature.

7.2 [Changing Insulation Thickness](#)

To help retain the cold air within the compartment and to stop any leaks, insulation foam was used to aid this however, the thickness which was required for best effect was not clear. Thicknesses of 5mm, 10mm and 15mm were used to compare each thickness. 20mm insulation foam was on longer lead times from the supplier, so this thickness can be tested in future work.

To test the different insulation thicknesses, they had to be ordered then cut to the dimensions of the exterior of the unit. They were then secured to the exterior of the compartment to act as an insulator. The aim of the tests were to see which thickness could help achieve the target temperature. Too much thickness would have added unnecessary weight to the system and taken up more space when installed within a suite.

Increasing the thickness of insulation can enhance the thermal insulation properties of the compartment, reducing heat transfer between the interior of the compartment and the external environment. This can result in improved temperature stability and reduced energy consumption of the cooling system, as less cooling capacity is required to maintain the desired temperature.

7.3 [Changing Location of Thermoelectric Device](#)

To optimise the system, the thermoelectric device was mounted in the side and top of the compartment to see which performed better. These were the only locations in which the device could be installed due to space constraints, so it was important to compare these thoroughly. Various designs were created to be able to account for various factors such as maintenance accessibility, condensation, moisture management and temperature distribution.

7.4 [Changing Contents in Compartment](#)

The contents within the cooled compartment such as plastic bottles, glass bottles and cans were changed as all of these materials have different thermal conductivity properties. It was important to measure the temperature of the fluid in different materials, as the thermal conductivity of each plastic, glass and aluminium is different. The cans were likely to get colder quicker than the glass and plastic due to having a better thermal conductivity. The glass and aluminium were likely to stay colder for longer, once removed from the cooled compartment

due to the material characteristics and can typically reach the same temperature rise in a similar time frame (Bailey & Elban, 2008).

7.5 System Electrical Architecture

The electrical architecture that was used when carrying out all of these tests can be found in Appendix 8. The junior controller can be used to set target values, then the controller will provide adequate current to achieve that set target as informed by European Thermodynamics Limited (2017). This was also connected to a laptop to be able to use the junior controller software, where the set points were input manually.

For the production solution, the thermoelectric device will be powered by the ECU which will transform and filter the aircraft power to the required 28V to run the thermoelectric system. Figure 25 demonstrates the simple architecture of the thermoelectric device.

UNIT UNDER REVIEW

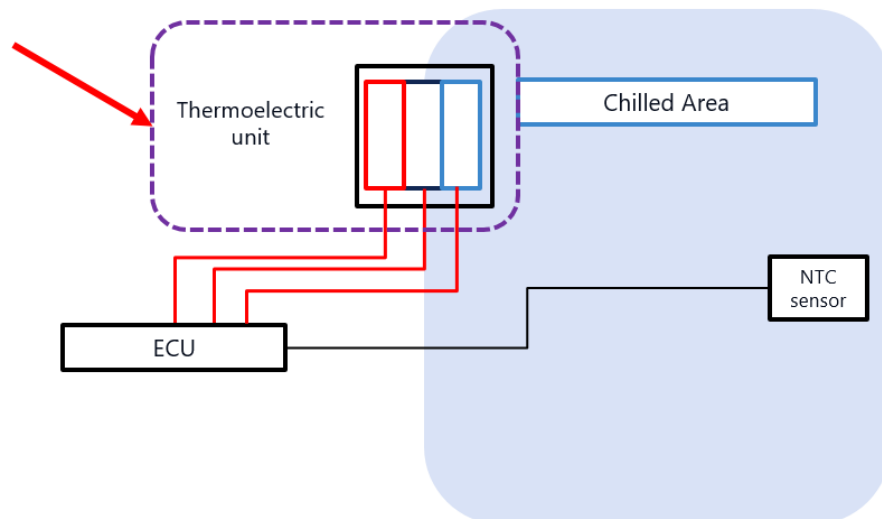


Figure 27 - Production Electrical Architecture

To find a location for the hot air to be exhausted to, it must either have acted as a cooling flow for an already hot area, or have been routed to a large open space to stop heating up any other surfaces of the suite to high temperatures. This could have had effects on some glues and adhesives used within the suite. To see if the hot air could act as a cooling flow, the temperature under the seat was measured as that is where the ECU's and electrical hardware are installed. If the exhaust air can act as a cooling air flow, it will help maintain cooler temperatures for the electrical hardware.

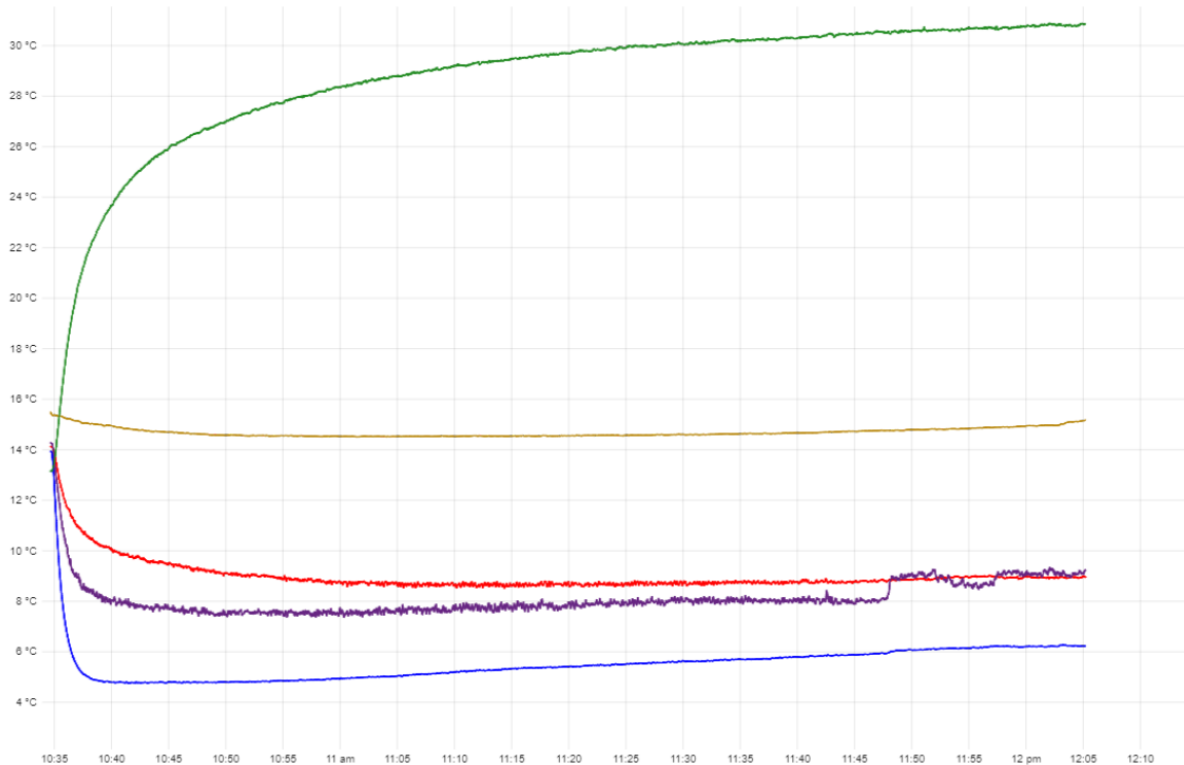
The temperature under the seat structure got to temperatures of 32°C to 34°C next to the ECU and comfort system pumps. This coincided well with the hot air exhaust gases exiting from the thermoelectric device. The hot air is able to be pumped under the seat without increasing the temperature and provides an easy route for exhaust piping to be implemented.

8. [Discussion of results](#)

8.1 [Test 1 – No insulation in a cold workshop](#)

PicoLog

Jan 24, 2024 12:18 PM



Channel configuration

■	Cold Side Heat Sink (Internal)	AO130/159 1 Type K	1s - Average
■	Far Side (Internal)	AO130/159 2 Type K	1s - Average
■	Ambient Temp	AO130/159 3 Type K	1s - Average
■	Centre (Internal)	AO130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	AO130/159 5 Type K	1s - Average

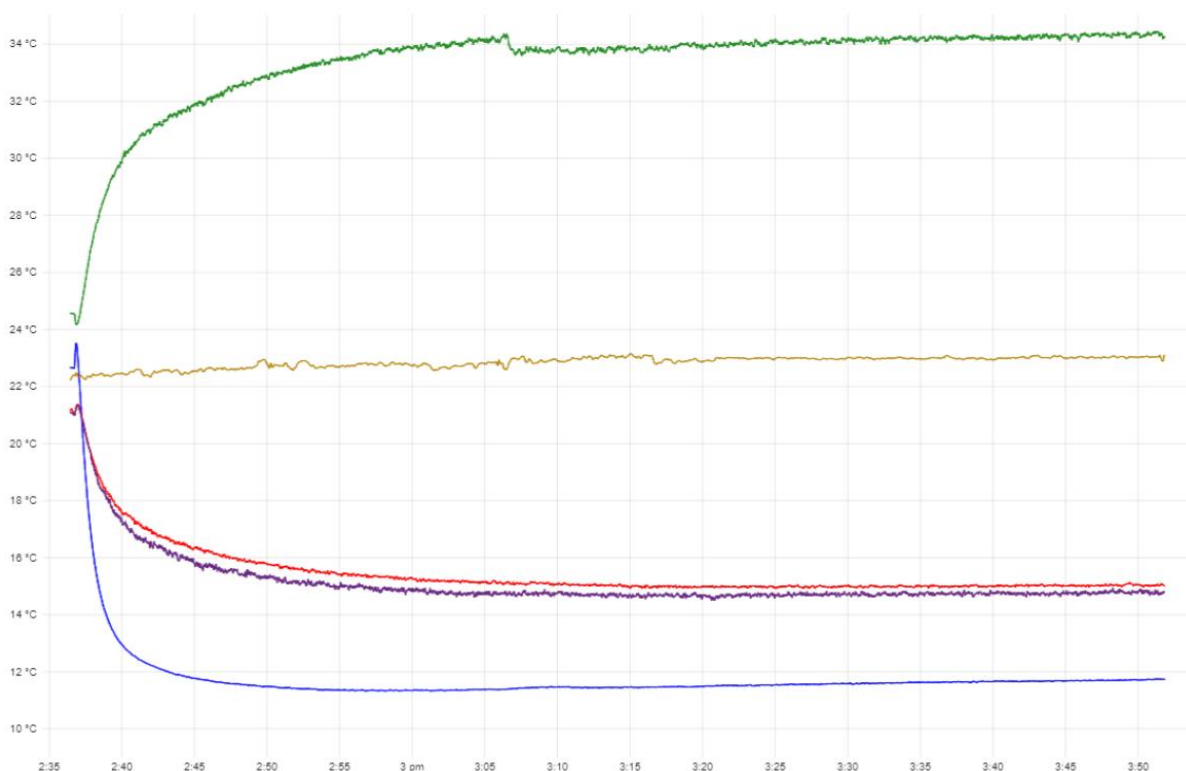
[Figure 28 - Test 1 - Empty Compartment With No Insulation in Cold Environment](#)

In Figure 28, this was the first test that was carried out on the cooled compartment. The compartment was empty and had no insulation surrounding the exterior of the compartment. This was planned to see how much cold air could be retained within the compartment as a baseline without any insulation. The first tests were conducted in a cold workshop with an ambient temperature of 15°C. This is 8°C below the ideal temperature for testing as an aircraft cabin temperature is maintained at 22°C - 24°C in 'normal conditions' according to Korean Air (2024). It's visible from the graph that there was a significant temperature drop within the compartment in the first ten minutes. The temperature started to creep back up which could suggested that the internal volume could be too large to be cooled sufficiently, without some form of insulation material. This test was repeated three times to ensure that the results were valid and there were no anomalies within the results. The other two test graphs can be found in Appendix 9 and 10. Due to the cold ambient temperature, it was important to see how much

of an effect this had on the cooling of the compartment so the next trial was to move the demo unit into a warmer environment which can be controlled by a thermostat.

8.2 Test 2 – No insulation in representative aircraft cabin temperature

When testing the thermoelectric device at an ambient temperature of 22°C, the performance of the thermoelectric device did not perform as well as when in a cold environment. The ambient temperature is a very important factor, as the thermoelectric device could only decrease the temperature by a certain amount below room temperature.



Channel configuration

■	Cold Side Heat Sink (Internal)	AO130/159 1 Type K	1s - Average
■	Far Side (Internal)	AO130/159 2 Type K	1s - Average
■	Ambient Temp	AO130/159 3 Type K	1s - Average
■	Centre (Internal)	AO130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	AO130/159 5 Type K	1s - Average

Figure 29 - Test 1 - Empty Compartment With No Insulation in Aircraft Ambient Environment

Comparing Figure 28 to Figure 29, it shows that as the ambient temperature increased, the effectiveness of the thermoelectric device decreased. As the ambient temperature has increased by 7°C, the lowest temperature achieved by the thermoelectric device was

approximately 12°C. This result does not meet the required target of five to eight degrees however, these tests also had no insulation installed.

8.3 [Test 3 – Additional fan setup in aircraft ambient temperature](#)

The next test which was carried out was with the extra fan being installed on the top of the unit. These were carried out at aircraft cabin temperatures as they are the most representative conditions.

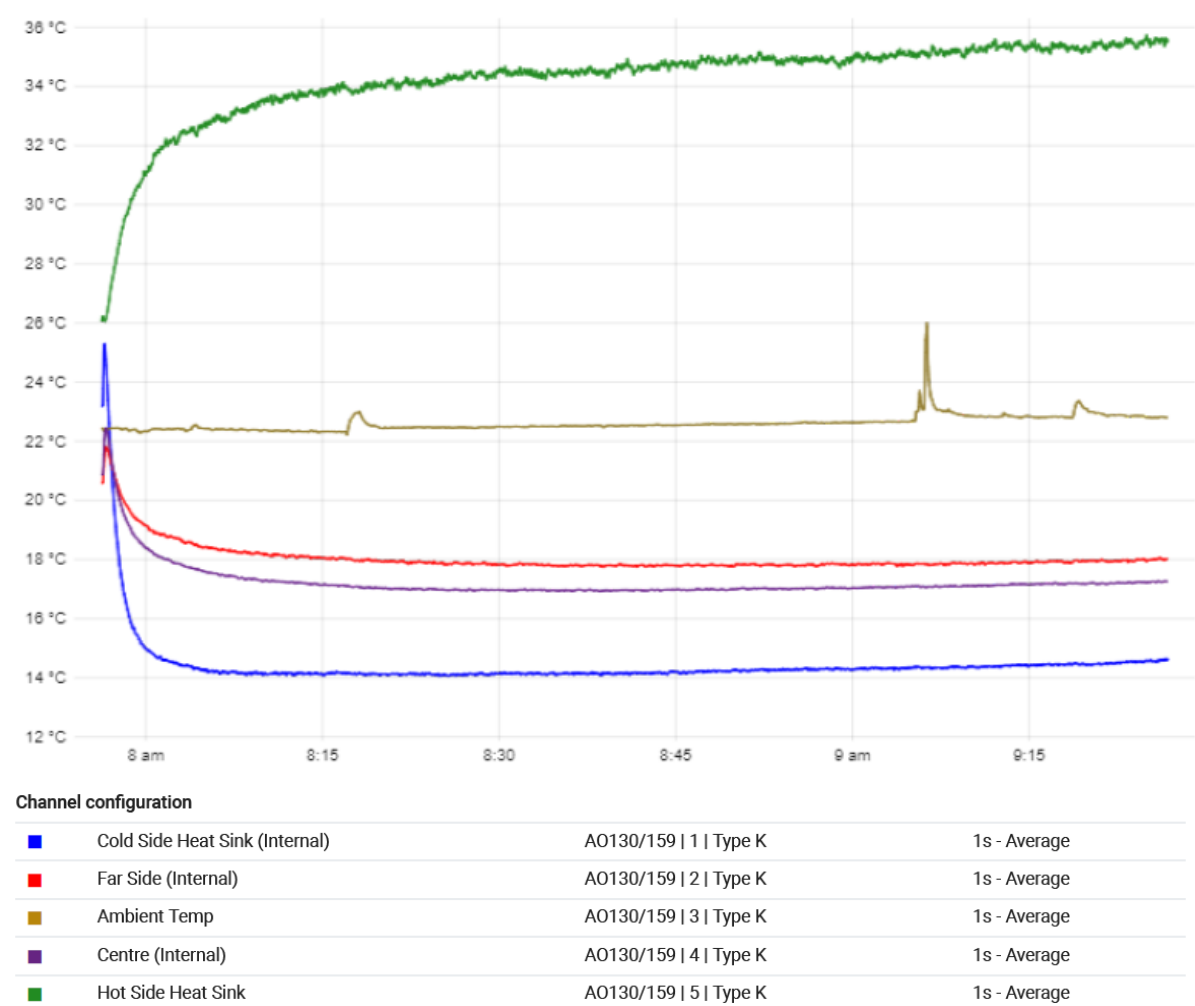


Figure 30 - Additional Fan System Test 1

The first test carried out showed a surprising result as the temperature did not decrease as expected. After carrying the test out two more times, the results were very similar which were disappointing. After some investigation into the system, a conclusion was made that the space the system is installed in is too small. This small space envelope meant that the hot air builds up in the area and it's then much harder to circulate cold air. This also meant that another

solution had to be created for exhausting the hot air to a suitable location, as it was just accumulating around the thermoelectric cooler system, which affected the efficiency quite dramatically. The other two tests for this set up can be found in Appendix 11 and 12.

8.4 Test 3 – Additional fan setup in aircraft ambient temperature

To test that this was having a negative effect, the removable panel to the thermoelectric device was removed while another test was carried out. Removing the panel allowed the hot air to exit the enclosure and prove it was having an effect on the efficiency. An image of the panel can be found in Appendix 13.

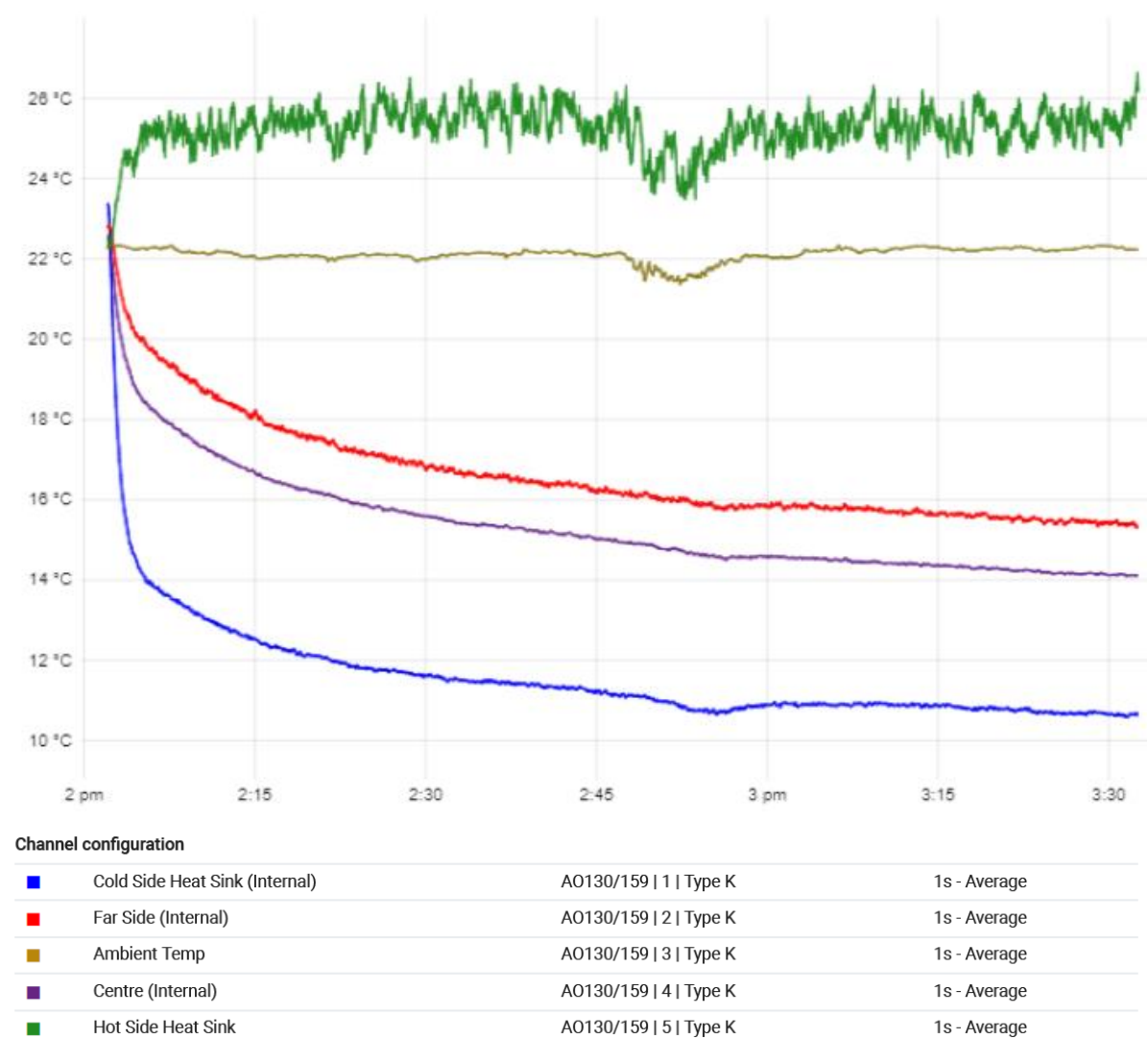


Figure 31 - Removing Back Panel For Ventilation

Comparing the test results in Figure 31 and Appendix 14 and 15, after an hour and thirty minutes, the temperature was still decreasing towards two degrees lower than previous tests when the back panel was installed. This indicated a good step which could be optimised to help lower the temperature by a couple of degrees.

8.5 Test 4 – Cooling plastic aluminium and glass bottles

To investigate if there was a better material to use for the container of the fluid, plastic, aluminium and glass bottles were inserted into the fridge and tested at the same time to measure the rate of cooling for each. From the results below, the rate of cooling was quite consistent with only 1.5°C being the maximum difference between all different materials. This difference could have been due to the locations of the containers as one would have been closer to the fan side of the compartment, the other would be further away due to the layout of the drink shelf.

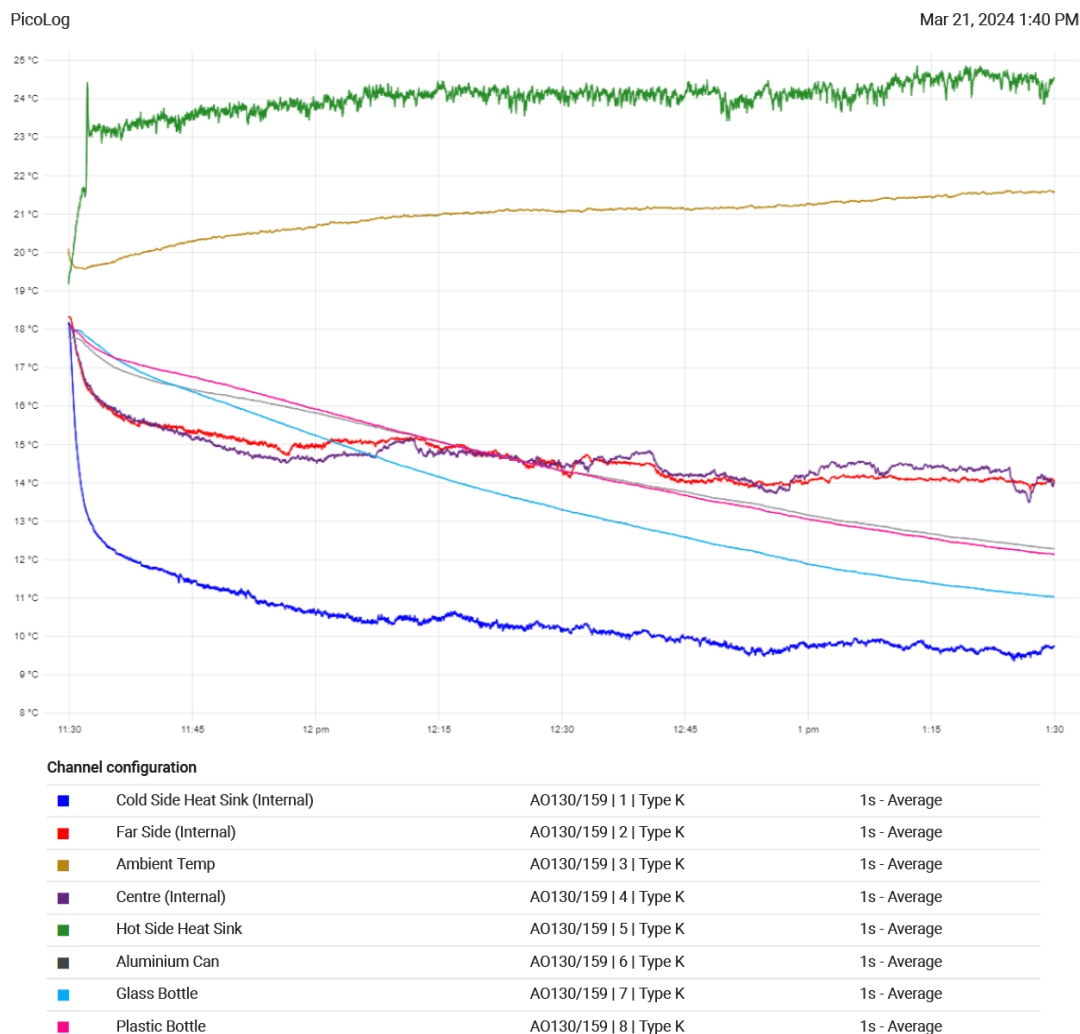


Figure 32 - Three Different Material Fluid Containers

The two additional tests can be found in Appendix 16 and 17.

To then determine the heat transfer of each container, the Peltier device was switched off and the bottles were left in the compartment for two hours, to see how much the temperature of the fluid increased. The results below demonstrates how the temperature of the fluid only increased by 1.5°C over two hours, so it would take a couple of hours for the bottles to get back to ambient temperature, as long as the door to the cooled compartment was closed.

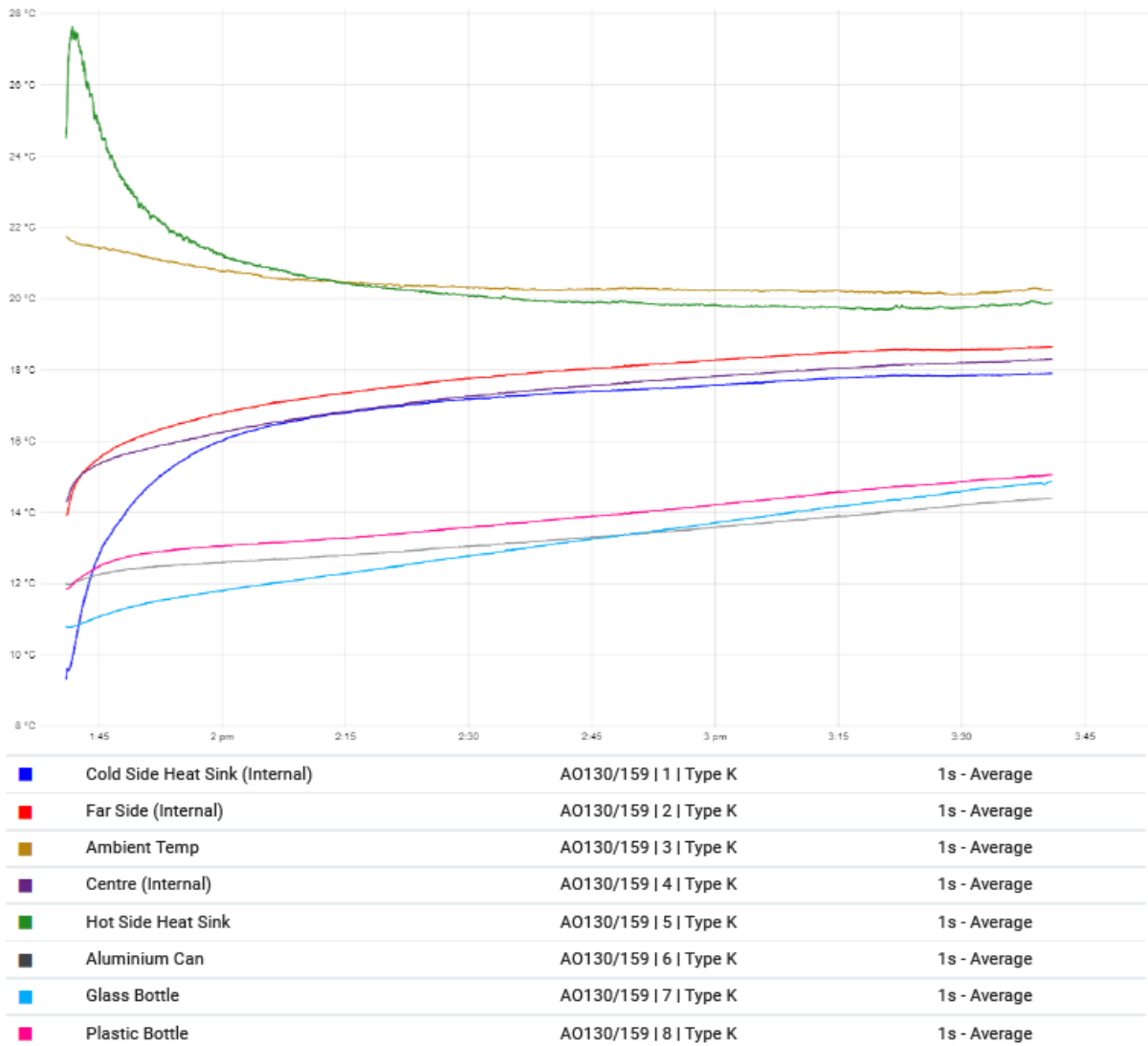


Figure 33 - Fans Turned Off For Drinks to Return to Ambient Temperature

The remaining two tests that consisted of leaving the bottles to return back to ambient temperature for two hours can be found in Appendix 18 and 19.

8.6 Test 5 – 5mm Plastezote foam installed

To stop the cold air escaping from the compartment, an insulation foam was installed around the external walls of the compartment. This also helped to block any small orifices from joints or fixing points. The Plastezote foam helped to retain the cold air within the compartment so the same air could be re-circulated and cooled through every cycle.

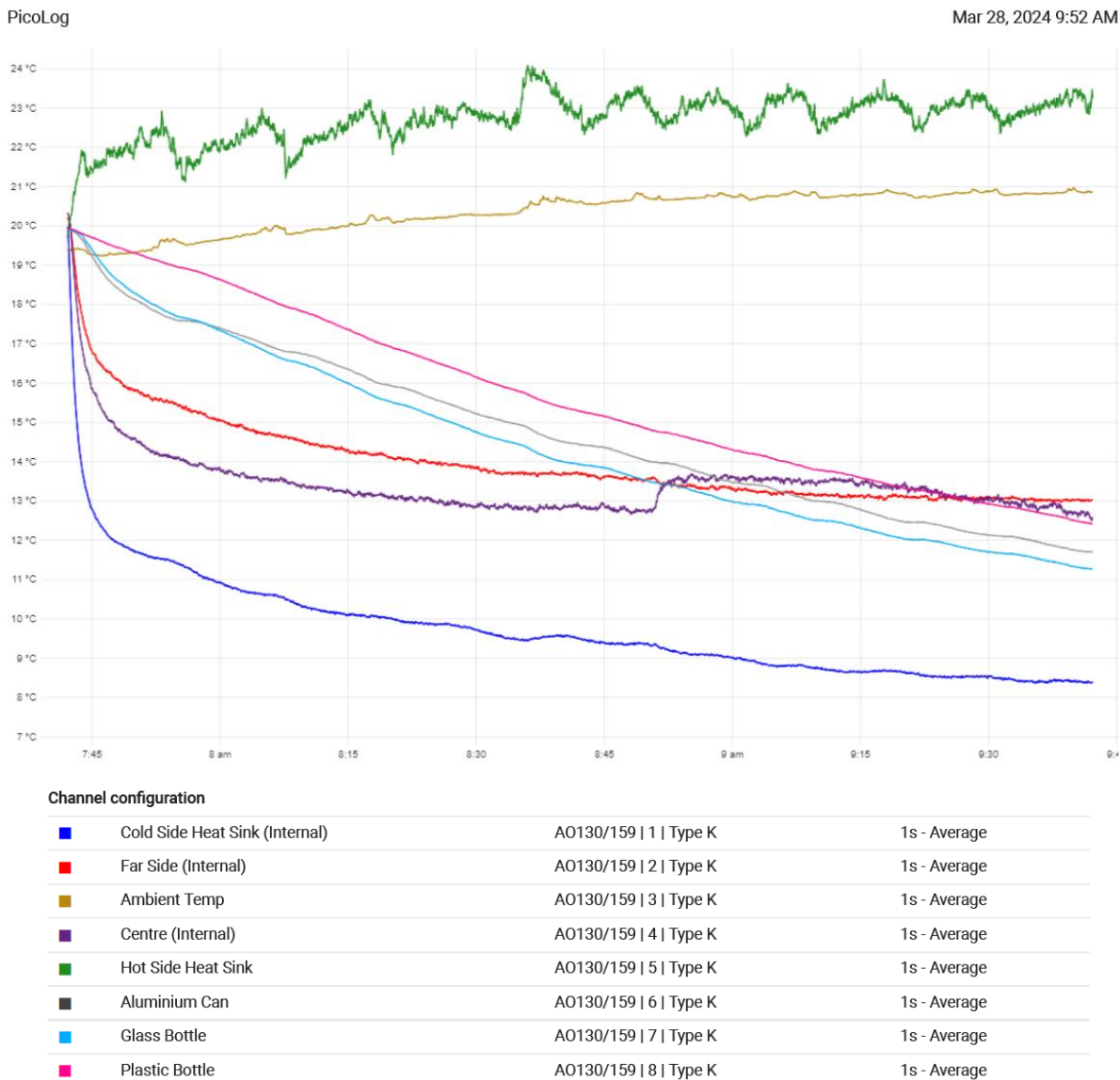


Figure 34 - 5mm Plastezote Foam Installed

As seen in Figure 34, there was a small temperature decrease of 1.2°C from 8.3°C with the 5mm insulation, compared to 9.5°C without the insulation. This provides evidence that the insulation reduces the amount of convection heat transfer in the compartment. The time it took to reach below nine degrees Celsius took one hour seventeen minutes.

The two additional tests for repeatability can be found in Appendix 20 and 21.

The three drinks were then left for two hours to return to ambient temperature, to see how the insulation effected the retention of cold air, and to determine if the drinks would stay colder for longer.

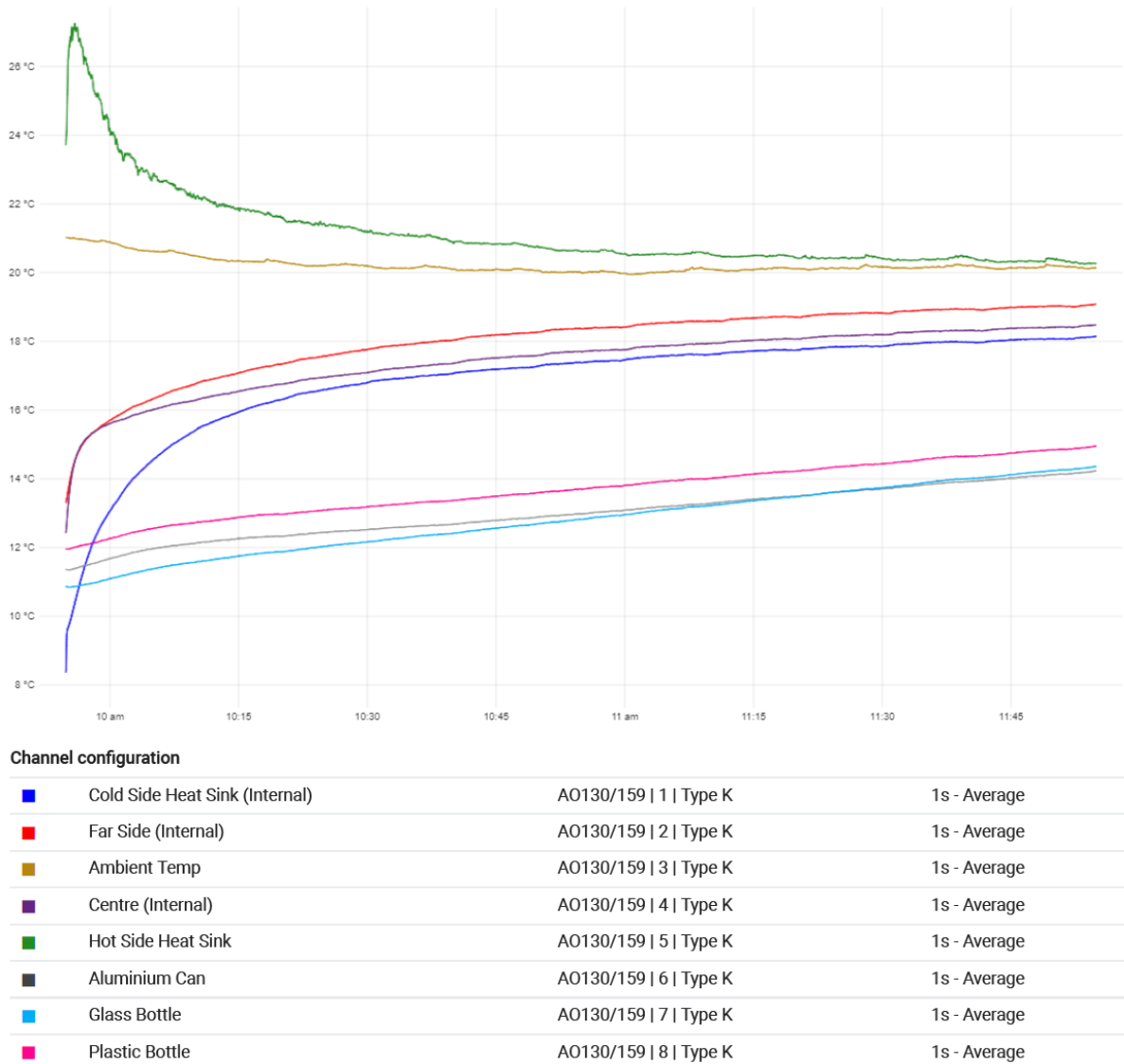


Figure 35 - 5mm Foam Insulation - Drinks Returning to Ambient Temperature

The two additional tests for reliability can be found in Appendix 22 and 23.

All three of the containers had a similar rate of change when returning to ambient temperature. The aluminium and glass container retained the cold fluid longer than the plastic bottle. The plastic and glass bottle temperature increased roughly three degrees after two hours, while the aluminium can increased 2.4°C in the two hours.

8.7 Test 6 – 10mm Plastezote foam installed

Once the 5mm insulation was tested, 10mm insulation was installed to compare the results, and how much heat transfer was reduced between inside and outside of the compartment. The extra insulation thickness really helped to improve the reduction in heat transfer, this can be seen from Figure 36. The 10mm insulation assisted the compartment in reaching 6.8°C which is well within the targets SSGB initially set out to achieve. The increased insulation thickness will also aid in reducing some of the noise generated from the system.

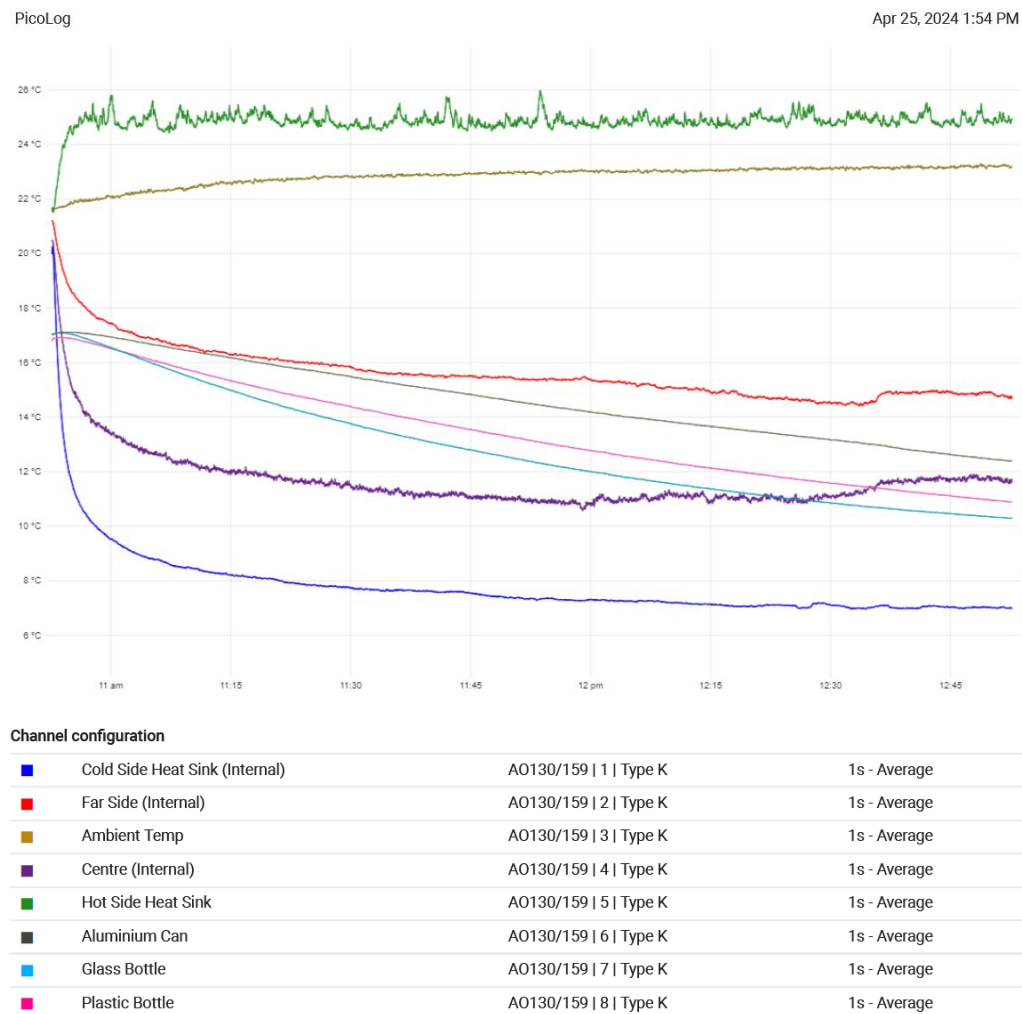


Figure 36 - 10mm Insulation Installed

The drinks initial temperature was approximately 20°C, which ended up between 12°C and 13°C. This is a suitable temperature for the fluid as it felt chilled and pleasant to drink however, this will be subjective to each person's preference.

The cold side of the heat sink achieved a temperature below nine degrees Celsius in the first ten minutes. This meant that the fluid within the containers could start to cool down at a quicker rate and sooner.

The additional tests can be found in Appendix 24 and 25.

The drinks were then left for two hours, to identify how the different fluid container materials handled convection heat transfer. From the graph below, it indicates how the aluminium can is a good conductor of heat, meaning it can quickly transfer heat from one place to another. However, it does not facilitate convection as readily as glass or plastic, because it does not allow for the same kind of fluid movement. Glass and plastic, being insulators, tend to trap heat more effectively and allow for more convection to occur within them.

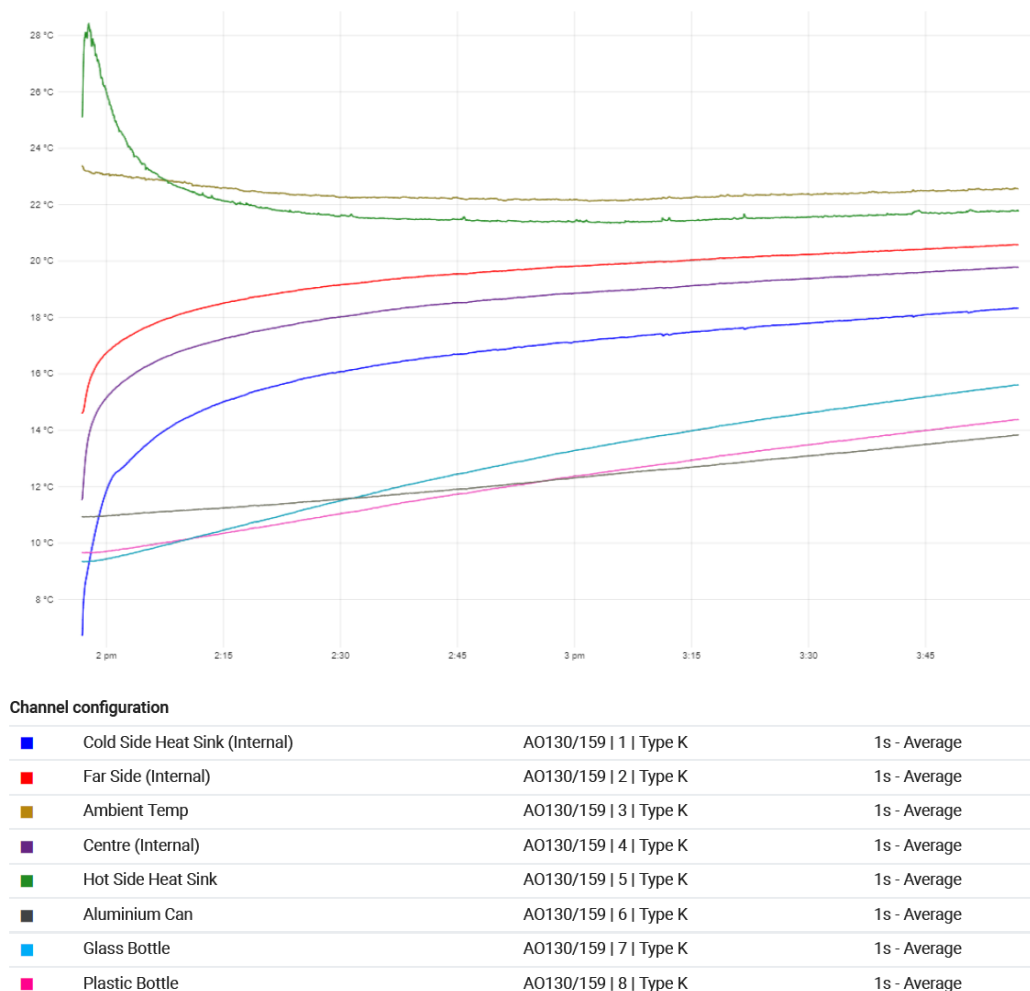


Figure 37 - 10mm Foam Insulation - Drinks Returning to Ambient Temperature

The additional tests can be found in Appendix 26 and 27.

As can be seen from Figure 37, the plastic bottle and glass bottle reached a similar temperature of 9.7°C while the aluminium can only reached 11°C. After switching off the thermoelectric device for two hours, the aluminium can was the coldest of all containers. This could have happened because although Aluminium cans have a higher thermal conductivity, the containers react to the temperature of the compartment. Due to the plastic and glass containers being at a colder temperature than the aluminium can, the rate of change in temperature will be greater in the glass and plastic containers.

8.8 Test 7 – 15mm Plastezote foam installed

Due to long lead times, the 15mm Plastezote foam was unavailable to be tested as a single thickness foam. To get around this, a 5mm and 10mm thick section of foam were stuck together to make the 15mm stack, required to compare the impact of different insulation thicknesses. The results displayed below demonstrate that the extra thickness of insulation did not benefit the heat retention of the compartment massively. The cooling rate to reach below nine degrees Celsius was nineteen minutes. This was eleven minutes slower than the 10mm insulation, the lowest temperature within the two hours was 7.2°C compared to 6.9°C with the 10mm insulation.

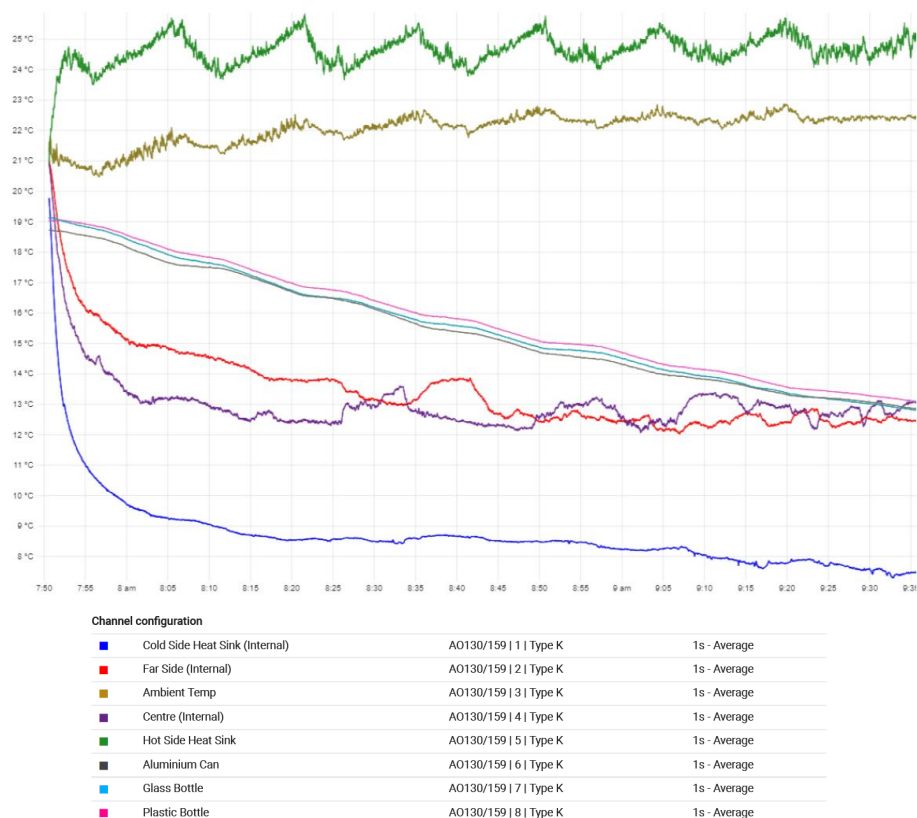


Figure 38 - 15mm Insulation Foam Installed

As a result of limited testing time and long lead times on the 20mm insulation sheets, it was decided the 10mm insulation was the most optimal for the desired application. The 20mm insulation would have required a lot of extra footprint within the suite which is rarely available. After proving that 10mm is sufficient enough to meet the specified requirements, the thicker material would start to add unnecessary weight to the product, which could affect the customers appeal for installing the system on their aircraft.

8.9 [Comparison of insulations](#)

To visually display how the different thicknesses compared to each other, the graph below in Figure 39 shows how the 10mm thick insulation foam outperformed the 5mm and 15mm thickness insulation. It reached below nine degrees Celsius in the quickest time, reached the lowest temperature of all, also maintained a steady decrease in temperature throughout the two hour tests.

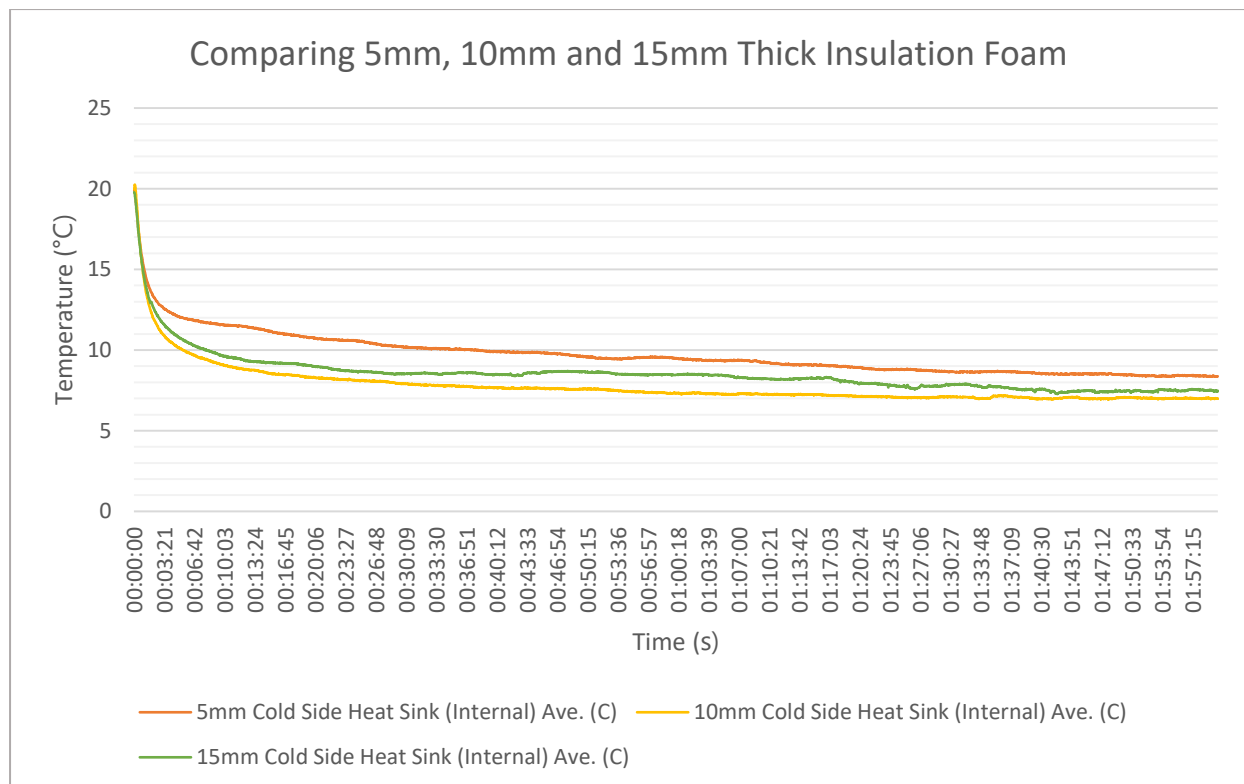


Figure 39 - Comparing 5mm, 10mm and 15mm Thick Insulation Foam (Cold Side)

8.10 Complete Prototype

For AIX24, ensuring a high-quality finish was paramount in the design process. The images below vividly depict the professional, modern appearance of the cooled compartment, highlighting its seamless integration with the aircraft's interior aesthetics. Every aspect, from the sleek contours to the premium finishes radiates sophistication and functionality. Moreover, the emphasis on attention to detail guarantees not only an aesthetically pleasing design, but also optimal performance in maintaining the desired temperature for stored items.



Figure 40 - Internal Images of Cooled Compartment



Figure 41 - Internal Images of Cooled Compartment with Lighting



Figure 42 - Internal Images of Cooled Compartment with Bottles



Figure 43 - Integrated Cooled Compartment

9. Conclusion

The series of tests conducted on the thermoelectric cooling system provided valuable insights into its performance under various conditions.

The first test, Test 1, was conducted in a 'cold' workshop without insulation. It established a baseline for temperature retention within the compartment. Subsequent tests demonstrated the impact of ambient temperature on the system's efficiency, with Test 2 highlighting a decrease in performance at higher temperatures.

Introducing an additional fan into the system, initially seemed promising, but the test revealed limitations due to spatial constraints. This led to a re-evaluation of ventilation strategies. Removing the back panel of the system to increase ventilation, showed that there was potential for improving the efficiency of the system due to the resulting heat dissipation.

Investigations into the use of different container materials used for the storage of the cooling fluid, indicated that there were minimal differences in cooling rates – this, with insulation playing a crucial role in maintaining cold temperatures over extended periods.

The implementation of insulation, particularly the 10mm Plastezote foam, significantly improved temperature retention within the compartment, with the target temperatures being met effectively. Further tests confirmed the efficacy of 10mm insulation and highlighted practical considerations regarding thickness and weight.

Overall, these tests provided valuable data for optimising the thermoelectric cooling system, ensuring its effectiveness and practicality for real-world applications, particularly within aircraft environments. Further refinement based on these findings, will enhance the system's performance and customer satisfaction.

10 [Recommended further work](#)

Future recommendations for work following the AIX event encompass several key areas aimed at enhancing the production solution and functionality of the system. These recommendations are outlined below:

Production representative article: Develop a comprehensive production representative article that integrates all production materials, retention mechanisms, door locking latches, and foam insulation materials. This article will serve as a tangible representation of the final product, allowing for thorough evaluation and validation of its design and functionality.

Integration of junior controller: Incorporate a junior controller into the system to regulate the operation of the fan, based on the position of the door. By implementing this control mechanism, the system will be able to optimise energy efficiency and maintain optimal temperature conditions within the compartment.

Gasper valve for suite ventilation: SSGB should look at installing a gasper valve to facilitate ventilation in suites from the exhaust air from the fans, not the air conditioning system located in the ceiling of the aircraft. This solution will ensure adequate airflow and ventilation within business / first-class suites, enhancing passenger comfort and satisfaction during flight.

Testing and validation: Conduct thorough testing and validation of the implemented recommendations to ensure compatibility, functionality, and safety within the aircraft environment. This phase will involve rigorous testing under simulated conditions to identify any potential issues and refine the system accordingly.

Continuous improvement and feedback loop: Establish a continuous improvement process and feedback loop to gather insights from stakeholders, including passengers, flight crew, and maintenance personnel. By soliciting feedback and incorporating suggestions for improvement, the system can evolve to meet evolving needs and address any emerging challenges effectively.

Documentation and training: Develop comprehensive documentation and training materials to support the implementation and operation of the system. This will include user manuals, maintenance guides, and training programs to ensure that all stakeholders are equipped with the necessary knowledge and skills to manufacture and maintain the system effectively.

Computational Fluid Dynamics (CFD): For better understanding of the fluid flow path around the thermoelectric device system, CFD should be carried out to gain a better understanding on how the system can be optimised. This will also save time and money on creating prototypes which may not give the desired result.

Unit Price: To ensure the unit will be commercially viable, discussions and meetings will need to be held involving all of the correct parties to determine a sensible cost per unit, once a production representative is complete.

By focusing on these recommendations, SSGB can further enhance the functionality, efficiency, and reliability of the system, ultimately delivering an exceptional passenger experience and maximising the value proposition for airlines.

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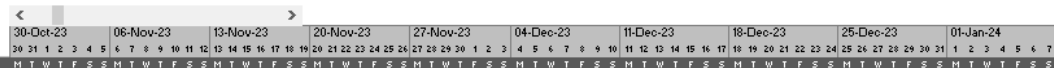
Appendix 1 – Gantt Chart (Timing Plan)



Updated Timing Plan

Morgan Wheeler
Safran Seats GB - Cooled Compartment

Project Start:	Mon,4-Sep-2023
Display Week:	9

[illegible]

Updated Timing Plan

Morgan Wheeler
Safran Seats GB - Cooled Compartment

Project Start:	Mon,4-Sep-2023
Display Week:	18

01-Jan-24	08-Jan-24	15-Jan-24	22-Jan-24	29-Jan-24	05-Feb-24	12-Feb-24	19-Feb-24	26-Feb-24	04-Mar-24
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[illegible]

Dissertation Topic

[illegible]

Industrial Design

[illegible]

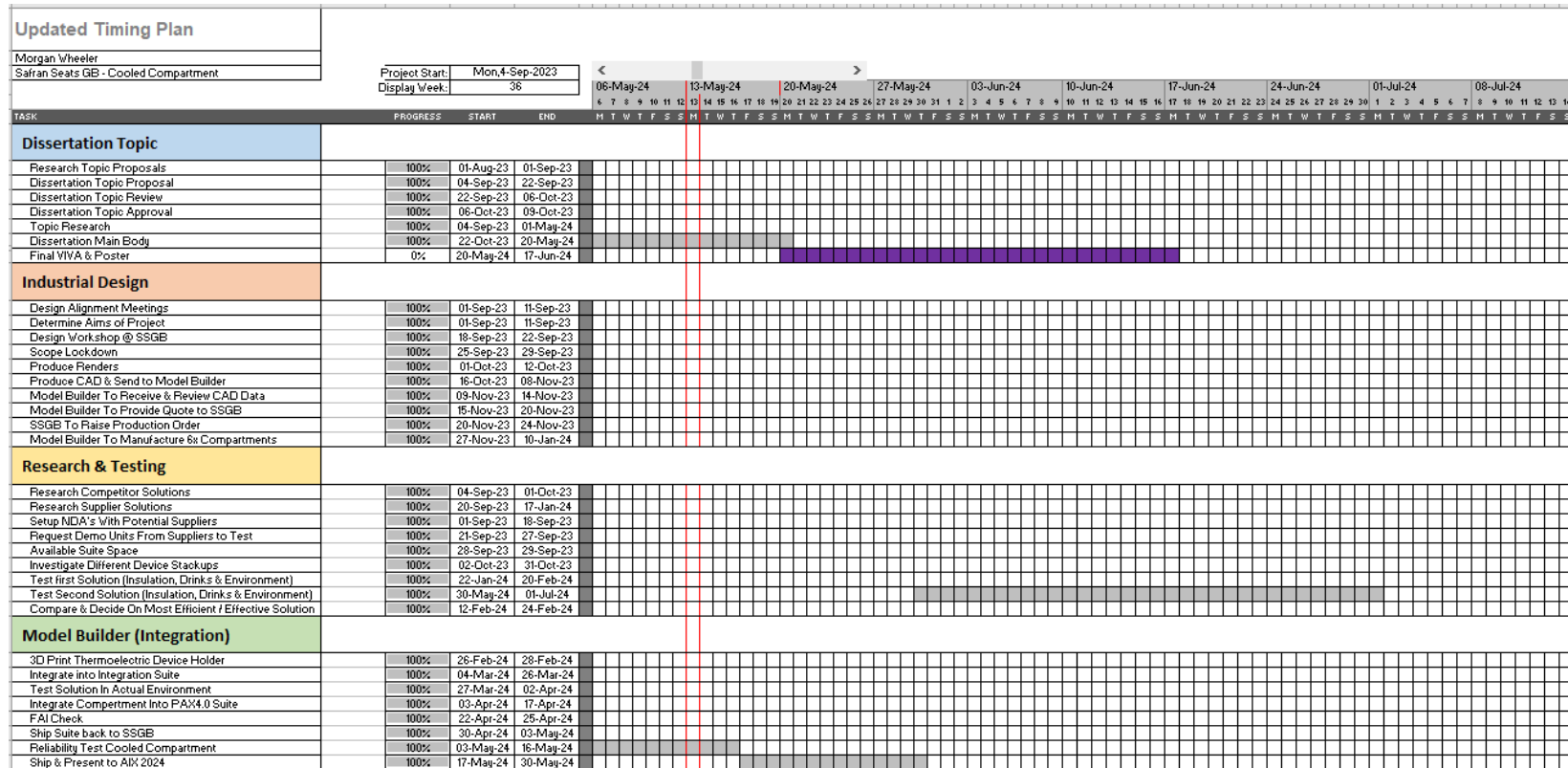
Research & Testing

[illegible]

Model Builder (Integration)

[illegible]

Updated Timing Plan		
Morgan Wheeler		
Safran Seats GB - Cooled Compartment		
Project Start:	Mon,4-Sep-2023	
Display Week:	27	



Appendix 2 – Zotek foam data sheet

Product Information Sheet PIS – Z009



ZOTEK® F OSU SR GY High Performance Foams

ZOTEK®

Product information

Typical values

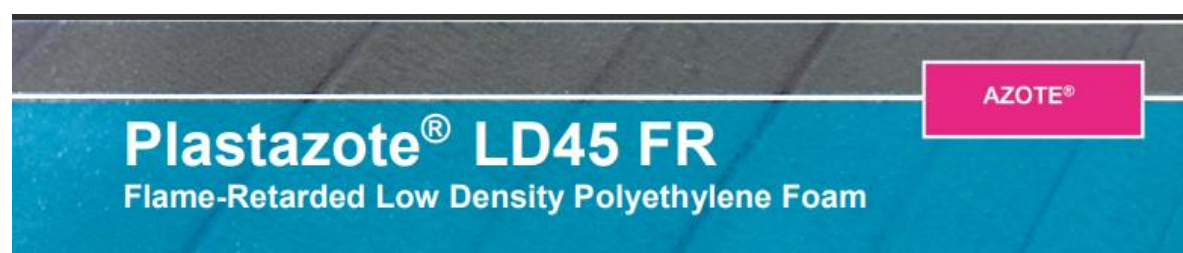
ZOTEK® F OSU Semi-Rigid Grey is a closed cell, foam of density 38 kg/m³ made from poly vinylidene fluoride available in sheet form. The foam will thermoform into simple and complex shapes. This product information sheet provides typical values for the foam and does not constitute a specification.

Property	Test Standard	Units	Typical Value
Apparent Density			
Skin/Skin	BS EN ISO 7214:2012	kg/m ³ (pcf)	38 (2.4)
Cell Size (cell diameter)	Internal	mm (in)	0.26 (0.01)
Compression Stress-Strain	BS EN ISO 7214:2012		
25% compression	1 st Compression	kPa (psi)	85 (12.3)
Tensile Strength	BS EN ISO 7214:2012	kPa (psi)	680 (98.6)
Tensile Elongation		%	120
Thermal conductivity			
Mean temperature of 25 °C (77 °F)	ISO 8301	W/m.K	0.0334 (0.232)
Mean temperature of 38 °C (100 °F)		(Btu in/ft ² .hr.°F)	0.0352 (0.245)
Flammability			
Heat Release	FAR/CS 25.853 (d) App F Pt IV		Pass at 13mm (1/2")
Smoke Density	FAR/CS 25.853 (d) App F Pt V		Pass at 25mm (1")
Smoke Density	ABD0031 para.7.3.2.		Pass at 25mm (1")
Toxic Gas Emission	ABD0031 para.7.4		Pass at 25mm (1")
Vertical Burner (60 sec)	FAR/CS 25.853(a) App F Pt I(a), (1), (i)	Pass at 1.5, 13 & 25mm (1/16", 1/2" & 1")	
Recommended maximum operating temperature*	Internal	°C (°F)	140 (284)

* Recommended maximum operating temperature

The maximum operating temperature shown is defined as the temperature which will typically cause a linear shrinkage of 5% after a 24hr exposure period, using sample dimensions of 100mm x 100mm x 25mm. This figure is provided for general guidance only. The actual level of shrinkage the foam will undergo at any temperature is dependent on several system variables such as, sample dimensions, cell size, loading conditions and exposure period.

AZOTE® / ZOTEK® / T-FIT® / MuCell®



Product Information

Typical Values

Plastazote® is a closed cell, cross-linked polyethylene block foam manufactured using Zotefoams unique production process.

The values provided in this product information represent data gathered from random samples of our production of Plastazote® LD45 FR foam and represent typical data. These are given to the best of our knowledge and should be considered as guidance for selecting a suitable grade for a given application.

Property	Test Standard	Units	Typical value
Apparent Density			(nominal)
Skin/Skin	BS EN ISO 7214:2012	kg/m ³	45
Cell Size (Cell Diameter)	Internal	mm	0.4
Compression Stress-Strain	BS EN ISO 7214:2012	kPa	
25% compression	25 mm cell-cell		88
50% compression			162
Tensile Strength	BS EN ISO 7214:2012	kPa	449
Tensile Elongation		%	158
Flammability	CS 25.853 App. F 1a 1ii		12 second test
Aviation **	FAR 25.853 App. F 1a 1ii		Pass at 3mm & 12mm
Flammability			HF1
UL94***	UL94 Ed.6		at 3mm
Compression Set	BS EN ISO 7214:2012	% set	
25% comp., 22hr, 23°C	25 mm cell-cell		
½ hr recovery			8
24 hr recovery			3
Tear Strength	BS EN ISO 8067:2008 Method B	N/m	2404
Shore Hardness	BS EN ISO 868:2003		
OO Scale			61
Recommended maximum operating temperature*	Internal	°C	105
Water absorption	ISO 2896:2001 Ed3.	%	<1
Thermal conductivity	ISO 8301:1991	W/mK	0.038
Mean temperature 10°C			

Appendix 4 – Aviation glass data sheet



0.088" Semi-transparent Mirror

Spec-sheet

GENERAL DESCRIPTION

Composition code C-GVPFFFFG-02

Sheet of glass with semi-transparent mirror layer (LTA of 10%) laminated with a transparent interlayer, additional print and a second sheet of glass

MAX DIMENSIONS

1450 x 950 mm

WEIGHT

5.312 gr/m²

Light Transmission & Reflectance

Light transmission & Reflectance will be optimized in cooperation with the Customer considering the foreseen monitor or light source

Fire Safety Tests

Test	Result	Standard
Vertical Bunsen Burner test 60 sec.	Passed*	FAR 25.853 (a), CS 25.853 (a)

Result

Standard

Other tests

Test	Result	Standard
Fluid Resistancy Test	Passed*	
Pencil Hardness Test	9B-9H	ASTM D3363

*Test performed as engineering tests.

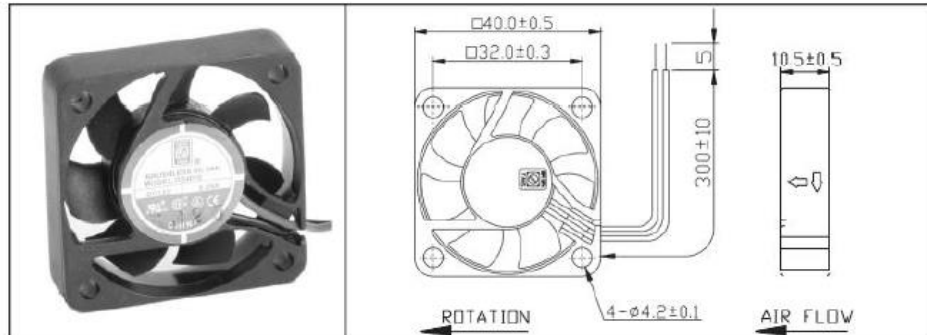
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Appendix 5 – Front Fan Data Sheet

Datasheet

RS Pro DC axial fan, 40x10mm 8.5cu.m/h 24V



Frame & Impeller	PBT, UL94V-0 plastic	Available Options: Tachometer Alarm PWM Sleeve bearing Life Expectancy (L10) Ball - 80,000 hrs (45C) Sleeve - 30,000 hrs (45C) Operating Temperature Ball: -20C ~ +75C Weight: ~ 0.04 lbs	
Connection	2x Lead wires 26AWG		
Motor	Brushless DC, autorestart, impedance and polarity protected		
Bearing System	Ball bearing		
Insulation Resistance	10M ohm between leadwire and frame (500VDC)		
Dielectric Strength	1 minute at 500 VAC, max leakage < 500MicroAmp		
Storage Temperature	-40C ~ +80C		

Model Number	Speed (RPM)	Airflow (CFM)	Noise (dB)	Volts DC	Voltage Range (VDC)	Amps	Max. Static Pressure ("H ₂ O)
OD4010-05H*	6000	7	25	5	4 ~ 5.5	0.19	0.10
OD4010-05M*	4800	6	20	5	4 ~ 5.5	0.11	0.08
OD4010-05L*	4200	5	14	5	4 ~ 5.5	0.08	0.06
OD4010-12H*	6000	7	25	12	10.8 ~ 13.2	0.10	0.10
OD4010-12M*	4800	6	20	12	10.8 ~ 13.2	0.08	0.08
OD4010-12L*	4200	5	14	12	10.8 ~ 13.2	0.07	0.06
OD4010-24H*	6000	7	25	24	21.6 ~ 26.4	0.09	0.10
OD4010-24M*	4800	6	20	24	21.6 ~ 26.4	0.08	0.08
OD4010-24L*	4200	5	14	24	21.6 ~ 26.4	0.07	0.06

General Specifications

Air Flow	11.9m ³ /h
Fan Speed	6000rpm
Static Pressure	0.10in/H ₂ O max.
Noise Level	25dB
Direction of Curve	Forward
Frame	PBT Plastic
Impeller	UL94-0 Plastic
Alarm Function	Yes
Special Features	Tachometer
IP Rating	IP44
Applications	Server racks, Electrical cabinets and enclosures; Production Lines, Ceiling fan/ventilation Desktop computers, Motor engines (radiator in a car), Generators, Air compressors

Electrical Specifications

Motor	Brushless DC, Auto Restart, impedance and Polarity Protected
AC or DC Operation	DC
Power Consumption	1.68W
Supply Voltage	24VDC
Maximum Current	90mA
Dielectric Strength	1 minute at 500 VAC, max leakage < 500 Micro Amp
Insulation Resistance	10M ohm between lead wire and frame (500VDC)

Mechanical Specifications

Dimensions	40mm x 40mm x10.5mm
Height	40mm
Width	40mm
Depth	10.5mm
Bearing Type	Ball
Weight	0.2Kg (0.04lbs)
Life Expectancy	60,000 hours (L10 at 45°C)

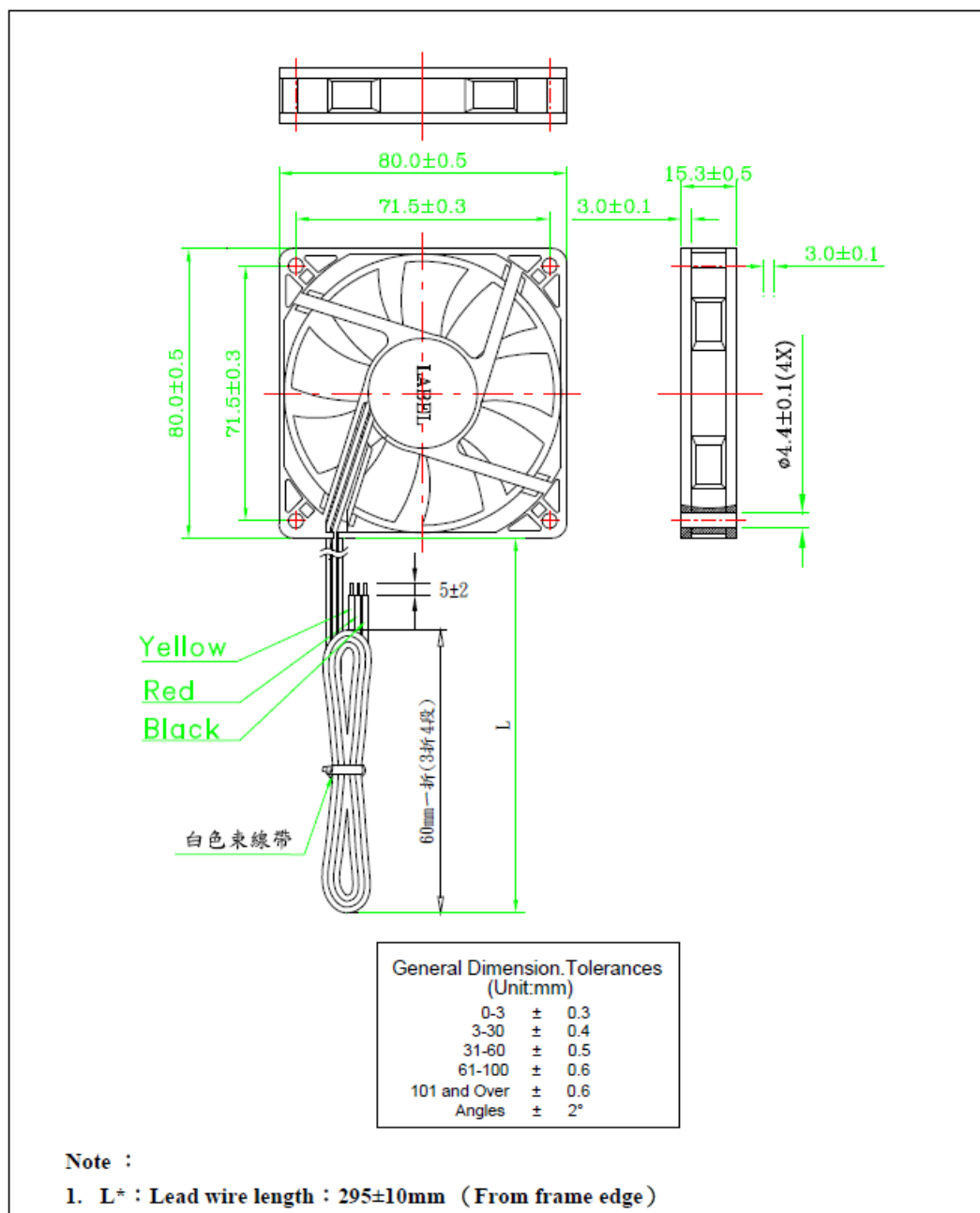
Operation Environment Specifications

Operating Temperature	-20°C to 75°C
Storage Temperature	-45°C to 80°C

Approvals

Compliance/Certifications	RoHS Certificate Of Compliance
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Appendix 6 – Rear Fan Data Sheet



	Item	Specification	Test Condition
1	Locked Rotor Test	Flameproof and damage free	Rotor locked for 72 hrs with Rated Voltage
2	Reverse Voltage Test Protection	Yes	Reverse 15 min with Rated Voltage
3	Balance Test	No protruding beyond the circle within 10 seconds	The fan runs in a circle, scaled by fan radius plus 20mm, on a perfectly smooth plate for 10 seconds under the ISO 1940 G6.3 grade Standard.
4	Drop Test	All specified characteristics remain unchanged	Drop D.U.T.(The standard packing) from the test machine at 76cm below. Individual one angle, three diagonal corners and six planes under the IEC 68-2-31 Standard.
5	Vibration Test	All specified characteristics remain unchanged	Ambient temp. : 25 °C±5 °C with Rated Voltage Amplitude : 0.4-2.5 mm Acceleration : 14.7 S/m ² Frequency : 10HZ-60HZ Sweeping period : 11 min 10HZ-60HZ : 10 min 60HZ-10HZ : 10 min Total : 10 cycles This test is under the IEC 68-2-6 Standard.
6	High/Low Temperature Cycling	All specified characteristics remain unchanged	20 minutes slew rate +75 °C (12 hr) , -20 °C (12 hr) Total : 25 cycles with Rated Voltage This test is under IEC 68-2-38 Standard.
7	Low Temp. Test	All specified characteristics remain unchanged	Tested under standard condition ; after 500hrs, -25 °C, with power supply. This test is under IEC 68-2-1 Standard.
8	High Temp. Test	All specified characteristics remain unchanged	Tested under standard condition ; after 500hrs, 80 °C, with power supply. This test is under IEC 68-2-2 Standard.
9	Hi Pot Test	All specified characteristics remain unchanged	Input 500V(AC) for 1 min between lead(+/-) and housing. This test is under CNS-C6013 Standard.

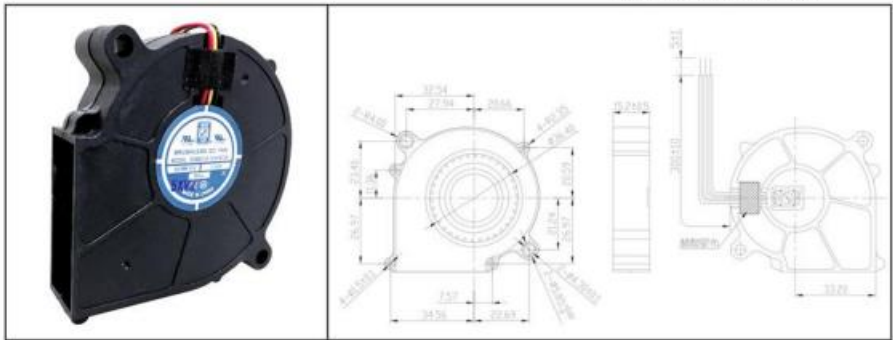


ENGLISH

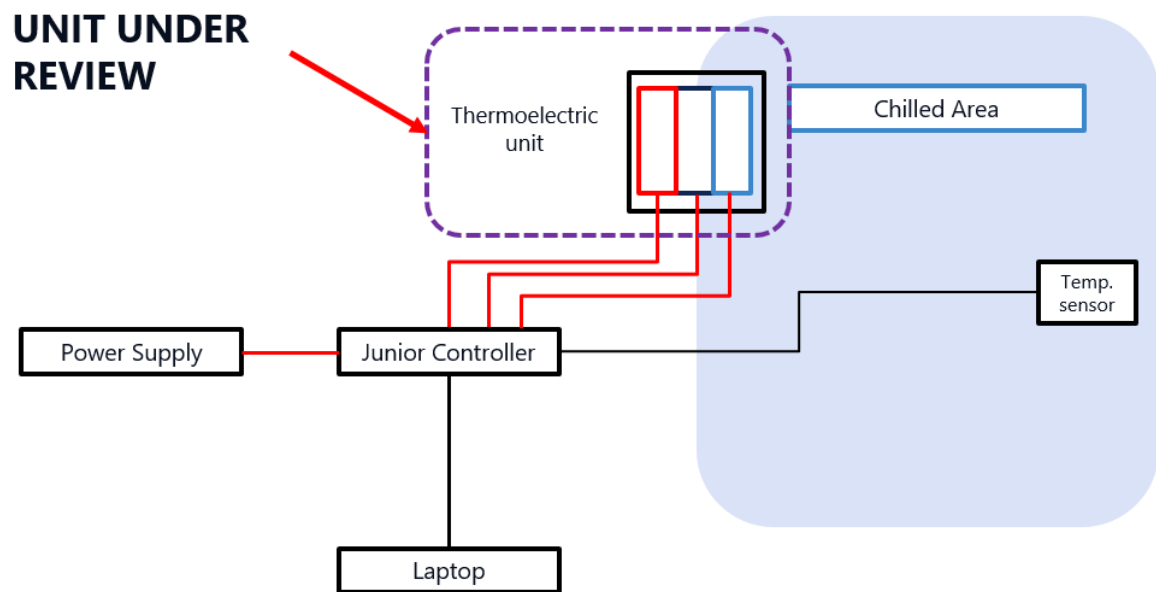
RS Pro DC Blower

ODB6015-12HHB02A

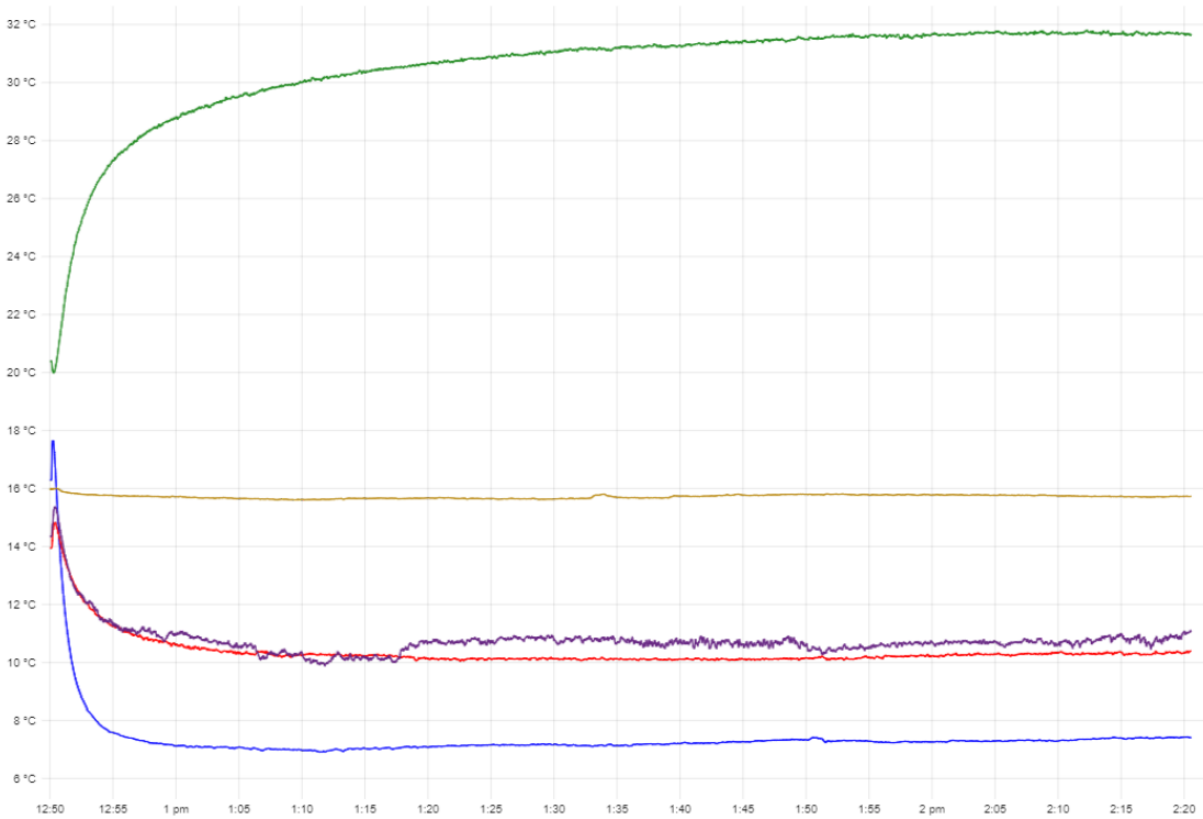
DC Blower 12V
60x15mm (2.36"x .59")



Frame & Impeller	PBT, UL94V-O plastic	Options Available	
Connecion	3x Lead wires *	Tachometer	
Motor	Brushless DC, auto restart, polarity protected.	Weight: ~ 35 g	
Bearing System	Dual ball bearing		
Insulation Resistance	Min. 10M at 500VDC	* Connection UL1571, 28AWG, ~320mm Red (+) Black (-) Yellow Alarm	
Dielectric Strength	1 minute at 500 VAC, max leakage < 500 MicroAmp		
Temperature Range	-10C ~ +70C		
Storage Temperature	-40C ~ +80C		
Life (L10)	70,000 hours (40C)	m1	



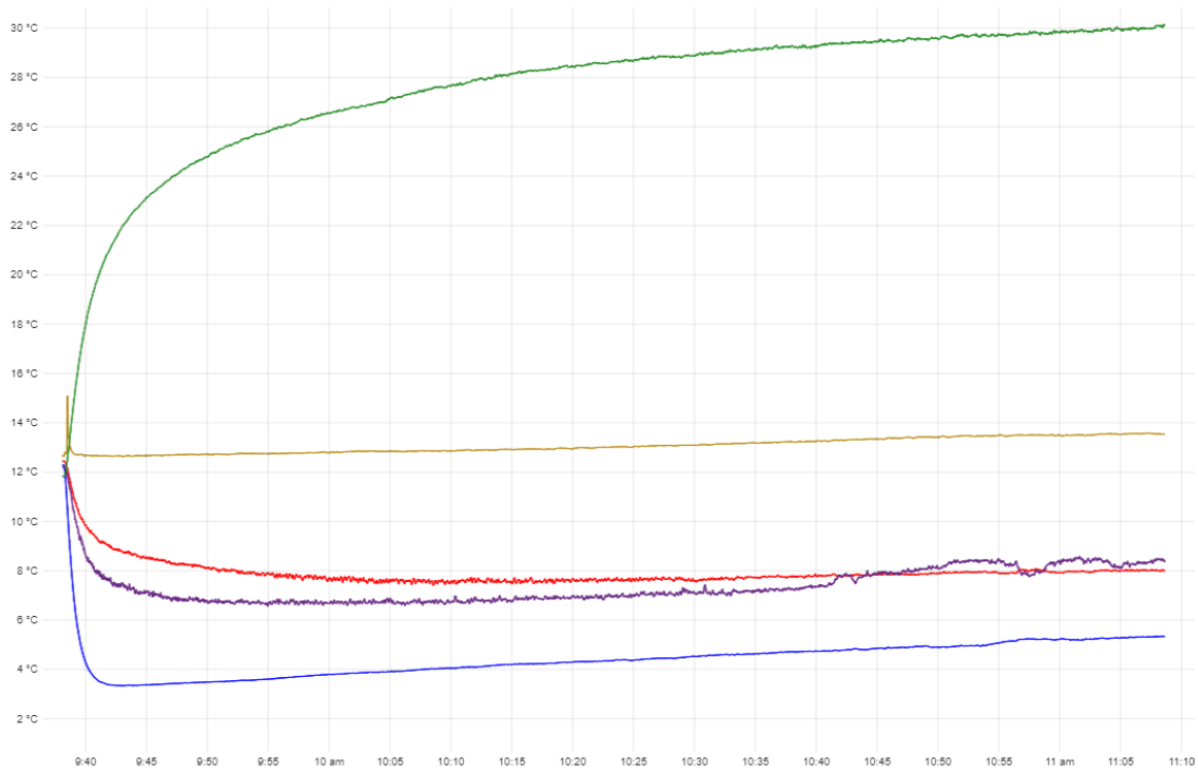
Appendix 9 – Test 1 (Second Result)



Channel configuration

■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1 s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1 s - Average
■	Ambient Temp	A0130/159 3 Type K	1 s - Average
■	Centre (Internal)	A0130/159 4 Type K	1 s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1 s - Average

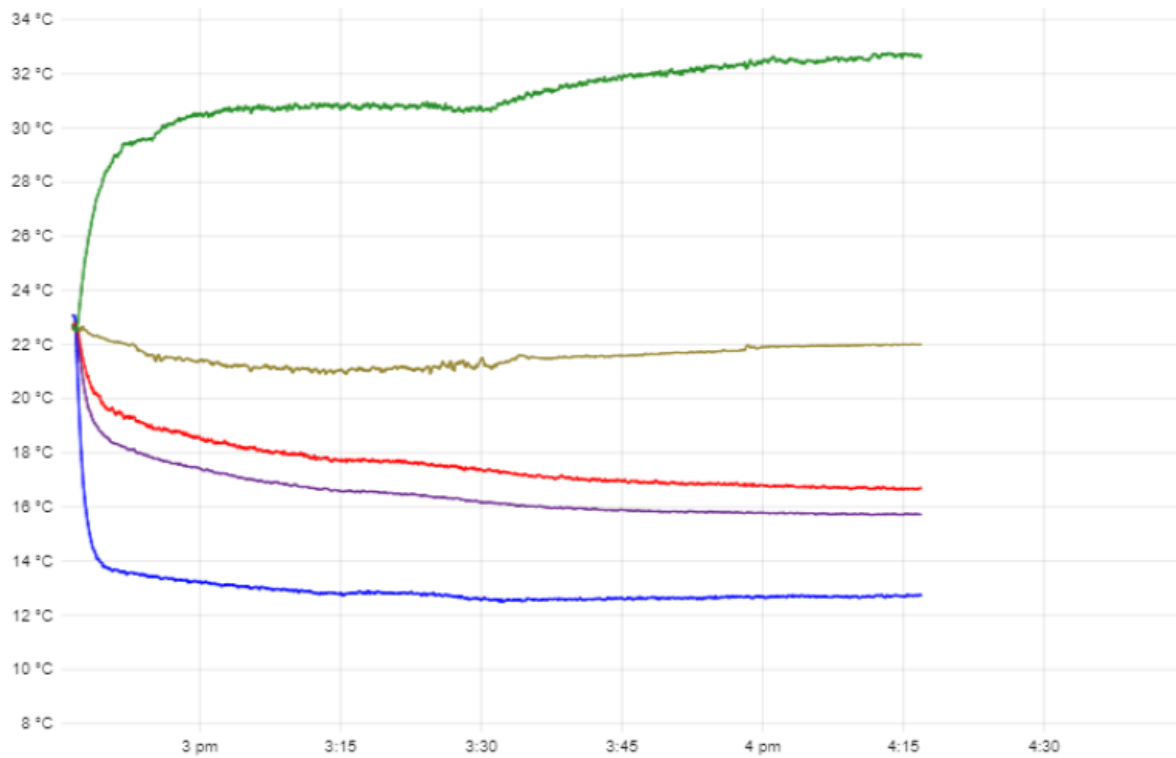
Appendix 10 – Test 1 (Third Result)



Channel configuration

	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1 s - Average
	Far Side (Internal)	A0130/159 2 Type K	1 s - Average
	Ambient Temp	A0130/159 3 Type K	1 s - Average
	Centre (Internal)	A0130/159 4 Type K	1 s - Average
	Hot Side Heat Sink	A0130/159 5 Type K	1 s - Average

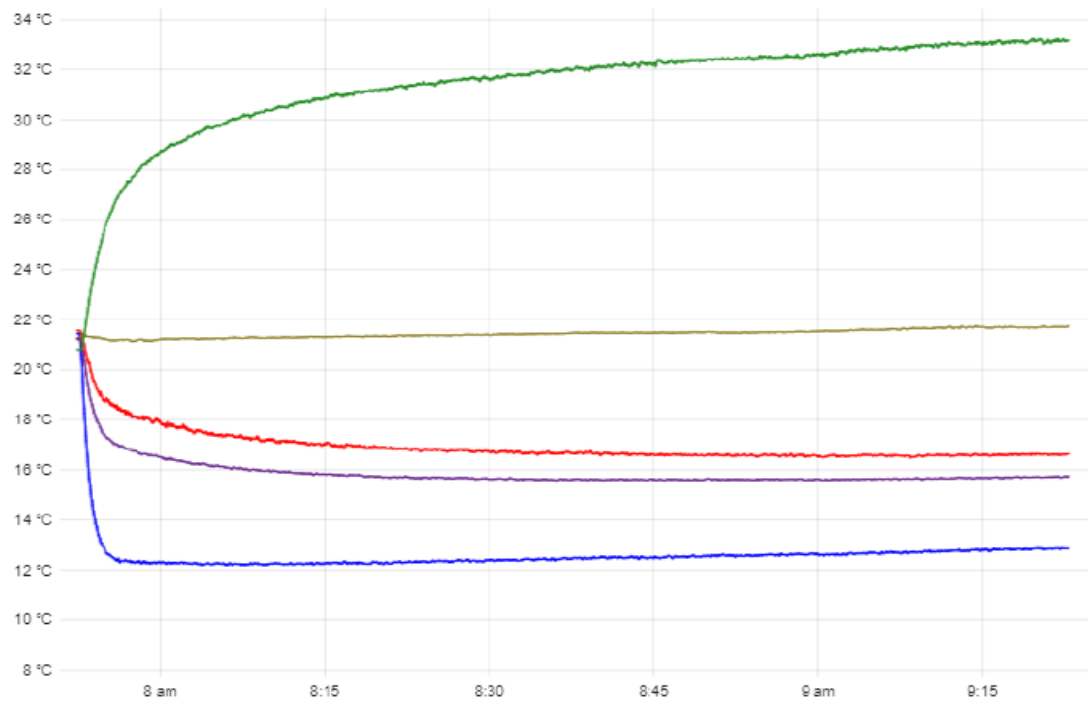
Appendix 11 – Test 2 (Second Result)



Channel configuration

■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average

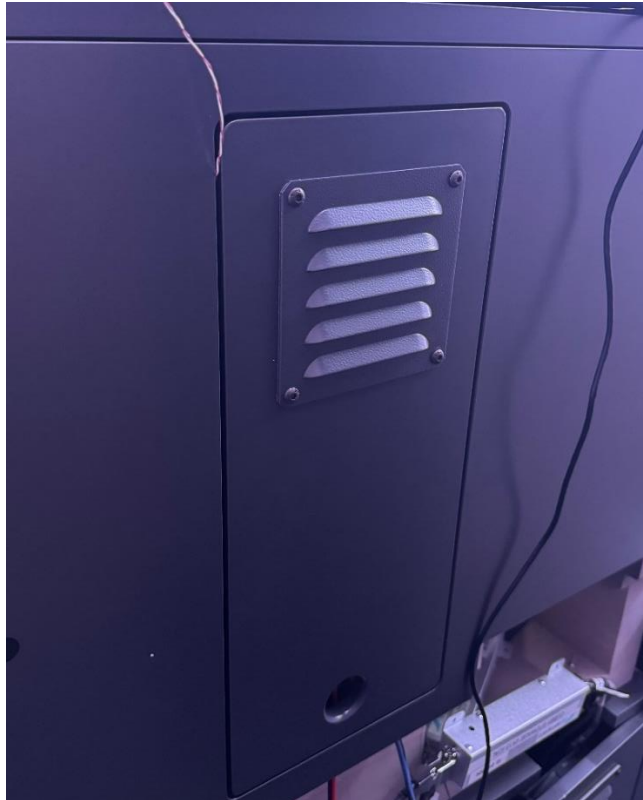
Appendix 12 – Test 2 (Third Result)



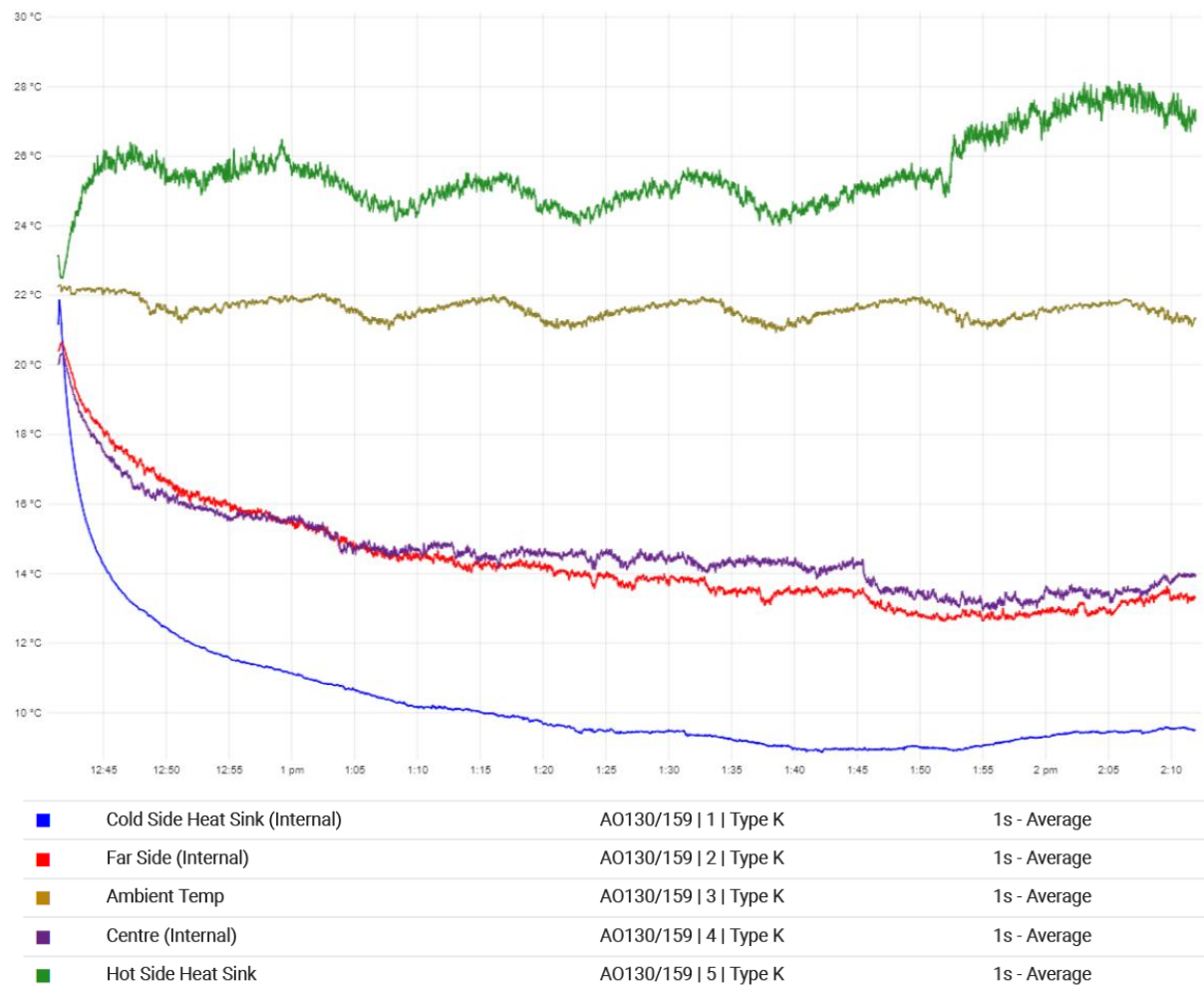
Channel configuration

■	Cold Side Heat Sink (Internal)	AO130/159 1 Type K	1 s - Average
■	Far Side (Internal)	AO130/159 2 Type K	1 s - Average
■	Ambient Temp	AO130/159 3 Type K	1 s - Average
■	Centre (Internal)	AO130/159 4 Type K	1 s - Average
■	Hot Side Heat Sink	AO130/159 5 Type K	1 s - Average

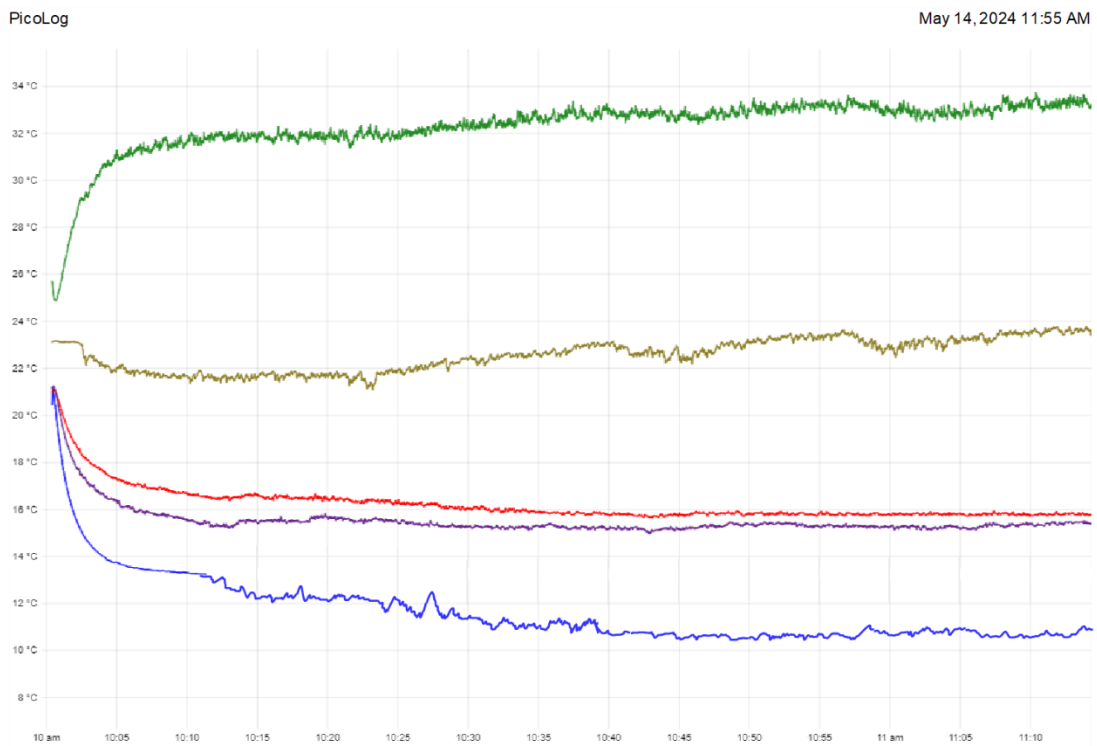
Appendix 13 – Removable Panel



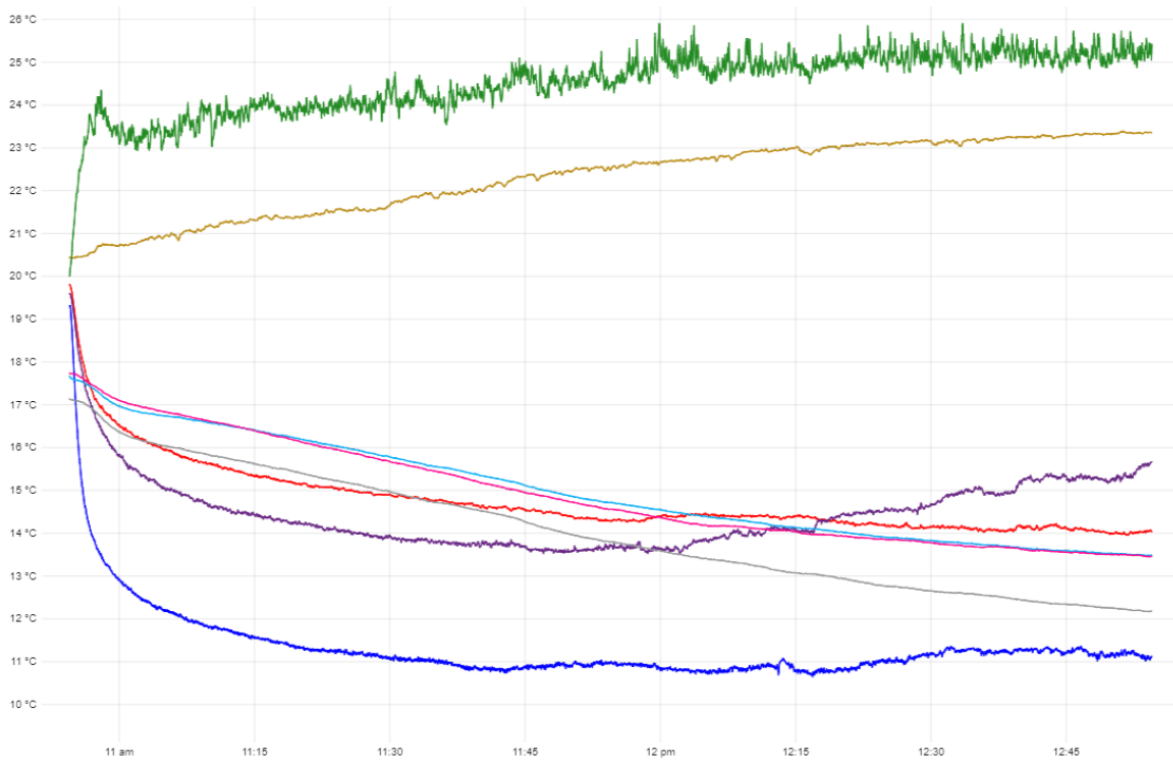
Appendix 14 – Test 3 (Second Result)



Appendix 15 – Test 3 (Third Result)

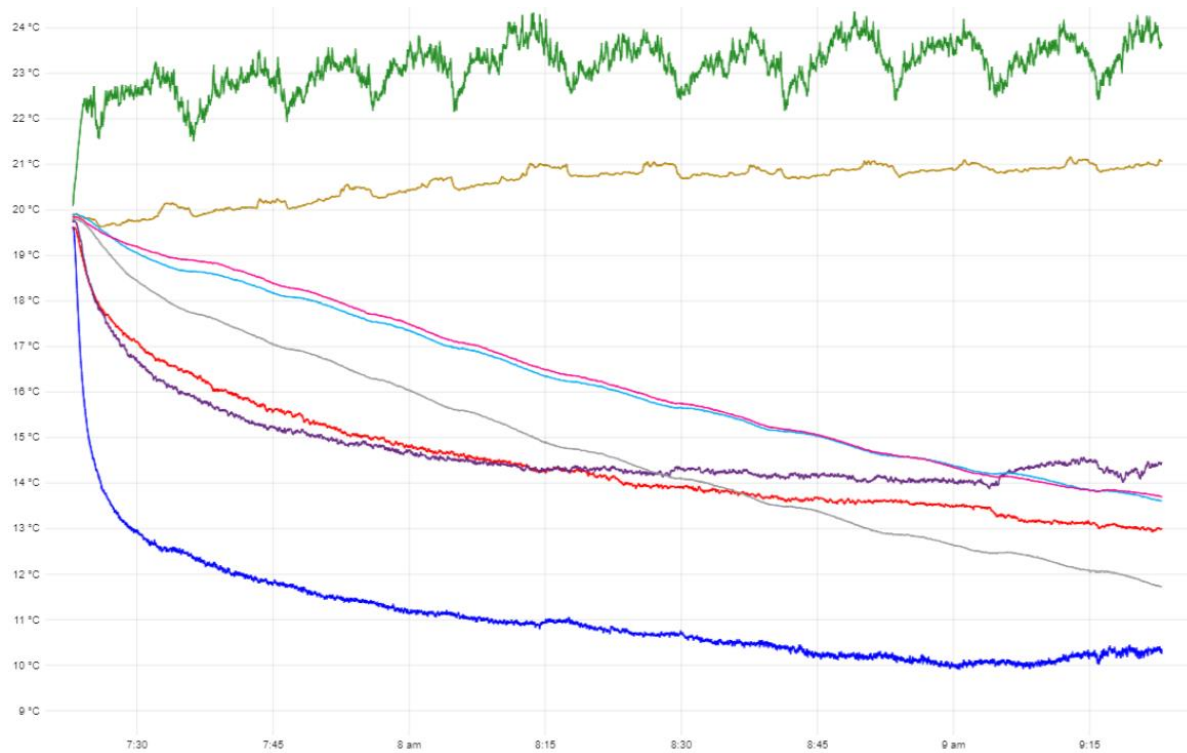


Appendix 16 – Test 4 (Second Result)



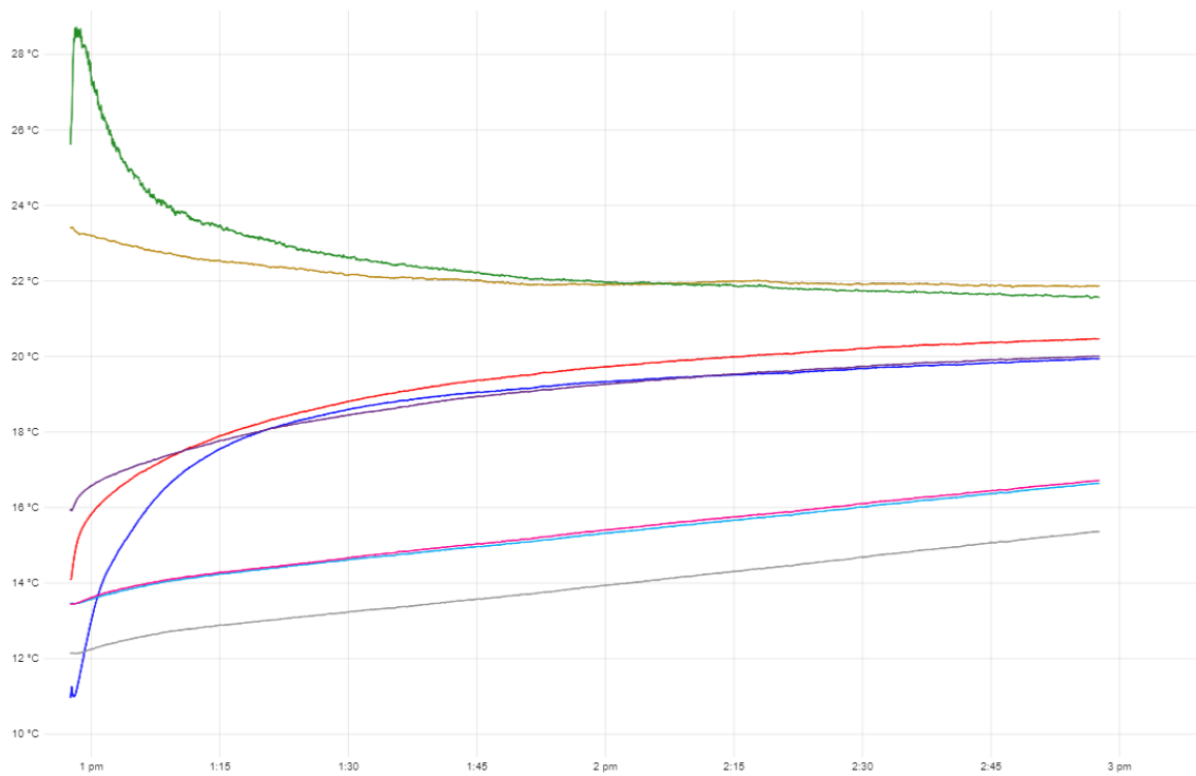
■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 17 – Test 4 (Third Result)



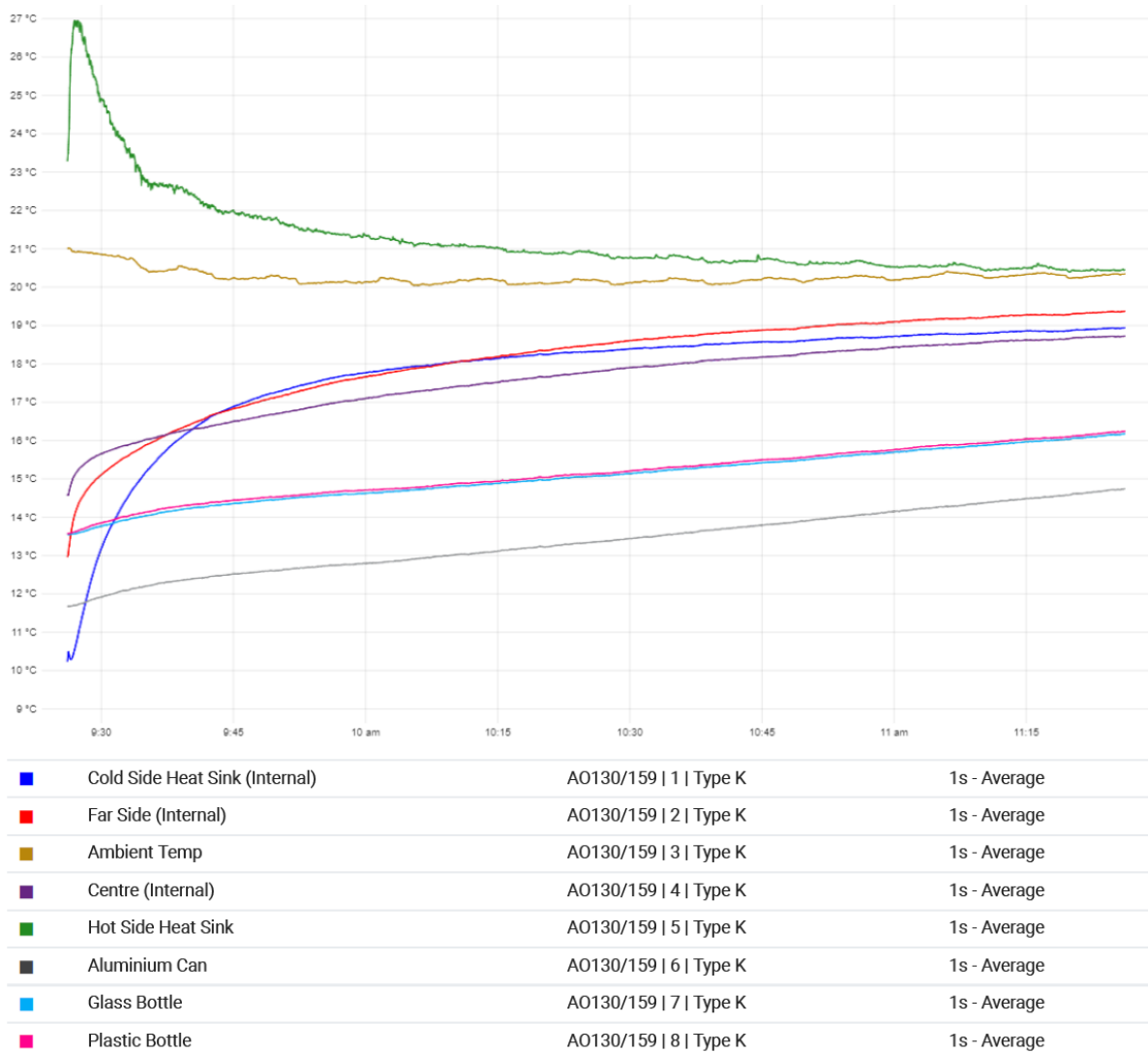
■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 18 – Test 4 Cooling (Second Result)

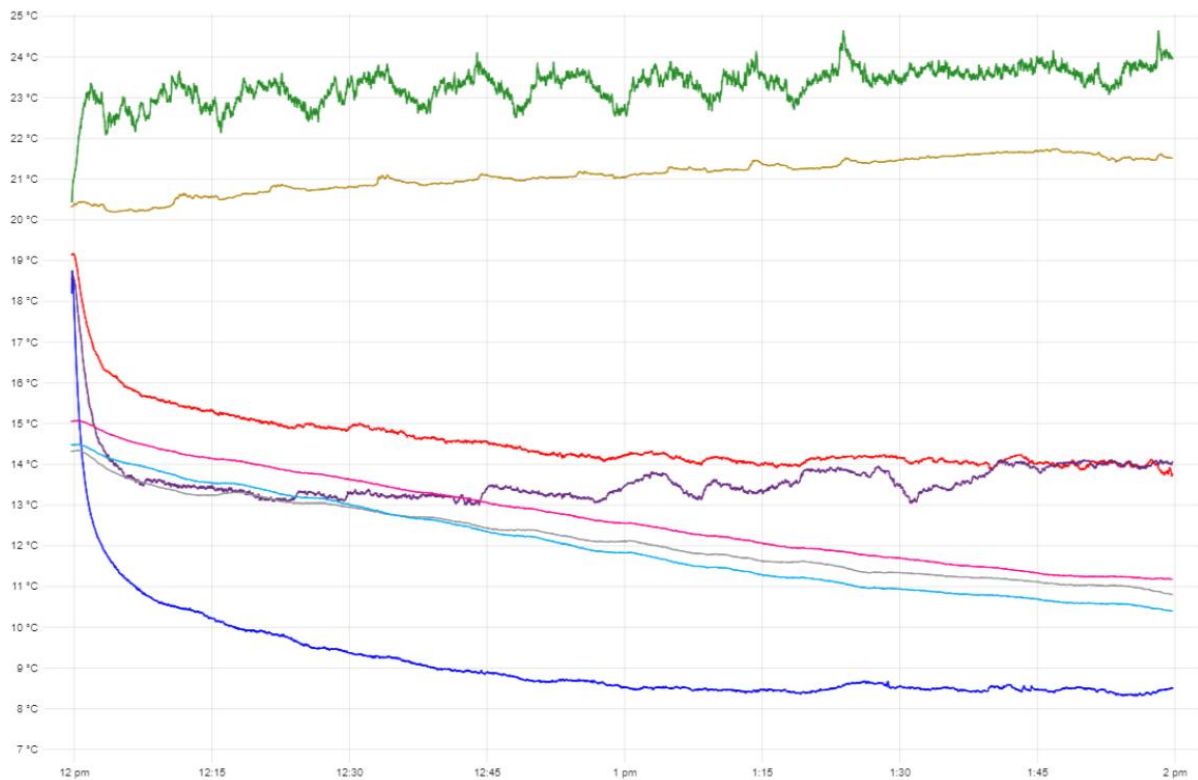


■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 19 – Test 4 Cooling (Third Result)

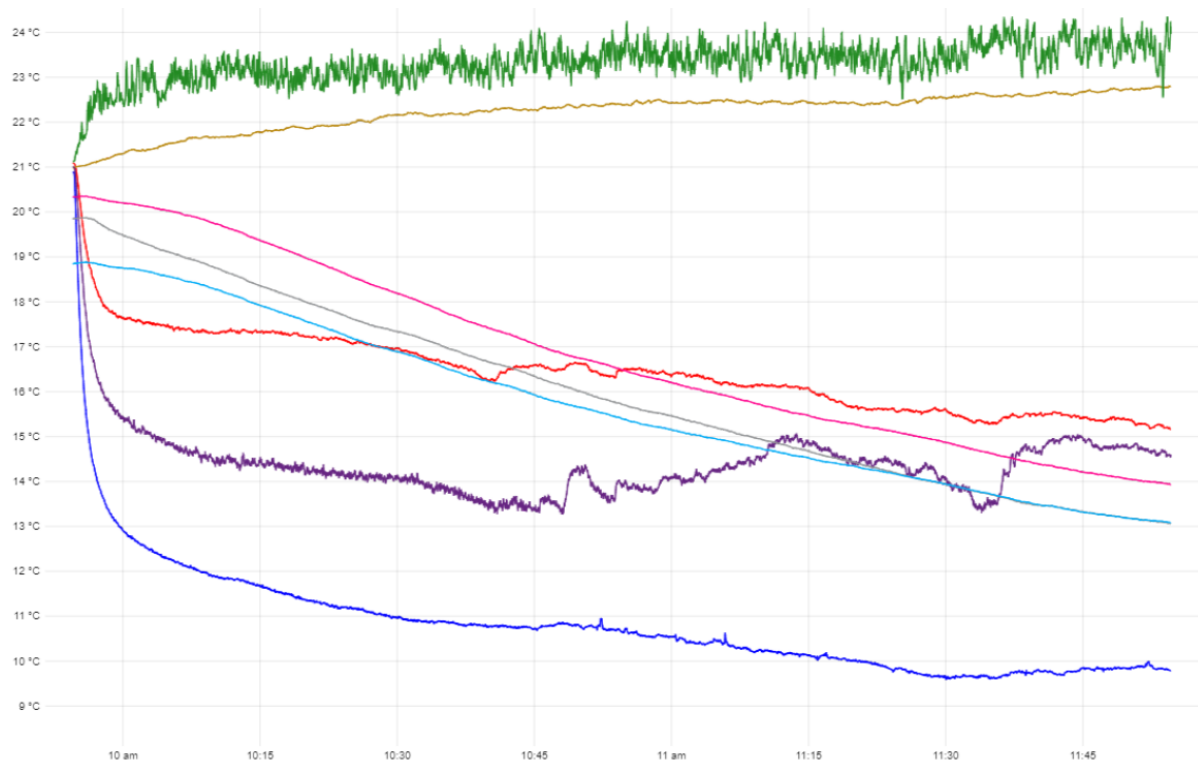


Appendix 20 – Test 5 (Second Result)



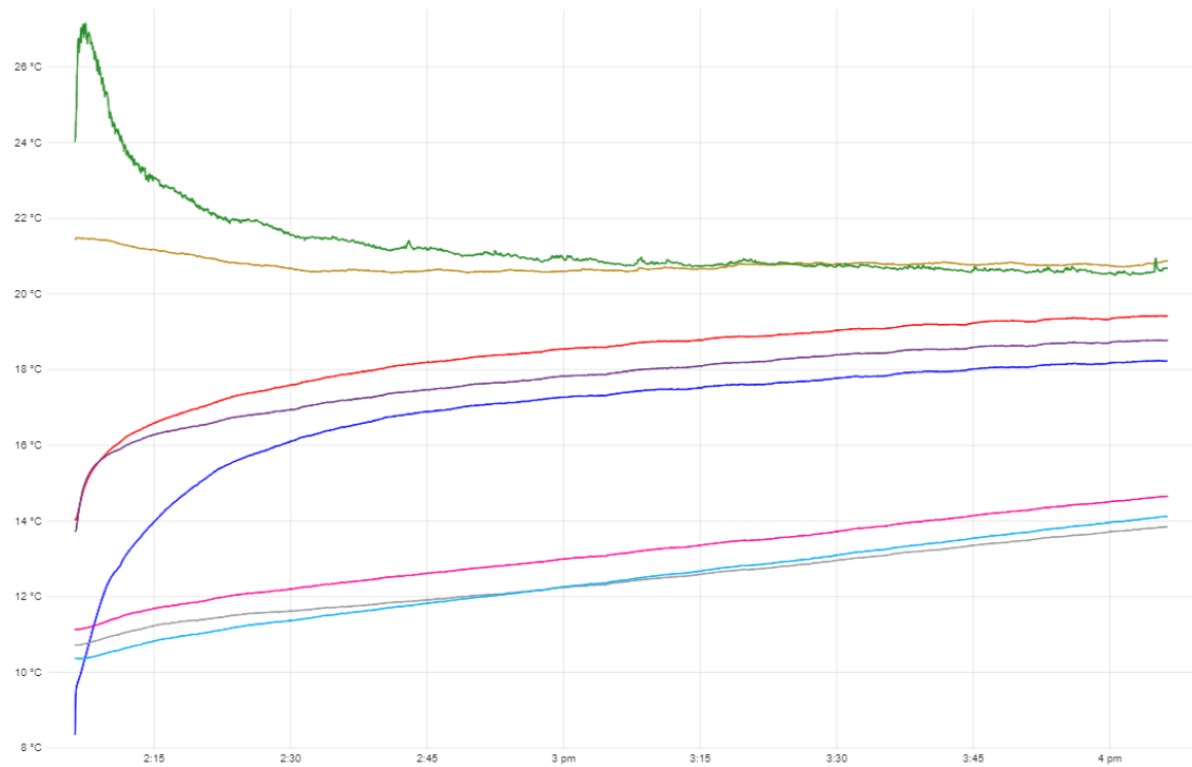
■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 21 – Test 5 (Third Result)



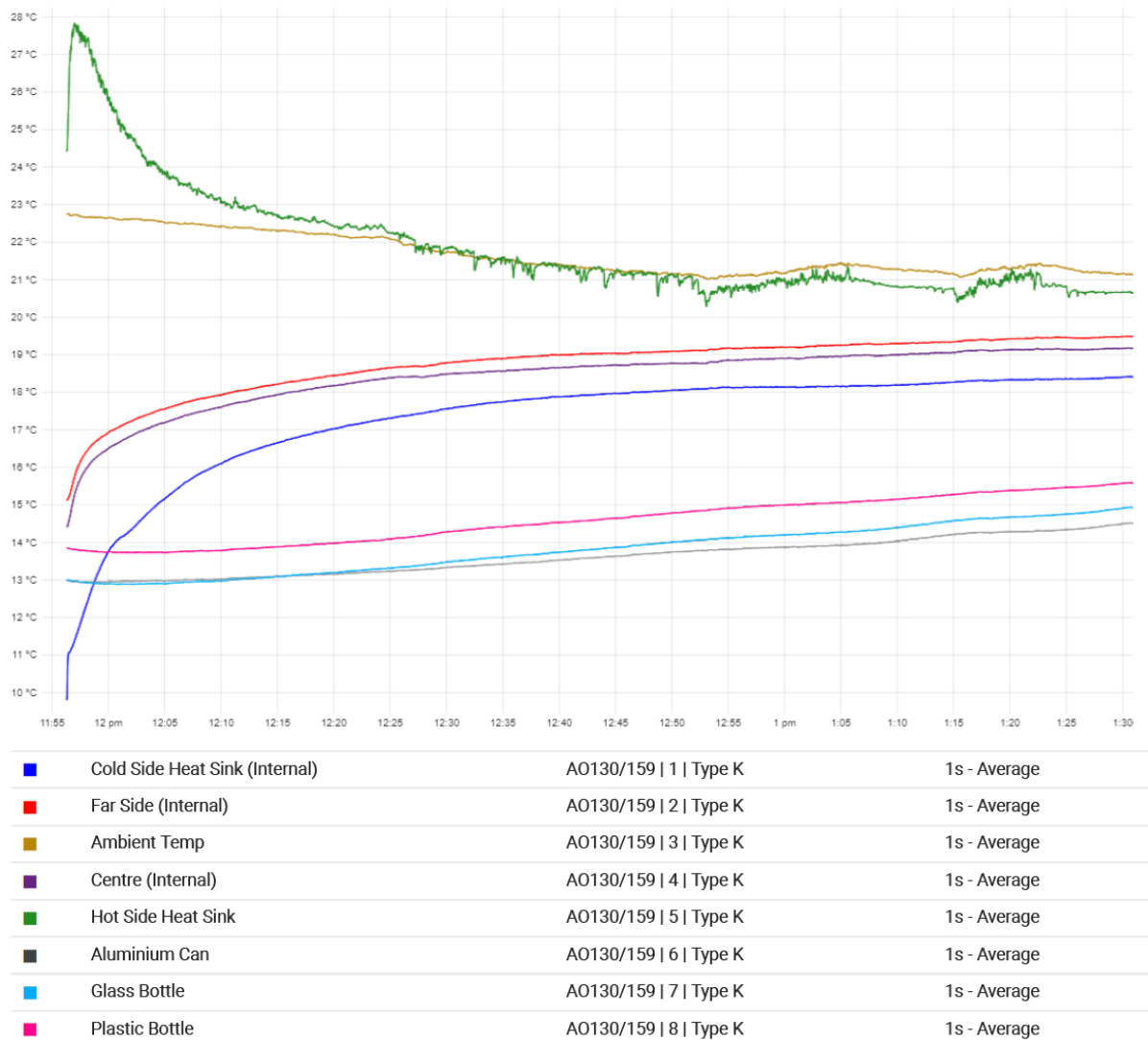
■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 22 – Test 5 Cooling (Second Result)

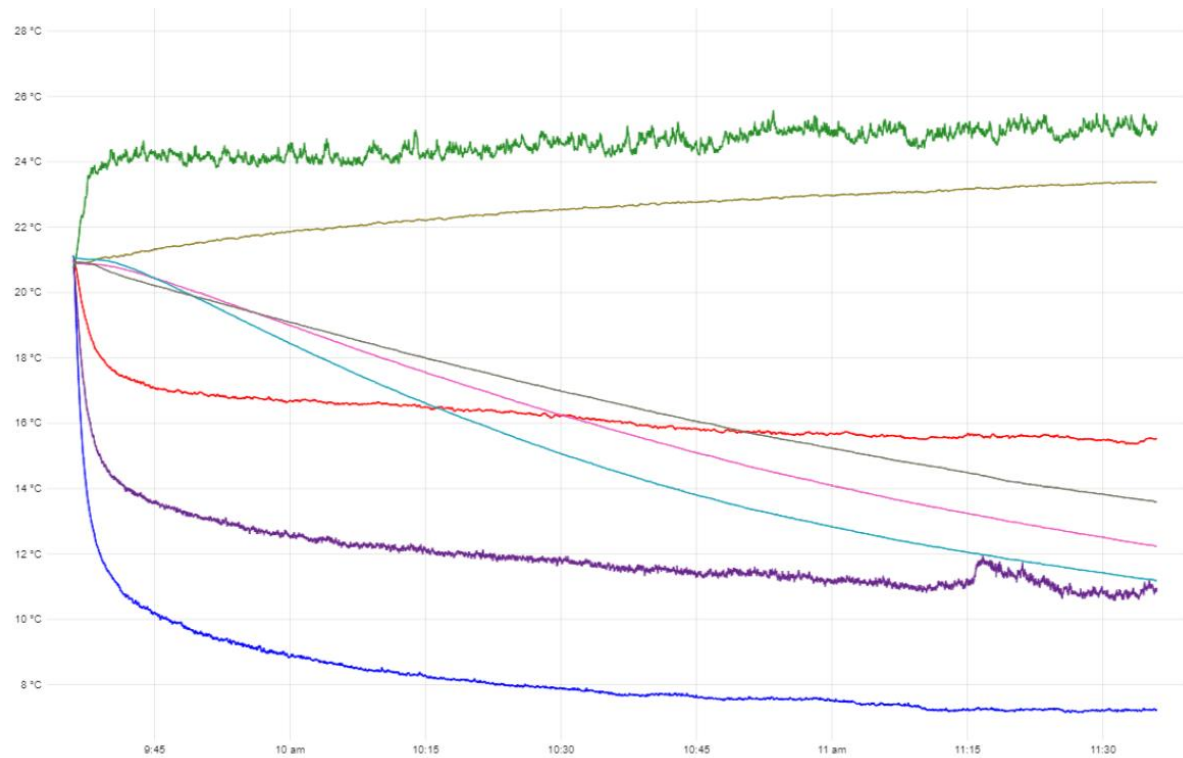


■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 23 – Test 5 Cooling (Third Result)

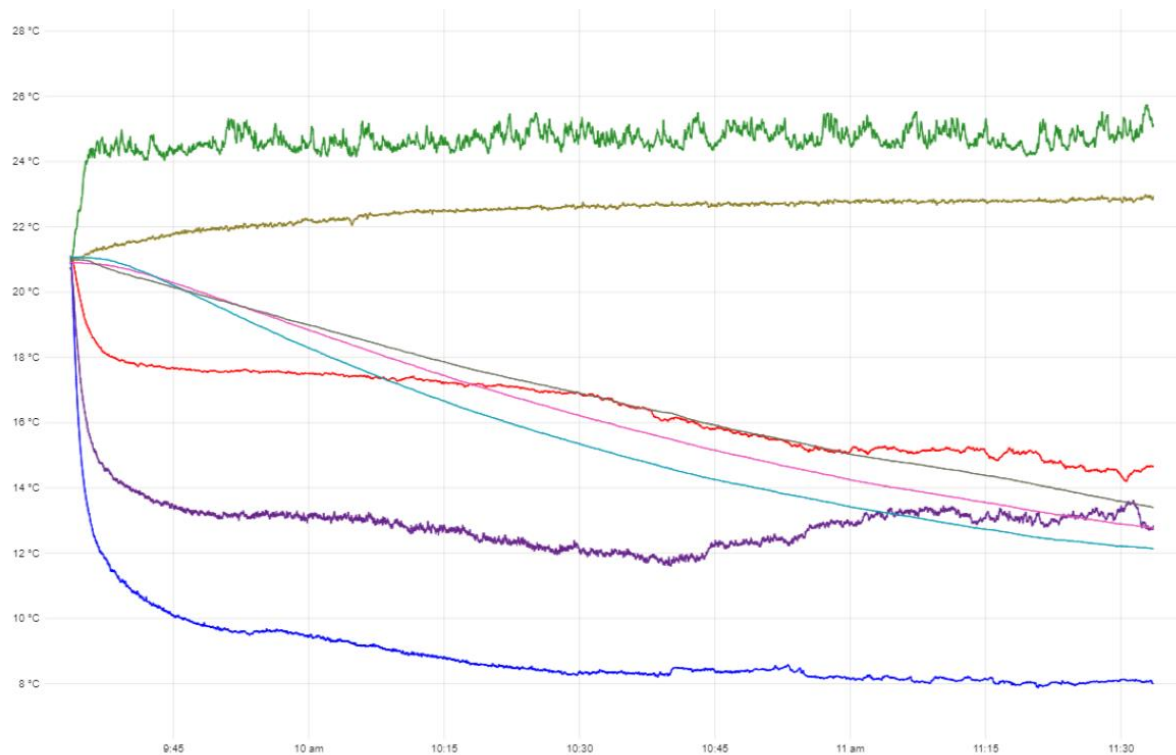


Appendix 24 – Test 6 (Second Result)



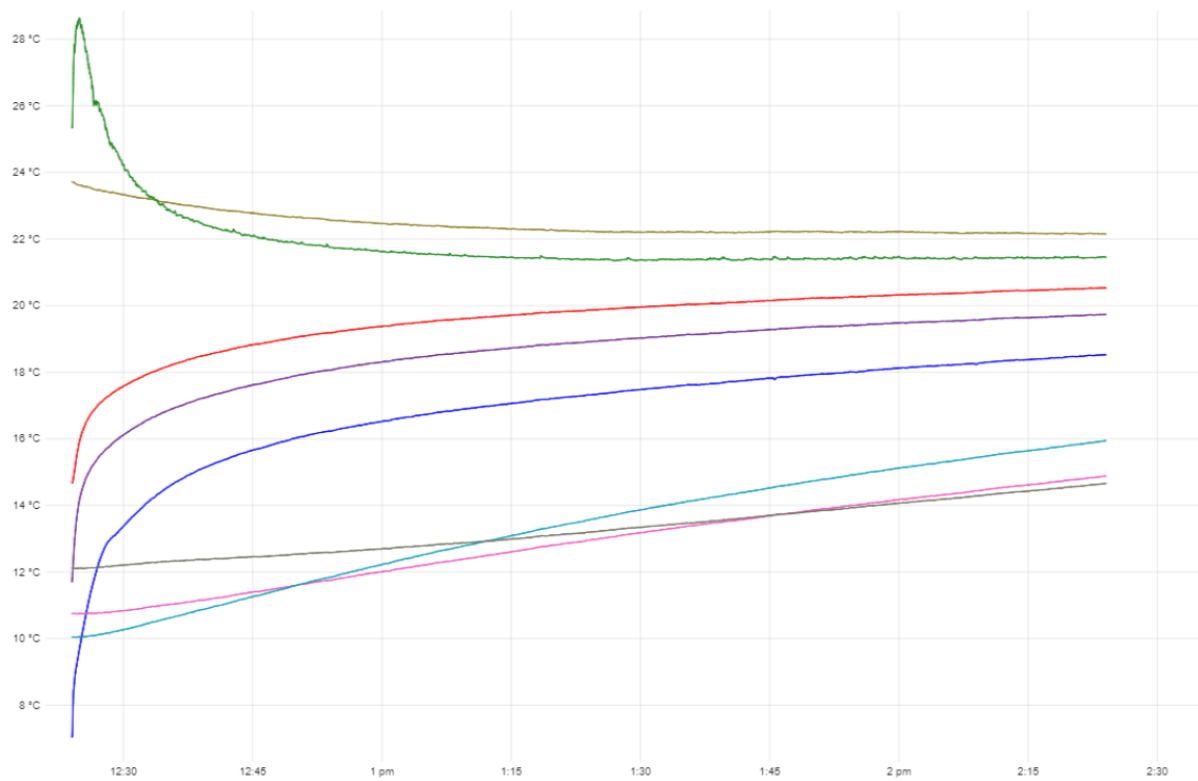
■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 25 – Test 6 (Third Result)



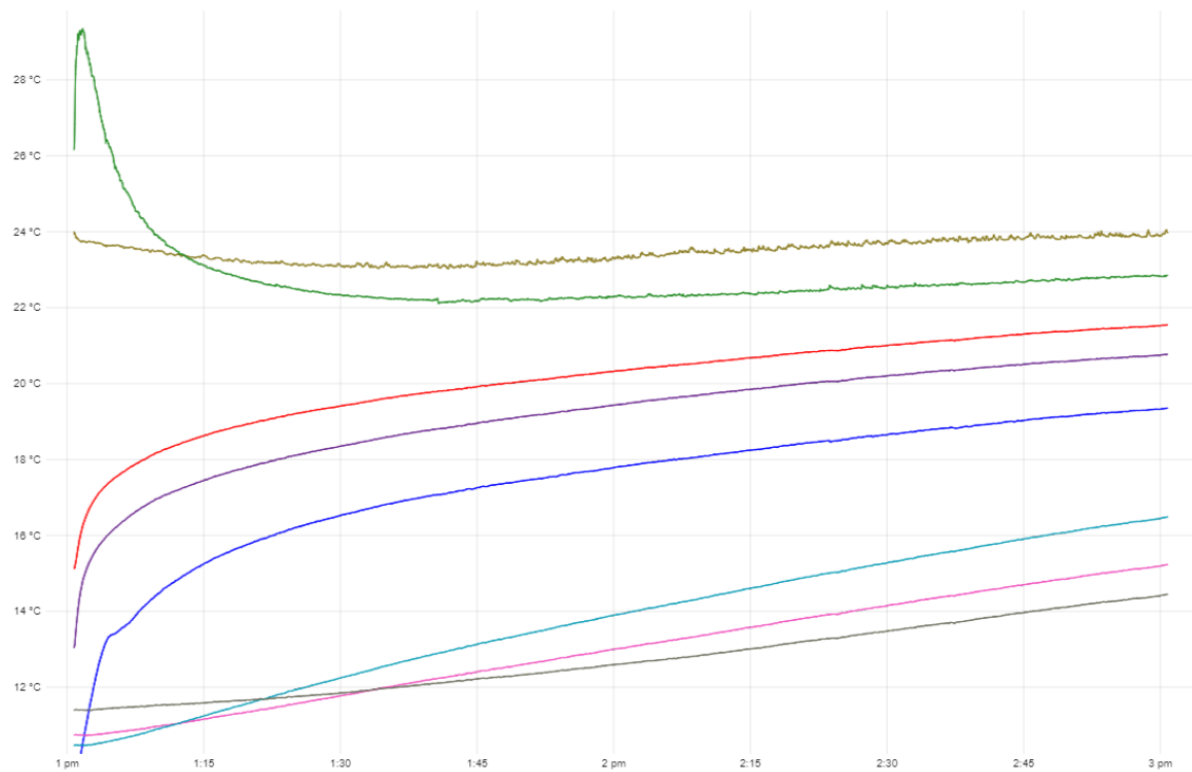
■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 26 – Test 6 Cooling (Second Result)



■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average

Appendix 27 – Test 6 Cooling (Third Result)



■	Cold Side Heat Sink (Internal)	A0130/159 1 Type K	1s - Average
■	Far Side (Internal)	A0130/159 2 Type K	1s - Average
■	Ambient Temp	A0130/159 3 Type K	1s - Average
■	Centre (Internal)	A0130/159 4 Type K	1s - Average
■	Hot Side Heat Sink	A0130/159 5 Type K	1s - Average
■	Aluminium Can	A0130/159 6 Type K	1s - Average
■	Glass Bottle	A0130/159 7 Type K	1s - Average
■	Plastic Bottle	A0130/159 8 Type K	1s - Average