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Andy Evans - Green Light Laboratories Ltd

Liebherr Cold Storage

INTRODUCTION

Cold storage is commonplace in a variety of lab types. Some researchers opt for stand alone fridges and freezers whilst other choose fridge freezers. Working with the University of Bristol a number of different cold storage models were tested to highlight their temperature performance and energy efficiency figure 1)

Model	Unit Type	Fridge Net Capacity (L)	Freezer Net Capacity (L)
LKUv1610	Fridge	142	
LKv3913	Fridge	332	
LGUex1500	Freezer		139
LCv4010	Fridge Freezer	240	105

Figure 1. Liebherr cold storage units tested.

Testing The Units

All units were tested at the Learning and Research Centre, University of Bristol. The laboratory space used was air conditioned with an ambient of 23C (+/-1.5C). This case study used the Logicall Wireless Monitoring system utilizing their energy monitors, temperature probes and online platform to record all the data. In each compartment a UKAS calibrated PT1000 probe was placed in the centrepoint of each shelf. In each unit tested the probe located in the centrepoint of the top compartment was always 14cm from the top of the chamber. A sample representative probe (PT1000 probe immersed in 5ml of glycol) was also placed in the centrepoint of the unit (figure 2).

Figure 2. Probe positioning inside the LKv3913.

Pull Down Time	The time taken in minutes for the last probe in the compartment to reach the mean temperature measured when the unit is empty with no door openings and at the desired setpoit.
Door Opening Recovery Times	The recovery time (in minutes) is the time taken following a timed door opening for the last probe in the freezer to either (1) recover to their mean temperature for that setpoint or (2) to recover to the desired setpoint temperature.
Energy Consumption	The energy consumed by a freezer at a set temperature. The energy consumption data is measured in kWh/day and standardised to Watts Per Litre Per Day (W/L/Day). This is calculated using following equation (kWh/day/Net Capacity Litres)*1000. Both the kWh/day and W/L/Day data is reported.

Figure 3. Cold storage performance criteria.

Units were examined to identify their temperature and energy performance as defined in figure 3. Units were tested at a number of different set temperatures. All fridges and fridge compartments were set to 4C (figure 4). All freezers and freezer compartments were initially set to -20C (figure 5).

Manufacturer	Liebherr	Liebherr
Model	LKUv1610	LKv3913
Net Capacity	142	332
kWh/Day at 4C Set Point	0.787	1.473
Energy - W/L/Day	5.54	4.44
Fan/Convection	Fan	Fan
Top Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	4.5C(4.3C/4.8C)[75 minutes]	4.5C(4.0C/7.7C)[54 minutes]
Middle Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	4.0C(3.6/6.6C)[78 minutes]	2.8C(2.0C/6.8C)[39 minutes]
Sample Avg. Temperature at Set Point (Lowest/Highest)	4.1C(3.7C/6.1C)	2.9C(2.5C/6.0C)
Bottom Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	5.1C(4.8C/6.8C)[73 minutes]	4.4C(4.0C/6.7C)[62 minutes]

Figure 4. Liebherr fridges energy and temperature performance.

The energy consumption of the LKv3913in figure xxx was with the internal light switched off. When the light is switched on the energy consumption is 1.620 kWh/day (4.88 W/L/Day) at the same temperature set point. When examining the Liebherr fridge freezers the freezer compartment was set to three different set temperatures. As each compartment in the fridge freezer had a dedicated controller and compressor it was possible to isolate the energy consumption of the respective compartments allowing for the determination of the W/L/Day at specific set points (figure 5).

Cold Storage

Manufacturer	Liebherr
Model	LGUex1500
Net Capacity	139
kWh/Day at 4C Set Point	0.77
Energy - W/L/Day	5.54
Top Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-21.9C(-24.0C/-19.5C)[81 minutes]
Middle Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-22.9C(-25.2C/-20.5C)[76 minutes]
Bottom Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-17.0C(-18.0C/-15.6C)[83 minutes]

Figure 5. Liebherr freezer performance.

Manufacturer	Liebherr
Model	LCv4010
Fridge Compartment Data	
Net Capacity	240
Fan/Convection	Fan
Temperatrure Set Point	4C
Energy Consumption (kWh/day)	0.700
W/L/Day	2.92
Top Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	5.2C(4.9C/7.0C)[51 minutes]
Middle Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	4.4C(3.5C/6.9C)[26 minutes]
Sample Avg. Temperature at Set Point (Lowest/Highest)	4.4C(4.2C/6.4C)
Bottom Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	4.1C(2.4C/6.8C)[24 minutes]
Freezer Compartment Data	
Net Capacity	105
Temperatrure Set Point	-20C
Energy Consumption (kWh/day)	0.4
W/L/Day	3.81
Top Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-19.9C(-21.1C/-18.2C)[110 minutes]
Middle Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-20.3C(-20.9C/-19.6C)[119 minutes]
Sample Avg. Temperature at Set Point (Lowest/Highest)	-20.3C(-20.8C/-19.6C)
Bottom Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-23.0C(-25.7C/-20.1C)[85 minutes]
Temperatrure Set Point	-25C
Energy Consumption (kWh/day)	0.635
W/L/Day	6.05
Top Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-24.4C(-25.3C/-23.1C)
Middle Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-25.2C(-26.0C/-24.4C)
Sample Avg. Temperature at Set Point (Lowest/Highest)	-25.1C(-25.7C/-24.6C)
Bottom Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-27.7C(-29.9C/-25.2C)
Temperatrure Set Point	-30C
Energy Consumption (kWh/day)	0.805
W/L/Day	7.67
Top Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-29.8C(-30.6C/-28.8C)
Middle Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-30.4C(-30.9C/-29.9C)
Sample Avg. Temperature at Set Point (Lowest/Highest)	-30.4C(-30.8C/-29.9C)
Bottom Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-32.7C(-34.7C/-30.6C)

Figure 6. Liebherr fridge freezer performance.

With the majority of lab freezers being set to -20C the impact of setting such units to colder temperatures was measured (figure 7).

Fridge Comp. Set Point	Fridge Comp. Energy	Freezer Comp. Set Point	Freezer Comp Energy Drawers	Unit Total Energy	Freezer Energy Increase Vs -20C
4C	0.7kWh/day	-20C	0.4 kWh/day	1.100 kWh/day	
4C	0.7kWh/day	-25C	0.635 kWh/day	1.335 kWh/day	58.75%
4C	0.7kWh/day	-30C	0.805 kWh/day	1.505 kWh/day	101.25%

Figure 7. Increase in energy consumption by setting the freezer compartment to colder set points.

The units were subjected to a number of timed door openings. During these openings the unit door is opening to a 90-degree angle (figures 8 & 9).

Model	LKUexv1610	LKv3913	LCv4010
60 Second Door Opening Data			
Top Avg. Air Temperature at Set Point (Recovery)	4.5C up 3.5C to 8.0C (15 minutes)	4.2C up 5.4C to 9.6C (20 minutes)	4.9C up 4.2C to 9.1C (11 minutes)
Middle Avg. Air Temperature at Set Point (Recovery)	4.0C up 3.7C to 7.7C (5 minutes)	3.3C up 3.4C to 6.7C (10 minutes)	3.9C up 4.2C to 8.1C (7 minutes)
Sample Avg. Temperature at Set Point (Recovery)	4.1C up 2.2C to 6.3C (16 minutes)	2.8C up 2.1C to 4.9C (13 minutes)	4.2C up 1.7C to 5.9C (9 minutes)
Bottom Avg. Air Temperature at Set Point (Recovery)	4.9C up 1.1C to 6.0C (4 minutes)	4.2C up 1.0C to 5.2C (9 minutes)	3.5C up 2.2C to 5.7C (4 minutes)
90 Second Door Opening Data			
Top Avg. Air Temperature at Set Point (Recovery)	4.5C up 4.7C to 9.2C (17 minutes)	4.6 up 6.8C to 11.4C (22 minutes)	4.9C up 5.5C to 10.4C (14 minutes)
Middle Avg. Air Temperature at Set Point (Recovery)	4.0C up 5.4C to 9.4C (8 minutes)	2.7C up 5.4C to 8.1C (12 minutes)	3.9C up 6.2C to 10.1C (7 minutes)
Sample Avg. Temperature at Set Point (Recovery)	4.1C up 3.1C to 7.2C (23 minutes)	2.9C up 2.9C to 5.8C (22 minutes)	4.3C up 2.3C to 6.6C (11 minutes)
Bottom Avg. Air Temperature at Set Point (Recovery)	5.0C up 1.5C to 6.5C (7 minutes)	4.5C up 1.3C to 5.8C (12 minutes)	3.3C up 3.4C to 6.7C (6 minutes)

Figure 8. Door opening performance of Liebherr fridges and fridge compartments.

Model	LCv4010	LGUex1500
Temperature Set Poiint	-20C	-20C
60 Second Door Opening Data (Drawers)		
Top Avg. Air Temperature at Set Point (Recovery)	-20.8C up 0.9C to -19.9C (N/A)	-22.8C up 2.8CC to -20.0C (11 minutes)
Middle Avg. Air Temperature at Set Point (Recovery)	-20.3C up 0.1C to -20.2C (5 minutes)	-23.9C up 1.5C to -22.4C (10 minutes)
Sample Avg. Temperature at Set Point (Recovery)	-20.0C no rise	
Bottom Avg. Air Temperature at Set Point (Recovery)	-25.5C no rise	-17.7C up 4.4C to -13.3C (11 minutes)
90 Second Door Opening Data (Drawers)		
Top Avg. Air Temperature at Set Point (Recovery)	-18.6C up 1.7C to -16.9C (12 minutes)	-23.4C up 3.7C to -19.7C (14 minutes)
Middle Avg. Air Temperature at Set Point (Recovery)	-20.0C up 0.9C to -19.1C (26 minutes)	-22.8C up 0.4C to -22.4C (9 minutes)
Sample Avg. Temperature at Set Point (Recovery)	-20.2C up 1.0C to -19.2C (29 minutes)	
Bottom Avg. Air Temperature at Set Point (Recovery)	-20.7C up 0.6C to -20.1C (13 minutes)	-17.7C up 6.0C to -11.7C (14 minutes)

Figure 9. Door opening performance of Liebherr freezers and freezer compartments.

The freezer compartment of the LCv4010 was also tested with the drawers removed to highlight their impact upon door opening temperatures and recovery (figure 10).

Make	Liebherr	Liebherr
Model	LCv4010	LCv4010
Drawer Status	Present	Absent
Temperatrure Set Point	-25C	-25C
Energy Consumption (kWh/day)	0.635	0.588
W/L/Day	6.05	5.60
Top Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-24.4C(-25.3C/-23.1C)	-23.1C(-23.3C/-22.7C)
Middle Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-25.2C(-26.0C/-24.4C)	-23.4C(-23.6C/-23.1C)
Sample Avg. Temperature at Set Point (Lowest/Highest)	-25.1C(-25.7C/-24.6C)	-23.4C(-23.5C/-23.2C)
Bottom Avg. Air Temperature at Set Point (Lowest/Highest)[Pull Down Time]	-27.7C(-29.9C/-25.2C)	-24.1C(-24.7C/-24.1C)
60 Second Door Opening Data (Drawers)		
Top Avg. Air Temperature at Set Point (Recovery)	-24.2C up 1.8C to -22.4C (24 minutes)	-23.1C up 6.8C to -16.3C (23 minutes)
Middle Avg. Air Temperature at Set Point (Recovery)	-25.1C up 0.8C to -24.3C (22 minutes)	-23.4C up 11.6C to -11.8C (24 minutes)
Sample Avg. Temperature at Set Point (Recovery)	-25.3C up 0.8C to -24.5C (29 minutes)	-23.4C up 3.7C to -19.7C (34 minutes)
Bottom Avg. Air Temperature at Set Point (Recovery)	-26.8C up 1.0C to -25.8C (15 minutes)	-24.0C up 3.7C to -19.9C (15 minutes)
Door Opening Energy Cost (kWh)	0.010	0.056

Figure 10. Impact of drawer usage on temperature rises and recovery times following a 60 second timed door opening.

As seen in figure 10 the impact of removing the drawers from the freezer compartment resulted in higher temperature rises following a door opening. In the middle compartment the temperature rise was over 10 times higher when the drawers were absent. Furthermore, the energy required to recover from the door opening without drawers was over 5.5 times higher.

When looking at figure 9, the bottom compartment of the LGUex1500 had the largest rise in temperature following a door opening. This compartment is not supplied with a drawer as standard.

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Mr Ben Jarvis, Calibre Scientific

Mr. Ian Morris, Logicall Wireless Monitoring

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Recirculating Microbiological Safety Cabinets (Class 2)

INTRODUCTION

Microbiological safety cabinets (MSC's) are an integral part of biological research. They ensure protection for the operator and the contents within them. Over recent years there have been improvements in the energy efficiency of MSC's. These improvements include the use of efficient fan motors and the replacement of fluorescent light bulbs with light emitting diodes (LED's). BY replacing older technology units with the new, modern units, energy consumption may be reduced by ≥80% (older units have been recorded as having energy consumptions of > 0.750 kWh/h), based upon the figures published by manufacturers. This case study tested 3 MSC's, all of which are recirculating using a double High Efficiency Particulate Air (HEPA) filter. These units were tested in the lab environment at the University of Bristol (figure 1).

Figure 1. The Envair, Scanlaf and Thermo units tested.

The Lab Environment

The 3 models tested were all tested in the Biomedical Sciences Building, Floor G. All the units had been installed and commissioned, passing their KI tests. The energy consumption was measured with each unit with its sash open at 20cm, lights on and operational. Each model had internal width of ~1200mm.

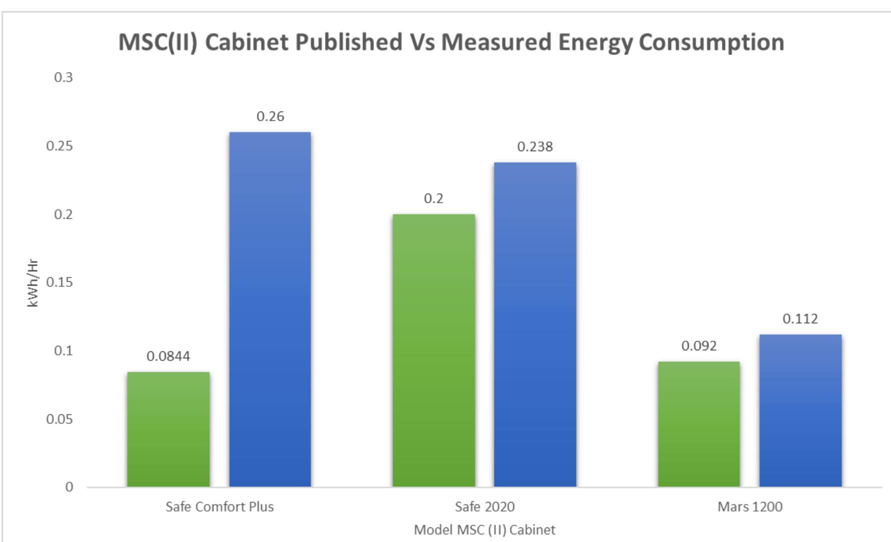

Figure 2. Measure Energy compared to the published figures for the MSC (II) Cabinets

Discussion

From the data shown in figure 2, all three models had a higher measured energy consumption compared to their published figures. In the case of the Thermo unit and the Scanlaf unit their measured energy consumption were 19% and 22% higher respectively. In the case of the Envair unit the measured energy consumption was 208% higher than the published consumption figure. It must be noted that these energy figures are only representative of those models, each in their unique place in the lab. In the case of the Scanlaf unit, this was the lowest energy consumption data measured over 24 hours. The Scanlaf unit was also energy monitored with only a single HEPA filter (installed, commissioned and KI test passed). The kWh/h data for this configuration was 0.113kWh/h – there was no significant difference following the addition of a second HEPA filter.

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Ms. Anna Lewis, Sustainable Science Manager, Sustainability Department, University of Bristol

For further information on this study, or lab sustainability in general please contact **Andy Evans**, office@greenlightlabs.co.uk. 07833 494727

Published Running Costs Data

https://pdfs.wolflabs.co.uk/Envair_Class_II_Cabinets_Comfort_Plus.pdf

https://www.thermofisher.com/order/catalog/product/51026637#/51026637
https://www.labogene.com/Class-2-Cabinets--Mars

7-Oct-21

Andy Evans - Green Light Laboratories Ltd

Autoclave Loading & Performance

Introduction

Autoclaves are vital items of equipment. Their usage is widespread allowing for the preparation of media and the sterilization of glassware, plasticware, lab garments and tools. Autoclaves are heavily used and replied upon. They carry out their function by using a combination of heat, steam and pressure. Understandably, these conditions require significant amounts of energy.

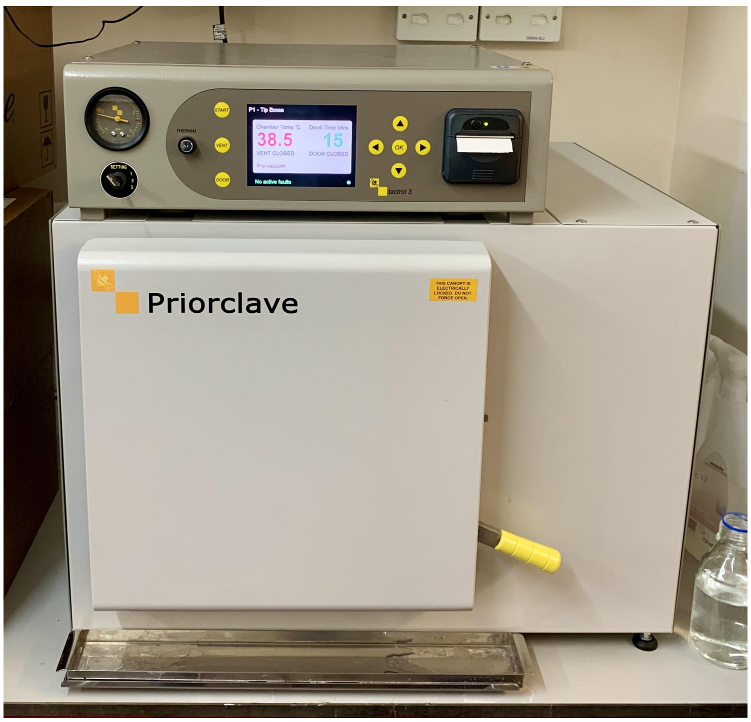

Figure 1. Priorclave Compact 40 autoclave with vacuum drying option.

Energy Cost Vs Loading

Working with staff from the Weatherall Institute of Molecular Medicine (WIMM), University of Oxford, a number of autoclave cycles were monitored using the Logicall Wireless Monitoring system energy monitors and online platform. To begin, a Priorclave Compact 40 autoclave with inbuilt vacuum drying (figure 1). The autoclave is a benchtop unit with a round chamber. The chamber was loaded with differing numbers of filled pipette tip boxes (figure 2) and the same cycle was ran (121C for 15 minutes cycle). Regardless of the load type the cycles all took 68 minutes to complete. Each load type was ran twice. The results of those runs are shown in figure 3.

Figure 2. ‘Minimal’ loading (left) and ‘maximum’ loading (right) of the Compact 40.

	Compact 40 Vacuum	
	Minimal Load	Maximum Load
Tip Boxes	3	24
1st Run Energy	1.739 kWh	1.704 kWh
2nd Run Energy	1.773 kWh	1.698 kWh
Mean Run Energy	1.756 kWh	1.701 kWh
Energy: Kg/CO2/Run	0.409	0.396

Figure 3. Running costs of carrying out the same cycle with different loads. Carbon emissions calculated at 0.233kg/kWh electricity.

Once again, same cycle using the maximum load of tip boxes was then carried out on a standard Compact 40 autoclave. This unit did not have the vacuum drying feature. Regardless of having the vacuum drying feature tip boxes from both autoclaves required drying in a glassware drying cabinet. The duration of drying required differed depending on which autoclave was used for their sterilization. To understand the total cost of sterilizing and then drying the tip boxes, the glassware drying cabinet, an E3 883 litre, fan driven unit was also energy monitored. The results from this testing is shown in figure 4.

	Maximum Tip Boxes Load (24 boxes)	
	Compact 40 Vacuum	Compact 40
Cycle Time	68 minutes	122 minutes
Cycle Energy	1.701 kWh	1.329 kWh
Drying Cabinet Drying Time (55C)	60 minutes	180 minutes
Drying Cabinet Energy (55C)	0.648 kWh	1.944 kWh
Cycle Time + Drying Time	128 minutes	302 minutes
Cycle Energy + Drying Energy	2.349 kWh	3.273 kWh
Energy: Kg/CO2/Run	0.547	0.763

Figure 5. Comparing the cycle times and costs to sterilize & dry the same load in the vacuum drying and standard versions of the Compact 40.

Discussion

The testing carried out at the WIMM has highlighted a number of interesting points. Firstly, is that the loading of an autoclave does have a small effect upon the energy consumption. Running costs per cycle appear to be slightly higher when the chamber is not fully loaded. Secondly, the use of vacuum drying had a number of benefits. To begin with, the cycle time was faster, with the cycle taking **79.4%** longer in the non-vacuum drying unit. This had a knock on effect upon drying with the vacuum drying tip boxes requiring one third of the time to dry (and one third of the energy) compared to the non-vacuum unit. The overall time to process the tip boxes was more than doubled when using the non-vacuum drying unit with the overall energy (and associated carbon emissions) also being **39.5%** higher.

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Mr. Ian Morris & Mr. Tom Hunt, Logicall Wireless Solutions Ltd.

For further information on this study, or lab sustainability in general please contact **Andy Evans**, office@greenlightlabs.co.uk. 07833 494727

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ULT Freezer Racking Study – Part II

INTRODUCTION

Ultra Low Temperature (ULT) freezers are a predominantly used in life sciences for the long term storage of valuable samples and products. The use of racking can vary between organizations with some ULT freezers being completely racked (figure 1) whilst others are devoid of any racking whatsoever. Racking can be made of aluminium or stainless steel. This study completes the case study from October 2018 by repeating the procedure using the same conditions, location and freezer unit, this time using stainless steel racking. This study now compares the impact of different types of metal racking upon the temperature and energy performance of a ULT freezer at the -80C set point.

Figure 1. ULT freezer fully racked with temperature loggers in place.

Testing The Impact Of Racking

The data was collected over a three week period at the Department of Plant Sciences, University of Oxford. The Eppendorf ULT freezer (F570h) tested was supplied for the study by Scientific Laboratory Supplies Ltd, with both companies jointly funding the study, and the racking was supplied by Wesbart UK Ltd. The racking was in the format of front opening outers designed to house standard cryoboxes. The total weight of the aluminium racking used was 90kg, the total weight of the steel racking used was 145kg. The unit was tested in an air conditioned laboratory where the ambient temperature was recorded at 19C (+/-1C). The ULT freezer had a temperature logger placed at the centre point of each of its shelf, with a further two loggers placed at the centre front and centre back points of the centre shelf (Compartment 3). This temperature logger recorded the internal temperature every minute, accurate to 0.1C. The temperature loggers used were MadgeTech Cryotemp Data Loggers, supplied by Wessex Power. Compartments were numbered in descending order meaning that the top compartment was labelled as compartment 1 and the bottom compartment is compartment 5. The energy monitors used had a kWh reading variance of +/- 1%. The ULT freezer was subjected to a number of tests. The tests measuring temperature and energy performance at the -80C set point without any door openings are summarized in Figure 1. Please note that a different method has been employed to measure pull down times. In this case study, the pull down time has been calculated for **each freezer compartment**. The pull down time is measured as when the compartment reaches its **exact** average temperature at the -80C set point (measured over a 24 hour period), meaning it was measured to the tenth of a degree Celsius. Most existing methods of measuring pull down times are not measured so precisely, relying on a single probe in many cases.

Measurement	Empty F570h ULT Freezer	Aluminium Racked F570h ULT Freezer	Steel Racked F570h ULT Freezer
Energy Consumption	7.57 kWh	7.20 kWh	7.77 kWh
Compartment 1 Average Temperature (Pull Down Time)	-78.6C (5 Hours 24 Minutes)	-78.9C (9 Hours 31 Minutes)	-76.7C (9 Hours 29 Minutes)
Compartment 2 Average Temperature (Pull Down Time)	-79.9C (6 Hours 38 Minutes)	-79.3C (12 Hours 31 Minutes)	-78.6C (10 Hours 29 Minutes)
Compartment 3 Back Avg. Temperature (Pull Down Time)	-81.5C (3 Hours 34 Minutes)	-80.5C (13 Hours 19 Minutes)	-79.3C (20 Hours 59 Minutes)
Compartment 3 Middle Avg. Temperature (Pull Down Time)	-80.2C (4 Hours 57 Minutes)	-79.4C (15 Hours 32 Minutes)	-78.9C (20 Hours 59 Minutes)
Compartment 3 Front Avg.Temperature (Pull Down Time)	-80.4C (4 Hours 36 Minutes)	-79.5C (18 Hours)	-78.6C (19 Hours 27 Minutes)
Compartment 4 Average Temperature (Pull Down Time)	-79.2C (3 Hours 44 Minutes)	-79.2C (15 Hours 12 Minutes)	-77.9C (17 Hours 59 Minutes)
Compartment 5 Average Temperature (Pull Down Time)	-76.7C (3 Hours 39 Minutes)	-77.4C (19 Hours 43 Minutes)	-75.3C (7 Hours 28 Minutes)
Compartment 1 Warm Up Time To -50C	4 Hours 19 Minutes	8 Hours 44 Minutes	8 Hours 11 Minutes
Compartment 2 Warm Up Time To -50C	5 Hours 12 Minutes	11 Hours 4 Minutes	11 Hours 1 Minute
Compartment 3 Back Warm Up Time To -50C	5 Hours 55 Minutes	13 Hours 11 Minutes	13 Hours 8 Minutes
Compartment 3 Middle Warm Up Time To -50C	5 Hours 54 Minutes	13 Hours 5 Minutes	13 Hours 30 Minutes
Compartment 3 Front Warm Up Time To -50C	5 Hours 49 Minutes	13 Hours 2 Minutes	13 Hours 15 Minutes
Compartment 4 Warm Up Time To -50C	6 Hours 10 Minutes	14 Hours 23 Minutes	14 Hours 36 Minutes
Compartment 5 Warm Up Time To -50C	6 Hours 10 Minutes	14 Hours 24 Minutes	14 Hours 24 Minutes

Figure 2. ULT Temperature and energy performance at -80C set point, empty and racked.

A number of timed door openings were also carried out. All doors were opened to a 90 degree angle and then closed within the allotted time. Figure 3 shows the temperature changes following a 60 second door opening. Please note that when reading the legend all data with the prefix E is from the empty freezer and data with the prefix R is from the racked freezers.

In total there were 4.5 minutes of door openings carried out on each unit configuration during those two weeks of testing. In the empty ULT freezer these door openings used 0.78 kWh of electricity whilst in the aluminium racked unit these door openings used 1.27 kWh of electricity. When steel racking was used these door openings used 1.47 kWh of electricity.

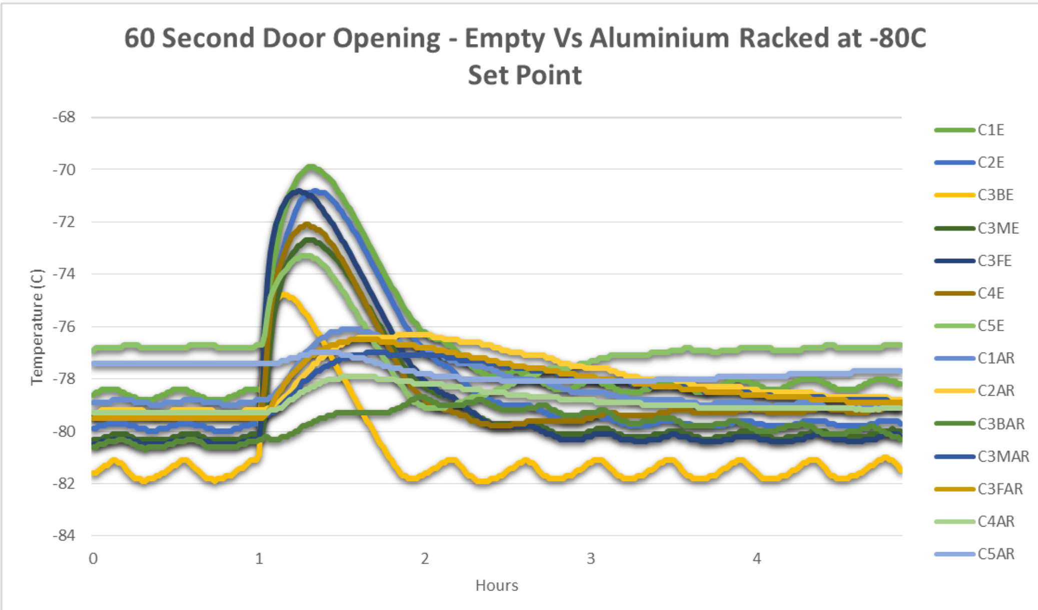

Figure 3. Effects of a 60 second door opening on ULT freezer compartment temperatures (aluminium racked Vs empty)

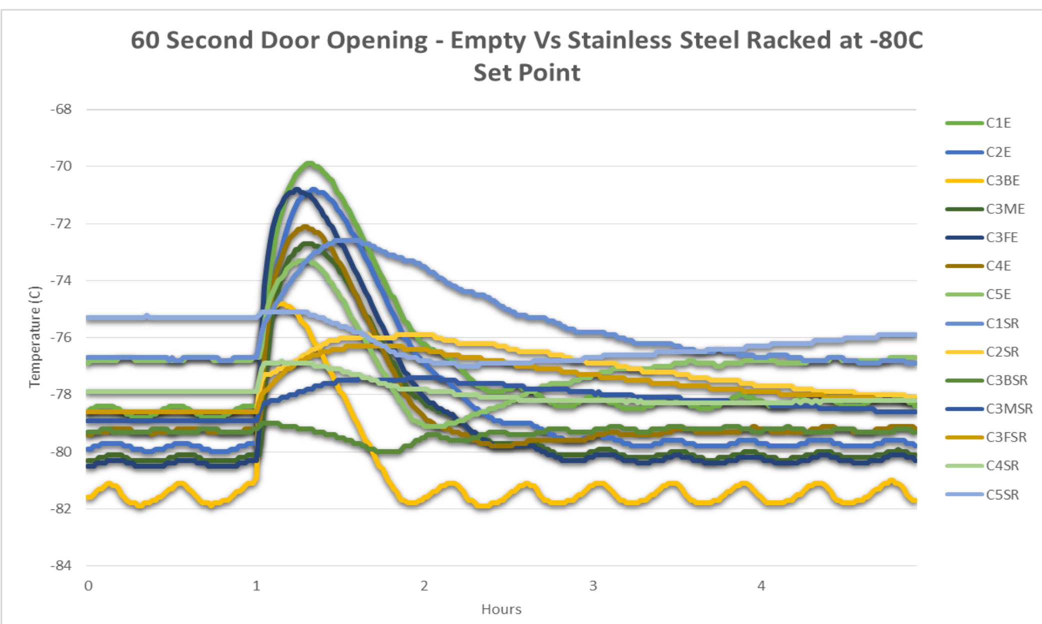

Figure 4. Effects of a 60 second door opening on ULT freezer compartment temperatures (stainless steel racked Vs empty)

F570h ULT Freezer Compartment	Warmest Temperature Following: 60 Second Door Opening	90 Second Door Opening	120 Second Door Opening
Empty Unit, Compartment 1	-69.9C	-66.1C	-63.1C
Empty Unit, Compartment 2	-70.8C	-66.9C	-64.1C
Empty Unit, Compartment 3, Back	-74.8C	-71.9C	-69.9C
Empty Unit, Compartment 3, Middle	-72.7C	-69.3C	-66.6C
Empty Unit, Compartment 3, Front	-70.8C	-66.3C	-63.0C
Empty Unit, Compartment 4	-72.1C	-68.8C	-66.5C
Empty Unit, Compartment 5	-73.4C	-71.6C	-70.3C
Aluminium Racked Unit, Compartment 1	-76.1C	-74.4C	-72.7C
Aluminium Racked Unit, Compartment 2	-76.3C	-74.6C	-73.3C
Aluminium Racked Unit, Compartment 3, Back	-78.7C	-77.6C	-76.8C
Aluminium Racked Unit, Compartment 3, Middle	-77.0C	-75.4C	-74.4C
Aluminium Racked Unit, Compartment 3, Front	-76.5C	-74.8C	-73.7C
Aluminium Racked Unit, Compartment 4	-77.9C	-76.5C	-75.9C
Aluminium Racked Unit, Compartment 5	-77.0C	-76.5C	-76.4C
Steel Racked Unit, Compartment 1	-72.6C	-70.7C	-69.1C
Steel Racked Unit, Compartment 2	-75.9C	-73.8C	-71.9C
Steel Racked Unit, Compartment 3, Back	-79.0C	-77.6C	-76.6C
Steel Racked Unit, Compartment 3, Middle	-77.4C	-75.7C	-74.5C
Steel Racked Unit, Compartment 3, Front	-76.3C	-74.5C	-73.2C
Steel Racked Unit, Compartment 4	-76.8C	-75.8C	-75.0C
Steel Racked Unit, Compartment 5	-75.1C	-74.4C	-73.9C

Figure 5. Effect of timed door openings on ULT freezer compartment temperatures.

It was also observed that in the case of the steel racked ULT freezer, to recover temperature following a timed door opening was as follows 60 seconds = 5 hours 59 minutes, 90 seconds = 6 hours 52 minutes 120 seconds = 7 hours 51 minutes. In the empty ULT freezer, to recover temperature following a timed door opening was as follows 60 seconds = 2 hours 2 minutes, 90 seconds = 2 hours 30 minutes, and 120 seconds = 3 hours 30 minutes. In the racked unit these recovery times double.

DISCUSSION

Although it was observed that the racked units took longer to recover from a door opening those units remained significantly colder than the non-racked unit. After a 60 second door opening temperatures in a racked unit will be as much as 6C colder than the empty ULT freezer.

With longer door openings of 90 and 120 seconds these temperatures can be up to 7C and 10C colder respectively. The temperatures recorded in the aluminium and steel racked ULT freezer after a 120 second door opening were **colder** than those recorded in the empty ULT freezer following a 60 second door opening. The racking was able to absorb the heat following a door opening resulting in the lower rises in temperature. With the racked units containing 90kg (aluminium) and 145kg (steel) more metal than the empty unit the recovery times are subsequently longer.

The effect of the aluminium racking (figure 2) also resulted in the warmer temperatures observed in the empty ULT freezer (Compartments 1 and 5) being **colder** in the aluminium racked unit; there was a more even distribution of temperature. In the case of the steel racking all temperatures compared to the empty ULT freezer.

There was no significant difference between the warm up times observed in the aluminium and steel racked units. Although the racked units, more so the steel racked unit, had observed increases in average compartment temperatures racking also resulted in at least a doubling of the warm up times to -50C. In some compartments this warm up time was **137% longer**. This would give end users longer to manage the safe transfer of samples following a loss of power/failure. Also, although door openings were compared during this study it must be noted that when a ULT freezer is racked keeping an inventory and therefore locating contents is easier and faster. Therefore in a racked unit door openings would logically be shorter compared to that of an equally full non-racked ULT freezer. The impact of this in the racked ULT freezer would be even smaller rises in internal temperatures and a lower cost in electricity associated with accessing samples (providing end users were employing a proper inventory).

Furthermore, to save energy end users could fully rack a ULT freezer and operate it at warmer temperatures (-75C or -70C). The racking would greatly decrease the impact of a door opening ensuring that samples always remained at an acceptable temperature. This will be further explored in future case studies.

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