Cold Storage: Usage & Performance

IMPACTS OF LOADING, INVENTORY, AND SET TEMPERATURE UPON ENERGY CONSUMPTION

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Introduction

Cold storage is mandatory for many researchers. Researchers require their samples or products to be stored at a specific temperature. Typically, a fridge will be set to maintain a chamber temperature of 4°C, the set temperature for a lab freezer is -20°C. Unit performance at these set points will vary between models and will be impacted by usage such as the use of an inventory (figure 1).

Figure 1. A simple fridge inventory employed during the case study, indicating ownership of each shelf.

Case Study Aims

Usage can be translated as best practice and is an effective tool for end users to minimize their running costs and waste. Conversely, end user actions can result in higher equipment running costs. This case study aimed to highlight the following:

1. Baseline energy consumption and temperature performance of brand-new fridges and freezers.
2. Measure temperature recovery times following a door opening and quantify the energy used to do so.
3. Measure energy consumption and temperature performance of fridges storing identical loads.
4. Measure the impact of inventory usage upon loaded fridge door opening times and energy.
5. Compare the changes in freezer energy consumption from changing the set temperature.

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 temperature of 23°C (+/-1.5°C). 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 centre point of each shelf. In each unit tested the probe located in the centre point 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 centre point of the unit. The energy monitors employed had an accuracy of +/-1%.

The criteria used during the testing are defined in figure 2.

Pull Down Time	The time taken in minutes for the last probe in the chamber/comparment to reach the mean temperature measured when the unit is empty with no door openings and at the desired set temperature,
Doopr Opening Recovery Time	The time taken in minutes following a door opening or series of door openings for the unit to recover to the mean temperature for that setpoint, or, the desired set temperature if the mean temperature were to be colder than the setpoint (-20C).
Energy Consumption	The energy consumed by the fridge or freezer at a set temperature.The energy consumption data is measured in kWh/day and stadardised to Watts Per Litre Per Day (W/L/Day). This is calculated using the following equation (kWh/day/Net Litre Capacity)*1000. Both the kWh/day and W/L/Day data is reported.
Warm Up Time	The time taken in minutes for each probe in the chamber/comparment to reach the specific threshold temperature after the unit is switched off, during this time the doors remain closed.

Figure 2. Cold storage performance criteria.

Fridge and Freezer Baseline Performance Data

All fridges and freezers were tested empty. The data collected from the fridges is shown in figure 4. However, prior to this data it was observed that both the Haier Biomedical and Liebherr fridges had specific **loading lines** affixed to their chambers (figure 3). Loading contents past these lines was prohibited and this was adhered to throughout the case study. However, these unusable spaces were not discounted from the published net capacity of the fridges. Therefore, these unusable spaces were measured and their volume discounted from the published net capacity.

In the case of the Haier Biomedical fridge the usable net capacity was measured at 214 litres. This was a 31% reduction compared to their published net capacity of 310 litres. In the case of the Liebherr fridge the usable net capacity was measured at 291 litres. This was a 2% reduction compared to their published net capacity of 298 litres. The measured usable net capacity for both units were employed in calculating unit space efficiency and energy efficiency (W/L/Day).

Figure 3. The two loading lines inside the Haier Biomedical fridge. On the left, no contents may be stored above the red line. The right, no contents may be stored below the red line.

Fridge Performance Data

All three fridge models were upright models, also referred to as 'tall' fridges. All units used hydrocarbon refrigerants and had solid doors. All fridges employed an in chamber fan. Which improves temperature uniformity and door opening recovery times. The energy consumption and temperature performance of each fridge at the set temperature of 4°C is shown in figure 4.

Manufacturer	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Published Net Capacity (L)	310	410	298
Adjusted Net Capacity (L)*	**214**	**410**	**291**
kWh/Day at 4C Set Point	**1.192**	**1.19**	**0.916**
Energy - W/L/Day	**5.57**	**2.90**	**3.15**
Top Comp. Mean Air Temp(Lowest/Highest)(Pull Down Time)	4.2C(3.4C/5.9C)(35 minutes)	4.9C(4.6C/5.2C)(70 minutes)	3.7C(3.2C/4.5C)(50 minutes)
Mid Comp. Mean Air Temp(Lowest/Highest)(Pull Down Time)	3.5C(2.8CC/4.9C)(51 minutes)	4.2C(3.6C/4.9C)(42 minutes)	3.4C(2.8C/4.4C)(27 minutes)
Mid Comp. Mean Sample Temp(Lowest/Highest)	3.5C(3.2C/4.6C)	4.1C(3.8C/4.3C)	3.4C(3.1C/4.0C)
Bottom Comp. Mean Air Temp(Lowest/Highest)(Pull Down Time)	3.2C(-0.3C/5.8C)(24 minutes)	5.3C(5.0C/5.6C)(71 minutes)	4.1C(3.7C/4.9C)(49 minutes)

Figure 4. Fridge energy and temperature performance at the set temperature of 4°C.

Two timed door openings were then carried out. The door opening recovery times, temperature performance and energy consumption is shown in figure 5. Each fridge was then subjected to a series of door openings each carried out over an 8 hour period, representing a working day, the results of these door openings are shown in figure 6.

Manufacturer	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Adjusted Net Capacity (L)	214	410	291
A. Single 60 Second Door Opening			
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.5C(9.6C/6.1C)[7 minutes]	5.0C(9.3C/4.3C)[30 minutes]	3.8C(8.8C/5.0C)[11 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	2.9C(4.9C/2.0C)[3 minutes]	4.4C(8.4C/4.0C)[29 minutes]	3.5C(7.6C/4.1C)[9 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.3C(3.6C/0.3C)[0 minutes]	4.2C(6.5C/2.3C)[22 minutes]	3.6C(5.6C/2.0C)[12 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	1.8C(2.5C/0.7C)[0 minutes]	5.3C(7.3C/2.0C)[30 minutes]	4.2C(4.9C/0.7C)[10 minutes]
B. Single 90 Second Door Opening			
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.8C(11.0C/6.2C)[8 minutes]	4.8C(10.9C/6.1C)[30 minutes]	3.3C(9.9C/6.6C)[14 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	2.9C(5.9C/3.0C)[5 minutes]	4.1C(10.2C/6.1C)[9 minutes]	2.8C(9.6C/6.8C)[12 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.3C(4.0C/0.7C)[0 minutes]	3.9C(6.6C/2.7C)[20 minutes]	3.1C(6.5C/3.4C)[15 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	0.6C(3.4C/2.8C)[0 minutes]	5.3C(8.2C/2.9C)[19 minutes]	3.8C(5.5C/1.7C)[13 minutes]
Door Opening Energy Cost (A+B)	**0.015 kWh**	**0.017 kWh**	**0.006 kWh**
W/L/Day of Door Opening Energy Cost (A+B)	**0.07 W/L/Day**	**0.04 W/L/Day**	**0.02 W/L/Day**

Figure 5. Fridge timed door opening performance data.

Manufacturer	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Net Capacity (L)	214	410	291
OCCASIONAL DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	**17**		
Interval Between Door Openings	**30 minutes**		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	4.2C(9.9C/5.7C)[8 minutes]	4.8C(10.1C/5.3C)[30 minutes]	3.4C(10.1C/6.5C)[13 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.6C(6.3C/2.7C)[3 minutes]	4.0C(9.3C/6.6C)[10 minutes]	3.0C(8.7C/5.7C)[9 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.5C(4.5C/1.0C)[0 minutes]	4.3C(7.0C/3.7C)[20 minutes]	3.3C(6.3C/3.0C)[12 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.9C(5.0C/1.1C)[0 minutes]	5.4C(7.8C/2.8C)[30 minutes]	3.9C(5.6C/1.7C)[13 minutes]
Occasional Door Openings Energy Consumption	**0.150 kWh**	**0.254 kWh**	**0.080 kWh**
Occasional Door Openings Energy Consumption W/L/Day	**0.70 W/L/Day**	**0.62 W/L/Day**	**0.27 W/L/Day**
REGULAR DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	**25**		
Interval Between Door Openings	**20 minutes**		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	4.1C(11.5C/7.4C)[7 minutes]	5.1C(10.6C/5.5C)[19 minutes]	3.3C(10.1C/6.8C)[14 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.6C(6.7C/2.9C)[5 minutes]	4.6C(10.7C/6.1C)[10 minutes]	2.9C(9.6C/6.7C)[12 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.5C(5.3C/1.8C)[5 minutes]	4.2C(6.7C/2.5C)[19 minutes]	3.3C(7.0C/3.7C)[14 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	4.0C(6.1C/2.1C)[0 minutes]	5.4C(8.1C/2.7C)[19 minutes]	3.7C(6.8C/3.1C)[15 minutes]
Regular Door Openings Energy Consumption	**0.192 kWh**	**0.343 kWh**	**0.097 kWh**
Regular Door Openings Energy Consumption W/L/Day	**0.90 W/L/Day**	**0.84 W/L/Day**	**0.33 W/L/Day**
FREQUENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	**33**		
Interval Between Door Openings	**15 minutes**		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	4.0C(10.2C/6.2C)[6 minutes]	5.2C(9.9C/4.7C)[29 minutes]	3.8C(9.3C/5.5C)[13 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.4C(6.2C/2.8C)[5 minutes]	4.6C(9.2C/4.6C)[10 minutes]	3.6C(8.1C/4.5C)[10 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.2C(5.0C/1.8C)[0 minutes]	4.2C(6.3C/2.1C)[11 minutes]	3.3C(6.5C/3.2C)[13 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.8C(5.8C/2.0C)[0 minutes]	5.6C(7.7C/2.1C)[29 minutes]	4.1C(6.1C/2.0C)[11 minutes]
Frequent Door Openings Energy Consumption	**0.201 kWh**	**0.366 kWh**	**0.131 kWh**
Frequent Door Openings Energy Consumption W/L/Day	**0.94 W/L/Day**	**0.89 W/L/Day**	**0.45 W/L/Day**
PERSISTENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	**48**		
Interval Between Door Openings	**10 minutes**		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.5C(9.0C/5.5C)[7 minutes]	4.8C(10.7C/5.9C)[27 minutes]	3.3C(10.5C/7.2C)[12 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.0C(5.0C/2.0C)[5 minutes]	3.9C(9.1C/5.2C)[7 minutes]	2.9C(9.1C/6.2C)[9 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.3C(3.9C/0.6C)[0 minutes]	4.1C(6.4C/2.3C)[17 minutes]	3.3C(7.3C/4.0C)[11 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	0.6C(2.7C/2.1C)[0 minutes]	5.1C(7.7C/2.6C)[27 minutes]	3.7C(6.0C/2.3C)[9 minutes]
Persistent Door Openings Energy Consumption	**0.340 kWh**	**0.525 kWh**	**0.234 kWh**
Persistent Door Openings Energy Consumption W/L/Day	**1.59 W/L/Day**	**1.28 W/L/Day**	**0.80 W/L/Day**

Figure 6. Fridge door openings at increasing frequencies.

Freezer Performance Data

All three freezer models were upright models, also referred to as 'tall' freezers. All units used hydrocarbon refrigerants and had solid doors. The Lec and Liebherr models were supplied with solid drawers. The Labcold model were supplied without drawers.

Typically freezers are operated at the -20°C set temperature. The Lec model had an advertised operating temperature range of -18°C to -25°C. However, upon consultation with the manufacturer it was confirmed that the model could only be set between -23°C and -26°C with the temperature range representing the typical chamber temperatures measured at the available set temperatures. For the purpose of this case study the -23°C set temperature was used for the Lec model however for performance criteria (figure 2) -20°C was the desired temperature.

The energy consumption and temperature performance of each freezer at the set temperature of -20°C is shown in figure 7. Two timed door openings were then carried out. The door opening recovery times, temperature performance and energy consumption is shown in figure 8. Each freezer was then subjected to a series of door openings each carried out over an 8 hour period, representing a working day, the results of these door openings are shown in figure 9.

Manufacturer	Labcold	Lec	Liebherr
Model	RLVF2025	LSFSF312BT	FSSfg4001
Net Capacity (L)	451	290	190
PERFORMANCE DATA			
Set Temperature	**-20C**	**-23C**	**-20C**
kWh/Day	**2.989**	**1.286**	**1.038**
Energy - W/L/Day	**6.63**	**4.43**	**5.46**
Top Comp. Mean Air Temp(Lowest/Highest)(Pull Down Time)	-19.2C(-20.1C/-17.6C)(141 minutes)	-19.6C(-21.6C/-16.8C)(122 minutes)	-18.8C(-19.5C/-17.9C)(122 minutes)
Middle Comp. Mean Air Temp(Lowest/Highest)(Pull Down Time)	-20.7C(-22.4C/-19.0C)(142 minutes)	-22.8C(-24.0/-21.6C)(121 minutes)	-21.4C(-21.6C/-22.4C)(121 minutes)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-20.2C(-21.0C/-19.3C)	-22.4C(-23.0C/-21.7C)	-21.5C(-21.6C/-21.3C)
Bottom Comp. Mean Air Temp(Lowest/Highest)(Pull Down Time)	-19.8C(-21.9C/-17.8C)(53 minutes)	-17.0(-17.7C/-16.3C)(91 minutes)	-22.7C(-23.3C/-21.9C)(91 minutes)
WARM UP TIME TO -9C			
Top Compartment	54 minutes	122 minutes	107 minutes
Middle Compartment	62 minutes	214 minutes	197 minutes
Middle Compartment Sample	68 minutes	212 minutes	203 minutes
Bottom Compartment	52 minutes	161 minutes	183 minutes

Figure 7. Freezer energy and temperature performance at the set temperature of -20°C.

Manufacturer	Labcold	Lec	Liebherr
Model	RLVF2025	LSFSF312BT	FSSfg4001
Net Capacity (L)	451	290	190
A. Single 60 Second Door Opening			
Top Comp. Start Air Temp(Peak/Rise)(Recovery Time)	-19.3C(-2.3C/17.0C)(17 minutes)	-17.5C(-7.2C/10.3C)(19 minutes)	-19.4C(-9.4C/10.0C)(18 minutes)
Middle Comp. Start Air Temp(Peak/Rise)(Recovery Time)	-20.8C(-6.5C/14.3C)(17 minutes)	-21.8C(-19.1C/2.7C)(6 minutes)	-21.4C(-20.2C/1.2C)(0 minutes)
Middle Comp. Start Sample Temp (Peak/Rise)(Recovery Time)	-20.5C(-13.1C/7.4C)(36 minutes)	-21.9C(-20.4C/1.5C)(0 minutes)	-21.4(-20.7C/0.7C)(0 minutes)
Bottom Comp. Start Sample Temp (Peak/Rise)(Recovery Time)	-19.8C(-11.9C/7.9C)(16 minutes)	-16.6C(-15.8C/0.8C)(45 minutes)	-23.2C(-22.6C/1.4C)(0 minutes)
B. Single 90 Second Door Opening			
Top Comp. Start Air Temp(Peak/Rise)(Recovery Time)	-19.4(2.2C/21.6C)(21 minutes)	-19.8C(-1.9C/17.9C)(24 minutes)	-19.5C(-7.2C/12.3C)(20 minutes)
Middle Comp. Start Air Temp(Peak/Rise)(Recovery Time)	-20.9C(-3.1C/17.8C)(19 minutes)	-22.6C(-18.6C/2.6C)(12 minutes)	-21.5C(-19.4C/2.1C)(16 minutes)
Middle Comp. Start Sample Temp (Peak/Rise)(Recovery Time)	-20.8C(-10.9C/9.9C)(40 minutes)	-22.6C(-19.8C/2.8C)(14 minutes)	-21.5C(-20.1C/1.4C)(0 minutes)
Bottom Comp. Start Sample Temp (Peak/Rise)(Recovery Time)	-19.9C(-10.1C/9.8C)(19 minutes)	-16.9C(-11.5C/5.4C)(112 minutes)	-22.9C(-22.1C/0.8C)(0 minutes)
Door Opening Energy Cost (A+B)	**0.132kWh**	**0.062 kWh**	**0.080 kWh**
Door Opening Energy Cost (A+B) W/L/Day	**0.29 W/L/Day**	**0.21 W/L/Day**	**0.42 W/L/Day**

Figure 8. Freezer timed door opening performance data.

Manufacturer	Labcold	Lec	Liebherr
Model	RLVF2025	LSFSF312BT	FSSfg4001
Net Capacity (L)	451	290	190
OCCASIONAL DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	17		
Interval Between Door Openings	30 minutes		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-19.0C(-0.3C/18.7C)[21 minutes]	-17.7C(-4.6C/13.1C)[52 minutes]	-19.6C(-8.8C/10.8C)[14 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-20.7C(-4.7C/16.0C)[19 minutes]	-21.8C(-18.3C/3.5C)[0 minutes]	-21.7C(-20.2C/1.5C)[0 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	-20.6C(-11.4C/8.8C)[41 minutes]	-21.7C(-19.4C/2.3C)[0 minutes]	-21.8C(-20.8C/1.0C)[0 minutes]
Bottom Comp. Start Air Temp (Peak/Rise)[Recovery Time]	-19.4C(-10.3C/9.1C)[19 minutes]	-16.3C(-11.2C/5.1C)[45 minutes]	-23.1C(-22.5C/0.6C)[0 minutes]
Occasional Door Openings Energy Consumption	1.020 kWh	0.593 kWh	0.576 kWh
Occasional Door Openings Energy Consumption W/L/Day	2.26 W/L/Day	2.04 W/L/Day	3.03 W/L/Day
REGULAR DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	25		
Interval Between Door Openings	20 minutes		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-20.4C(-1.3C/19.1C)[23 minutes]	-18.3C(-2.0C/16.3C)[DNR]	-18.9C(-9.5C/9.4C)[17 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-21.7C(-6.9C/14.8C)[18 minutes]	-22.6C(-17.5C/5.1C)[8 minutes]	-21.5C(-18.7C/2.8C)[8 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	-20.7C(-10.9C/9.8C)[25 minutes]	-22.4C(-19.8C/2.6C)[10 minutes]	-21.3C(-19.4C/1.9C)[0 minutes]
Bottom Comp. Start Air Temp (Peak/Rise)[Recovery Time]	-21.3C(-11.3C/10.0C)[19 minutes]	-16.7C(-9.1C/7.6C)[268 minutes]	-21.9C(-22.3C/-0.4C)[0 minutes]
Regular Door Openings Energy Consumption	1.792 kWh	0.796 kWh	0.881 kWh
Regular Door Openings Energy Consumption W/L/Day	3.97 W/L/Day	2.74 W/L/Day	4.64 W/L/Day
FREQUENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	33		
Interval Between Door Openings	15 minutes		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-18.6C(-1.7C/16.9C)[22 minutes]	-16.4C(-0.9C/15.5C)[DNR]	-18.8C(-8.6C/10.2C)[17 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-20.3C(-8.3C/12.0C)[18 minutes]	-22.3C(-15.4C/6.9C)[14 minutes]	-21.2C(-17.3C/3.9C)[16 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	-20.2C(-12.6C/7.4C)[22 minutes]	-22.3C(-18.3C/4.0C)[19 minutes]	-21.3C(-18.5C/2.8C)[19 minutes]
Bottom Comp. Start Air Temp (Peak/Rise)[Recovery Time]	-19.0C(-11.5C/7.5C)[20 minutes]	-16.2C(-9.4C/6.8C)[292 minutes]	-22.4C(-21.6C/0.8C)[0 minutes]
Frequent Door Openings Energy Consumption	1.847 kWh	0.787 kWh	0.944 kWh
Frequent Door Openings Energy Consumption W/L/Day	4.10 W/L/Day	2.71 W/L/Day	4.97 W/L/Day
PERSISTENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings	48		
Interval Between Door Openings	10 minutes		
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-17.3C(0.8C/18.1C)[28 minutes]	-17.3C(1.2C/18.5C)[DNR]	-18.7C(-7.9C/10.8C)[17 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	-19.0C(-9.6C/9.4C)[21 minutes]	-24.0C(-11.9C/12.1C)[36 minutes]	-20.9C(-14.5C/6.4C)[20 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	-20.7C(-17.3C/3.4C)[27 minutes]	-23.7C(-13.8C/9.9C)[40 minutes]	-20.9C(-16.5C/2.2C)[21 minutes]
Bottom Comp. Start Air Temp (Peak/Rise)[Recovery Time]	-17.8C(-8.1C/7.9C)[25 minutes]	-16.5C(-7.1C/5.0C)[DNR]	-21.9C(-21.6C/0.3C)[0 minutes]
Persistent Door Openings Energy Consumption	2.080 kWh	0.929 kWh	1.385 kWh
Persistent Door Openings Energy Consumption W/L/Day	4.61 W/L/Day	3.20 W/L/Day	7.29 W/L/Day

Figure 9. Freezer door openings at increasing frequencies. The Lec model did not recover (DNR) all probes to the mean probe temperature from the regular door opening sequence (figure 10) through to the persistent door opening sequence.

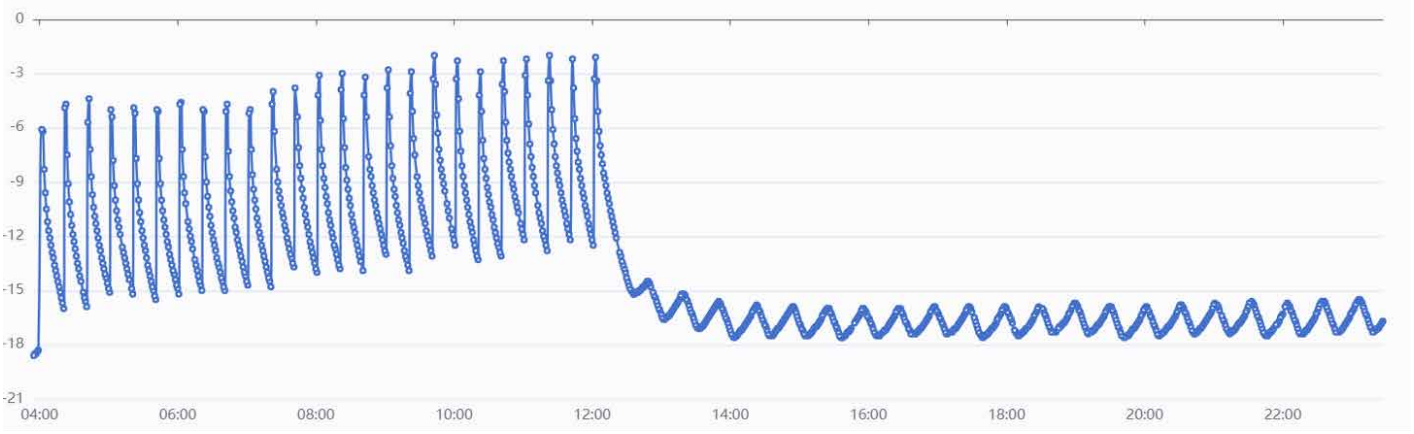

Figure 10. Following the completion of the regular door opening sequence the top compartment probe in the Lec model did not recover back down to its mean temperature, stabilising at a temperature range with a warmer mean temperature. This also occurred with the bottom compartment probe following the persistent door opening sequence.

Fridge Loading

The three fridges were then loaded with a variety of labelled storage containers (figure 11). Two types of Cryoboxes were used: aluminium. These were provided by Wesbart Ltd. Both cryobox types were supplied by Wesbart Ltd. Each cryobox contained 100ml of water housed in a 5g grip seal polyethene bag. Alongside the cryoboxes a variety of polypropylene tubes in racks or containers were also used and filled with water, these were all supplied by Calibre Scientific (figure 4). The Learning and Research Centre also donated 500ml and 1000ml Duran bottles. Once loaded, all fridges were left for >48 hours until all contents were chilled and chamber probe temperatures were stabilized.

Figure 11. Each fridge loaded with the same items and volumes of water. Each shelf has been labelled with a yellow sticker denoting ownership, these labels were used in the final phase of the inventory testing (highly organised access).

The total amounts of material stored in each fridge were measured and are summarized in figure 12.

Material	Total Weight
Glass	7.6505 kg
Plastics	3.9541 kg
Water	16.3800 kg
Metal	0.4346 kg
Total	**28.0592 kg**

Figure 12. Total amounts of material stored in each fridge.

The energy consumption and temperature performance of each fridge at the set temperature of 4°C is shown in figure 13. Two timed door openings were then carried out on the loaded fridges. The door opening recovery times, temperature performance and energy consumption is shown in figure 14.

Manufacturer	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Published Net Capacity (L)	310	410	298
Usable Net Capacity (L)	214	410	291
PERFORMANCE DATA			
kWh/Day at 4C Set Point	**1.197**	**1.18**	**0.899**
Energy - W/L/Day	**5.59**	**2.88**	**3.09**
Top Comp. Mean Air Temp(Lowest/Highest)[Warm up to 10C]	4.1C(3.3C/5.1C)[484 minutes]	4.8C(4.5C/5.0C)[85 minutes]	3.5C(3.1C/4.0C)[132 minutes]
Mid Comp. Mean Air Temp(Lowest/Highest)[Warm up to 10C)]	3.5C(3.1CC/5.3C)[497 minutes]	4.3C(3.9C/4.7C)[213 minutes]	2.9C(2.2C/3.8C)[420 minutes]
Mid Comp. Mean Sample Temp(Lowest/Highest)(Warm up tp 10C)	3.5C(3.4C/3.8C)[535 minutes]	3.9C(3.7C/4.7C)[262 minutes]	2.9C(2.8C/3.1C)[467 minutes]
Bottom Comp. Mean Air Temp(Lowest/Highest)[Warm up to 10C]	3.1C(0.1C/5.2C)[483 minutes]	5.1C(4.9C/5.4C)[263 minutes]	4.3C(4.0C/4.7C)[612 minutes]

Figure 13. Loaded fridge energy and temperature performance data.

Manufacturer	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Usable Net Capacity (L)	214	410	291
A. Single 60 Second Door Opening			
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	4.8C(9.7C/4.9C)[6 minutes]	4.7C(10.6C/5.9C)[17 minutes]	3.8C(10.4C/6.6C)[12 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.9C(5.3C/1.4C)[4 minutes]	3.9C(10.1C/6.2C)[9 minutes]	3.1C(8.4C/5.3C)[8 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.6C(3.8C/0.2C)[0 minutes]	3.7C(4.7C/1.0C)[8 minutes]	2.9C(3.7C/0.8C)[0 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	4.1C(-0.3/-4.4C)[0 minutes]	4.9C(6.9C/2.0C)[18 minutes]	4.3C(4.8C/0.5C)[13 minutes]
B. Single 90 Second Door Opening			
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.9C(11.7C/7.8C)[8 minutes]	5.0C(10.9C/5.9C)[21 minutes]	3.6C(11.2C/7.6C)[17 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.4C(5.6C/2.2C)[5 minutes]	4.7C(11.2C/6.5C)[11 minutes]	3.0C(10.2C/7.2C)[10 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.5C(3.8C/0.3C)[0 minutes]	3.9C(5.0C/1.1C)[14 minutes]	3.0C(4.0C/1.0C)[0 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.8C(-0.3C/-4.1C)[0 minutes]	5.4C(7.8C/2.4C)[20 minutes]	4.3C(4.9C/0.6C)[16 minutes]
Door Opening Energy Cost (A+B)	**0.013 kWh**	**0.049 kWh**	**0.012 kWh**

Figure 14. Loaded fridge door opening performance and energy data.

Unorganized, Organised and Highly Organised Access

To measure the impact of using a fridge inventory the three units went through three access procedures. Each procedure was carried out over a 24-hour period and used progressively more detailed inventories and labelling to facilitate content retrieval and replacement. The three levels of access procedure are shown in figure 15.

Access Procedure	Description
Unorganised	Labelled contents are retrieved and then replaced with no inventory or shelf labelling to guide end users.
Organised	Labelled contents are retrieved and then replaced with the aid of a basic inventory afixed to the outer door indicating the ownership of each shelf space.
Highly Organised	Labelled contents are retrieved and then replaced with the aid of a detailed inventory afixed to the outer door indicating the ownership of each shelf space and the exact location of all contents. In chamber, each shelf is also labelled indicating the owner.

Figure 15. The three different access procedures used reflected the varying levels of fridge inventory observed in the working laboratory. Unorganised access represented no inventory which is commonplace. Organised access represented end users employing a basic inventory that indicates ownership of shelf space (shown in figure 1). Highly organised represented end users employing a detailed inventory detailing the ownership of each shelf space both on the outer door and inside the fridge chamber (figure 17) together exact content location on each shelf space (figure 16)

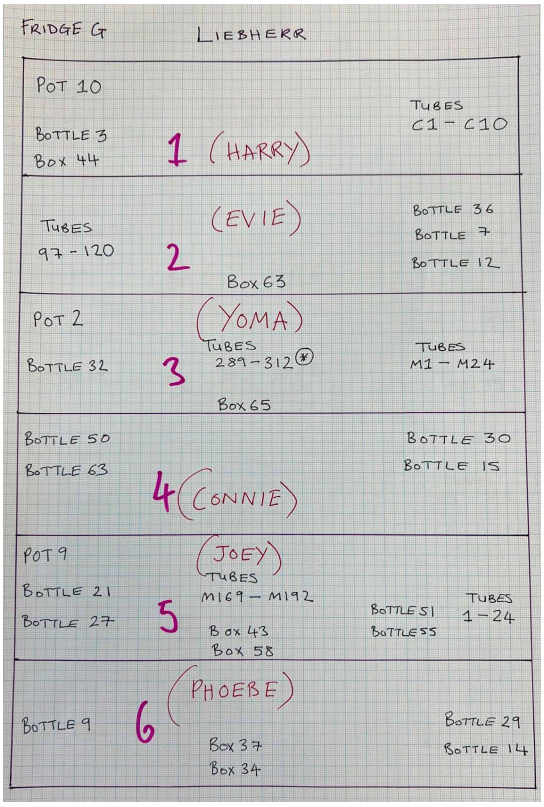

Figure 16. Detailed inventory indicating shelf space ownership and the exact location of contents.

End users from the Learning and Research centre were tasked with retrieving named, labelled contents. During each procedure the same contents were retrieved and replaced but never by the same end user. During each procedure the end users were given a note detailing the two items to be located and the name of the fictional owner of those items.

The first access of the day was carried out from 9am onwards and involved the simple retrieval of two specific items, a 1-minute wait and then those items were then placed back in their original locations. The second and third access of the say were carried out at ~12pm and ~3pm respectively.

Figure 17. Callum Hawkins, Learning and Research Centre, locating two specific items during the unorganised access procedure.

The data comparing the impact of the differing levels of fridge inventory upon door opening times is shown in figure 18.

Manufacturer		Haier	Labcold	Liebherr
Model		HLR-310F	RLPR1517	SRFvh4001
Unorganised Access				
1st Access	Retrieval Time	16 seconds	66 seconds	31 seconds
	Replacement Time	9 seconds	13 seconds	42 seconds
	Total Time [A]	25 seconds	79 seconds	73 seconds
2nd Access	Retrieval Time	22 seconds	33 seconds	19 seconds
	Replacement Time	11 seconds	13 seconds	11 seconds
	Total Time [B]	33 seconds	46 seconds	30 seconds
3rd Access	Retrieval Time	68 seconds	55 seconds	51 seconds
	Replacement Time	11 seconds	12 seconds	15 seconds
	Total Time [C]	79 seconds	67 seconds	66 seconds
Grand Total [A+B+C]		**137 seconds**	**192 seconds**	**169 seconds**
Organised Access				
1st Access	Retrieval Time	18 seconds	36 seconds	24 seconds
	Replacement Time	6 seconds	13 seconds	9 seconds
	Total Time [D]	24 seconds	49 seconds	33 seconds
2nd Access	Retrieval Time	13 seconds	15 seconds	11 seconds
	Replacement Time	7 seconds	8 seconds	6 seconds
	Total Time [E]	20 seconds	23 seconds	17 seconds
3rd Access	Retrieval Time	17 seconds	32 seconds	8 seconds
	Replacement Time	14 seconds	6 seconds	4 seconds
	Total Time [F]	31 seconds	38 seconds	12 seconds
Grand Total [D+E+F]		**75 seconds**	**110 seconds**	**62 seconds**
Highly Organised Access				
1st Access	Retrieval Time	10 seconds	26 seconds	11 seconds
	Replacement Time	6 seconds	9 seconds	8 seconds
	Total Time [G]	16 seconds	35 seconds	19 seconds
2nd Access	Retrieval Time	18 seconds	7 seconds	7 seconds
	Replacement Time	6 seconds	5 seconds	5 seconds
	Total Time [H]	24 seconds	12 seconds	12 seconds
3rd Access	Retrieval Time	6 seconds	14 seconds	11 seconds
	Replacement Time	5 seconds	6 seconds	6 seconds
	Total Time [I]	11 seconds	20 seconds	17 seconds
Grand Total [G+H+I]		**51 seconds**	**67 seconds**	**48 seconds**

Figure 18. Access procedure door opening times.

The temperature performance data, door opening recovery times and energy consumption data for each access procedure is shown in figure 19.

Manufacturer	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Net Capacity (L)	214	410	291
UNORGANISED ACCESS			
Retireval time	106	154	101
Replacement time	31	38	68
Total time	**137**	**192**	**169**
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.4C(9.2C/5.8C)[7 minutes]	4.7C(9.5C/4.8C)[19 minutes]	3.9C(8.8C/4.9C)[16 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.1C(4.0C/0.9C)[0 minutes]	4.7C(8.5C/3.8C)[7 minutes]	3.4C(8.1C/4.7C)[11 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.5C(3.6C/0.1C)[0 minutes]	3.8C(4.6C/0.8C)[9 minutes]	3.0C(3.8C/0.8C)[0 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	2.3C(-0.3C/-2.6C)[0 minutes]	5.2C(6.6C/1.4C)[18 minutes]	4.5C(4.9C/0.4C)[14 minutes]
Door Opening Energy Consumption	0.024 kWh	0.050 kWh	0.007 kWh
ORGANISED ACCESS			
Retireval time	48	83	43
Replacement time	27	27	19
Total time	**75**	**110**	**62**
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	4.7C(7.3C/2.6C)[6 minutes]	4.5C(8.5C/4.0C)[18 minutes]	3.1C(6.5C/3.4C)[9 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.9C(3.7C/-0.2C)[0 minutes]	3.8C(7.6C/3.8C)[8 minutes]	2.4C(5.1C/2.7C)[5 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.6C(3.7C/0.1C)[0 minutes]	3.8C(4.7C/0.9C)[9 minutes]	2.8C(3.2C/0.4C)[0 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.1C(0C/-3.1C)[0 minutes]	5.2C(6.4C/1.2C)[28 minutes]	4.4C(4.3C/-0.1C)[0 minutes]
Regular Door Openings Energy Consumption	0.005 kWh	0.030 kWh	0.000 kWh
HIGHLY ORGANISED ACCESS			
Retireval time	34	47	29
Replacement time	17	20	19
Total time	**51**	**67**	**48**
Top Comp. Start Air Temp(Peak/Rise)[Recovery Time]	4.9C(6.6C/1.7C)[5 minutes]	4.9C(7.9C/3.0C)[16 minutes]	3.0C(5.3C/2.3C)[7 minutes]
Middle Comp. Start Air Temp(Peak/Rise)[Recovery Time]	3.8C(4.0C/0.2C)[0 minutes]	4.6C(6.8C/2.2C)[7 minutes]	2.3C(4.1C/1.8C)[4 minutes]
Middle Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	3.6C(3.7C/0.1C)[0 minutes]	4.1C(4.4C/0.3C)[7 minutes]	2.9C(3.1C/0.2C)[0 minutes]
Bottom Comp. Start Sample Temp (Peak/Rise)[Recovery Time]	4.5C(4.7C/0.2C)[4 minutes]	5.4C(6.2C/0.8C)[459 minutes]	4.2C(3.7C/-0.5C)[0 minutes]
Regular Door Openings Energy Consumption	0.004 kWh	0.027 kWh	0.000 kWh

Figure 19. The temperature performance data, door opening recovery time and impact of access upon energy consumption. Door opening recovery times are 0 minutes where the temperature rise has not exceeded the desired set temperature 4°C.

Freezer Temperatures

Typically, a lab freezer is operated at the -20°C set temperature however end users may set freezers to colder temperatures. The impact of these setpoints upon chamber temperature and energy consumption is shown in figures 20-22. In the case of the Labcold model, the coldest set temperature possible was -22°C. As previously stated, the Lec model could only be set to a narrow temperature range, -23°C to -26°C, and so these two set temperatures were used for the case study.

Manufacturer	Liebherr
Model	FSSfg4001
Net Capacity (L)	190
Set Temperature	-18C
kWh/Day	0.917
Energy - W/L/Day	4.83
Top Comp. Mean Air Temp(Lowest/Highest)	-16.9C(-17.5C/-15.8C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-18.5C(-18.7C/-18.3C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-18.6C(-18.7C/-18.4C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-20.0C(-20.6C/-18.9C)
Set Temperature	-20C
kWh/Day	1.038
Energy - W/L/Day	5.46
Top Comp. Mean Air Temp(Lowest/Highest)	-18.8C(-19.5C/-17.9C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-21.4C(-21.6C/-22.4C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-21.5C(-21.6C/-21.3C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-22.7C(-23.3C/-21.9C)
Set Temperature	-23C
kWh/Day	1.328
Energy - W/L/Day	6.99
Top Comp. Mean Air Temp(Lowest/Highest)	-22.1C(-22.8C/-21.2C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-24.6C(-25.0C/-24.2C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-24.7C(-25.1C/-24.3C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-25.7C(-26.6C/-24.7C)
Set Temperature	-26C
kWh/Day	1.45
Energy - W/L/Day	7.63
Top Comp. Mean Air Temp(Lowest/Highest)	-25.1C(-27.3C/-24.3C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-27.8C(-28.8C/-27.6C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-27.9C(-29.0C/-27.8C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-29.0C(-31.5C/-28.3C)
Set Temperature	-28C
kWh/Day	1.646
Energy - W/L/Day	8.66
Top Comp. Mean Air Temp(Lowest/Highest)	-27.1C(-27.6C/-26.4C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-30.0C(-30.1C/-29.8C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-30.1C(-30.2C/-30.0C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-31.1C(-31.6C/-30.5C)
Set Temperature	-30C
kWh/Day	1.888
Energy - W/L/Day	9.94
Top Comp. Mean Air Temp(Lowest/Highest)	-29.1C(-29.6C/-28.5C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-32.1C(-32.2C/-32.0C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-32.2C(-32.3C/-32.1C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-33.2C(-33.6C/-32.7C)

Figure 20. Impact of operating the Liebherr FSSfg4001 at set temperatures above and below -20°C upon energy consumption.

Manufacturer	Labcold
Model	RLVF2025
Net Capacity (L)	451
Set Temperature	**-20C**
kWh/Day	**2.989**
Energy - W/L/Day	**6.63**
Top Comp. Mean Air Temp(Lowest/Highest)	-19.2C(-20.1C/-17.6C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-20.7C(-22.4C/-19.0C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-20.2C(-21.0C/-19.3C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-19.8C(-21.9C/-17.8C)
Set Temperature	**-22C**
kWh/Day	**3.612**
Energy - W/L/Day	**8.01**
Top Comp. Mean Air Temp(Lowest/Highest)	-20.8C(-22.3C/-19.1C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-23.0C(-24.9C/-21.1C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-22.9C(-24.1C/-21.6C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-21.2C(-23.1C/-19.2C)

Figure 21. Energy consumption of operating the Labcold RLVF2025 at -20°C and -22°C.

Manufacturer	Lec
Model	LSFSF312BT
Net Capacity (L)	290
Set Temperature	**-23C**
kWh/Day	**1.286**
Energy - W/L/Day	**4.43**
Top Comp. Mean Air Temp(Lowest/Highest)	-19.6C(-21.6C/-16.8C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-22.8C(-24.0/-21.6C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-22.4C(-23.0C/-21.7C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-17.0(-17.7C/-16.3C)
Set Temperature	**-26C**
kWh/Day	**1.549**
Energy - W/L/Day	**5.34**
Top Comp. Mean Air Temp(Lowest/Highest)	-19.6C(-20.2C/-19.0C)
Middle Comp. Mean Air Temp(Lowest/Highest)	-26.5C(-27.4C/-25.3C)
Middle Comp. Mean Sample Temp(Lowest/Highest)	-26.3C(-27.0C/-25.4C)
Bottom Comp. Mean Air Temp(Lowest/Highest)	-19.7C(-20.4C/-18.9C)

Figure 22. Energy consumption of operating the Lec LSFSF312BT at -23°C and -26°C.

Discussion

Fridge Temperature and Energy Performance

The Labcold model had the lowest W/L/Day at the 4°C set temperature. The Liebherr model used 9% more energy than the Labcold model. The Haier unit had the highest W/L/Day of the fridges consuming 77% more energy than the Liebherr model.

Three out of four probes recorded both the coldest mean and lowest temperatures in the Liebherr model. All four probes in the Labcold model recorded both the highest peak and mean temperatures.

The Liebherr model had the fastest pull-down time (50 minutes), closely followed by the Haier Biomedical model (51 minutes). The Labcold Unit took 70 minutes to pull down to the set temperature.

Fridge Door Opening Recovery and Performance Data

Fridge 60 & 90 Second Door Openings
The fastest door opening recovery times were measured in the Haier model. The Haier model took 7 minutes to recover from a 60 second door opening and 8 minutes to recover from a 90 second door opening. The Liebherr model took 12 minutes to recover from a 60 second door opening and 15 minutes to recover from a 90 second door opening. The Labcold model took 30 minutes to recover from both the 60 and 90 second door opening. The energy consumed to recover from the door openings was highest in the Haier unit at 0.07 W/L/Day. The Labcold model used 0.04 W/L/day to recover (43% less energy than Haier) and the Liebherr model used 0.02 W/L/day to recover (71% less energy than Haier).

Fridge Door Opening Sequences For 8 Hour Periods

The time taken for chamber temperatures to recover following each door opening sequence was similar for each model. The Haier was the fastest to recover from each door opening sequence with times ranging from 6-7 minutes (figure 23).

The Liebherr model took 12-15 minutes to recover from each door opening sequence whilst the Labcold model took 19-30 minutes to recover from each door opening sequence. The Liebherr model was the most energy efficient in recovering from the door opening sequences.

In the case of the Haier and Labcold models there was very little difference in door opening recovery energy between the regular and frequent door opening sequences. Although the step up from regular to frequent door opening sequences increased the number of door openings by 32% the energy consumed (W/L/Day) to recover only rose 4% in the Haier model and 6% for the Labcold model. This may indicate that the compressors remained active for similar periods of time during both door opening sequences. The step from frequent door opening sequences to persistent door opening sequences caused the largest increase in door opening recovery energy. This 45% increase in door openings resulted in door opening energy increasing by 69% for the Haier model, 43% for the Labcold model and 79% for the Liebherr model.

Manufacturer	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Net Capacity (L)	214	410	291
OCCASIONAL DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	17 (30 minutes)		
Peak Temperature (Rise)	9.9C(5.7C)	10.1C(5.3C)	10.1C(6.5C)
Recovery Time	8 minutes	30 minutes	13 minutes
Occasional Door Openings Energy Consumption	0.150 kWh	0.254 kWh	0.080 kWh
Occasional Door Openings Energy Consumption W/L/Day	0.70 W/L/Day	0.62 W/L/Day	0.27 W/L/Day
REGULAR DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	25 (20 minutes)		
Peak Temperature (Rise)	11.5C(7.4C)	10.7C(6.1C)	10.1C(6.8C)
Recovery Time	7 minutes	19 minutes	15 minutes
Regular Door Openings Energy Consumption	0.192 kWh	0.343 kWh	0.097 kWh
Regular Door Openings Energy Consumption W/L/Day	0.90 W/L/Day	0.84 W/L/Day	0.33 W/L/Day
FREQUENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	33 (15 minutes)		
Peak Temperature (Rise)	10.2C(6.2C)	9.9C(4.7C)	9.3C(5.5C)
Recovery Time	8 minutes	29 minutes	13 minutes
Frequent Door Openings Energy Consumption	0.201 kWh	0.366 kWh	0.131 kWh
Frequent Door Openings Energy Consumption W/L/Day	0.94 W/L/Day	0.89 W/L/Day	0.45 W/L/Day
PERSISTENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	48 (10 minutes)		
Peak Temperature (Rise)	9.0C(5.5C)	10.7C(5.9C)	10.7C(7.2C)
Recovery Time	7 minutes	27 minutes	12 minutes
Persistent Door Openings Energy Consumption	0.340 kWh	0.525 kWh	0.234 kWh
Persistent Door Openings Energy Consumption W/L/Day	1.59 W/L/Day	1.28 W/L/Day	0.80 W/L/Day

Figure 23. Summary of fridge performance vs. door opening sequences. The largest temperature rise for each model in red text.

Loaded Fridge Energy and Temperature Performance

The energy and temperature performance of each fridge empty and loaded is compared in figure 24. With no door openings the energy consumption for each model was almost identical. Door opening times were changed for the Labcold model, becoming ≥9 minutes faster. The door opening recovery times in the Haier unit only changed by one minute (faster) whilst the Liebherr door opening times increased by ≤2 minutes. Door opening recovery energy increased in all units when loaded; Haier 15%, Liebherr 100% and Labcold 188%.

Manufacturer	Haier		Labcold		Liebherr	
Model	HLR-310F		RLPR1517		SRFvh4001	
Published Net Capacity (L)	310		410		298	
Usable Net Capacity (L)	214		410		291	
PERFORMANCE DATA	Empty	Loaded	Empty	Loaded	Empty	Loaded
Energy - W/L/Day	5.57	5.59	2.90	2.88	3.15	3.09
A. Single 60 Second Door Opening Recovery Time	7 minutes	6 minutes	30 minutes	17 minutes	12 minutes	13 minutes
B. Single 90 Second Door Opening Recovery Time	8 minutes	8 minutes	30 minutes	21 minutes	15 minutes	17 minutes
Door Opening Energy Cost (A+B)	0.013 kWh	0.015 kWh	0.017 kWh	0.049 kWh	0.006 kWh	0.012 kWh

Figure 24. Fridge energy and performance, empty vs. loaded.

Inventory Impact Upon Fridge Door Opening Times and Energy Consumption

The impact of using any type of fridge inventory is positive. Employing a simple, basic inventory which indicated shelf ownership only halved door opening times and the recovery energy by 57% (figure 25). More detailed inventory usage decreased the door opening times by two thirds and the recovery energy by 62%.

Access Procedure	Total Door Opening Time	Door Opening Recovery Energy
Unorganised Access (U.A.)	498 seconds	0.081 kWh
Organised Access (saving vs. U.A.)	247 seconds (50%)	0.035 kWh (57%)
Highly Organisaed Access (saving vs. U.A.)	166 seconds (67%)	0.031 kWh (62%)

Figure 25. Summary of fridge door opening times and recovery energy when using increasingly detailed inventories.

In the case of the Liebherr model, the organised and highly organised accesses required no additional energy to recover from. The organised access procedure resulted in the door being open for a grand total of 62 seconds. The highly organised access procedure resulted in the door being open for a grand total of 48 seconds. In both cases these total times are the result of very short door openings, as brief as 4 seconds, and the small rises in temperature were recovered without any additional compressor activity being required.

Freezer Temperature and Energy Performance

The Labcold model had the lowest W/L/Day at the 4°C set temperature. The Liebherr model used 9% more energy than the Labcold model. The Haier unit had the highest W/L/Day of the fridges consuming 77% more energy than the Liebherr model.

Three out of four probes recorded both the coldest mean and lowest temperatures in the Liebherr model. All four probes in the Labcold model recorded both the highest peak and mean temperatures.

The Liebherr model had the fastest pull-down time (50 minutes), closely followed by the Haier Biomedical model (51 minutes). The Labcold Unit took 70 minutes to pull down to the set temperature.

Warm up times were the longest in the Lec model, taking ≥161 minutes, however it must be noted that this model was set to -23°C. The Liebherr model took ≥107 minutes to warm up whilst the Labcold model took ≥52 minutes.

Freezer Door Opening Recovery and Performance Data

Freezer 60 & 90 Second Door Openings

The fastest door opening recovery times were measured in the Liebherr model. The Liebherr model took 18 minutes to recover from the 60 second door opening and 20 minutes to recover from the 90 second door opening. The Labcold model took 46 minutes to recover from the 60 second door opening and 40 minutes to recover from the 90 second door opening. The Lec model took 45 minutes to recover from the 60 second door opening and 112 minutes to recover from the 90 second door opening.

In all freezers, the highest temperature rise following a door opening was measured in the top compartment. Although the Lec model was set to the colder -23°C set point, it was the Liebherr model that recorded the coldest compartment temperatures prior to and following timed door openings. The absence of solid drawers in the Labcold model resulted in the largest temperature rise in all compartments following timed door openings.

The energy consumed to recover from the timed door openings was highest in the Liebherr unit at 0.42 W/L/Day. The Labcold model used 0.29 W/L/day to recover (31% less energy than Liebherr) and the Lec model used 0.21 W/L/day to recover (50% less energy than Liebherr).

Freezer Door Opening Sequences For 8 Hour Periods

The Lec model took the longest to recover following the occasional door opening sequence (figure 26), requiring 52 minutes for all probes to recover. Proceeding door opening sequences resulted in chamber temperatures not recovering to their mean temperatures with compartments stabilizing at warmer mean temperatures. The energy required to recover from each door opening sequence was the lowest in the Lec model, however, based upon the performance criteria (detailed in figure 2) this model did not recover from the regular door opening sequence and proceeding sequences.

The Liebherr model took 14 minutes to recover from the occasional door opening sequence. Each proceeding sequence resulted in the unit requiring an additional 2 to 3 minutes to recover. The energy used to recover from each door opening sequence (W/L/Day) increased most significantly between the occasional to regular door opening sequences, increasing by 53%. The smallest increase in energy consumption was measured from regular to frequent door openings, requiring an additional 7% energy.

In three out of the four door opening sequences the temperatures recorded in the Labcold model were the warmest, attributable to the absence of solid drawers. The door opening times were slowest following the occasional access. In the proceeding door opening sequences the Labcold door opening recovery times improved. This may be attributable to the increased compressor activity. During the frequent door opening sequence the door opening recovery times were faster than those measured during the regular door opening sequence, with the energy consumed to do so increasing by only 3%.

Manufacturer	Labcold	Lec	Liebherr
Model	RLVF2025	LSFSF312BT	FSSfg4001
Net Capacity (L)	451	290	190
OCCASIONAL DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	17 (30 minutes)		
Peak Temperature (Rise)	-0.3C(18.7C)	-4.6C(13.1C)	-8.8C(10.8C)
Recovery Time	41 minutes	52 minutes	14 minutes
Occasional Door Openings Energy Consumption	1.020 kWh	0.593 kWh	0.576 kWh
Occasional Door Openings Energy Consumption W/L/Day	2.26 W/L/Day	2.04 W/L/Day	3.03 W/L/Day
REGULAR DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	25 (20 minutes)		
Peak Temperature (Rise)	-1.3C(19.1C)	-2.0C(16.3C)	-9.5C(9.4C)
Recovery Time	25 minutes	DNR	17 minutes
Regular Door Openings Energy Consumption	1.792 kWh	0.796 kWh	0.881 kWh
Regular Door Openings Energy Consumption W/L/Day	3.97 W/L/Day	2.74 W/L/Day	4.64 W/L/Day
FREQUENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	33 (15 minutes)		
Peak Temperature (Rise)	-1.7C(16.9C)	-0.9C(15.5C)	-8.6C(10.2C)
Recovery Time	22 minutes	DNR	19 minutes
Frequent Door Openings Energy Consumption	1.847 kWh	0.787 kWh	0.944 kWh
Frequent Door Openings Energy Consumption W/L/Day	4.10 W/L/Day	2.71 W/L/Day	4.97 W/L/Day
PERSISTENT DOOR OPENINGS PERFORMANCE DATA			
Number of 60 Second Door Openings (Interval)	48 (10 minutes)		
Peak Temperature (Rise)	0.8C(18.1C)	-1.2C(18.5C)	-7.9C(10.8C)
Recovery Time	28 minutes	DNR	21 minutes
Persistent Door Openings Energy Consumption	2.080 kWh	0.929 kWh	1.385 kWh
Persistent Door Openings Energy Consumption W/L/Day	4.61 W/L/Day	3.20 W/L/Day	7.29 W/L/Day

Figure 26. Summary of freezer performance vs. door opening sequences. The largest temperature rise for each model in red text.

Impact of Freezer Set Temperature Upon Energy Consumption

There were significant increases in freezer energy consumption resulting from employing colder set temperatures. In the case of the Lec freezer, chilling down from -23°C to -26°C increased energy consumption (W/L/Day) by 21%, consuming an additional 0.263 kWh/day. There was also a 21% increase in energy consumption when the Labcold model was operated 2°C colder at -22°C, consuming an additional 0.623 kWh/day. The energy consumption of the Liebherr freezer (figure 27) fell by 12% (0.121 kWh) when the set temperature was reduced by 2°C to -18°C. Operating the Liebherr unit at its coldest set temperature (-30°C) increased energy consumption by 82%.

Set Temperature	Energy Difference Vs -20°C
-18°C	-0.121 kWh/day (-12%)
-23°C	0.290 kWh/day (28%)
-26°C	0.412 kWh/day (40%)
-28°C	0.608 kWh/day (59%)
-30°C	0.850 kWh/day (82%)

Figure 27. Liebherr freezer energy consumption at set temperatures above and below -20°C.

Conclusion

The use of a simple fridge inventory had a significant impact upon door opening times and energy consumption, highlighting the impacts even simple action can have upon lab running costs. Creating such a simple inventory requires very little effort, simply naming who owns each shelf saved ≥50% in door opening times and energy consumption. Reducing the door opening times saves staff time, if used 240 days/ year the simple inventory would save 16.7 hours in door openings per fridge. Fridges using the more detailed inventory would save 22.1 hours in door openings per fridge. As energy consumption falls so does the heat output into the laboratory, reducing air conditioning costs.

When calculating fridge net capacity, it is advisable that the space deemed unusable for storage must be discounted from the published net capacity. Doing so will allow for standardized energy consumption data to be easily generated whilst end users will be fully aware of the cold storage capacity they will be procuring (figure 28).

Make	Haier	Labcold	Liebherr
Model	HLR-310F	RLPR1517	SRFvh4001
Adjusted Net (L)	214	410	291
Gross Footprint (L)	679	788	736
Usable Net % Gross Footprint	**32**	**52**	**40**

Figure 28. Fridge capacity and footprint.

Freezer set temperature had a significant effect upon running costs. Although a simple feature, being able to clearly set and display a chamber temperature should be a mandatory requirement in any procurement exercise. Units without such controllers retain the ability to have chamber temperatures ≤-30°C, increasing energy consumption by >80%. The impact of solid drawers must also be considered. During timed door openings the temperature rises measured in the Liebherr model (solid drawers) were ≥7°C lower compared to those in the Labcold model (no drawers).

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