university of groningen
faculty of science and engineering

University of Groningen

Integration Project - Group 18

FSE Green Labs - ULT Freezers

Author:
Myriam Kammüller Pont
S3632652

Supervisors:
M. Mohebbi
Drs. C.M. Ree
Dr. Ing. H. Kloosterman
N. Elzinga

June 30, 2023

Abstract

Ultra-low temperature (ULT) freezers are essential equipment in research laboratories. However, they consume an extreme amount of energy and thus pose a significant economic and environmental challenge. This research project aims to investigate the current ULT freezers within the Faculty of Science and Engineering (FSE), assess its inventory, energy consumption levels, cooling and refrigeration systems and explore other alternatives to reduce energy consumption. The study uses a combination of literature review, energy consumption measurements and survey responses from lab users to achieve its conclusions.

The results revealed that FSE currently owns 60 ULT freezers, of which 41 were analysed in this study. The inventory analysis provided crucial information on the distribution and models of the freezers, providing the basis for further analysis.
The energy consumption assessment demonstrated variations in energy usage among different models and temperature settings, highlighting areas for improvement. Additionally, the analysis of cooling and refrigeration systems revealed that most ULT freezers within the University of Groningen use refrigerants with high global warming potential (GWP). The survey responses indicated an increased awareness of the need for energy-efficient freezers, and financial incentives were also identified as a potential solution to address the high costs.
The study defines the importance of reducing energy consumption in ULT freezers and suggests measures to reduce such. By implementing these measures, FSE can significantly reduce energy costs and minimise the environmental impact.

Abbreviations

ULT: Ultra Low Temperature

UCL: University College London

FSE: Faculty of Science and Engineering

LB: Linnaeusborg Building

LEAF: Laboratory Efficiency Assessment Framework

NB: Nijenborgh Building

RDP: Research Design Proposal

HC: Hydrocarbon

HFC: Hydro-fluorocarbon

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Chapter 1

Introduction

Climate change has received an increasing amount of attention and recognition worldwide. Notably, the emission of CO2 is seen as the leading cause of this problem and thus needs to be mitigated. Hence, a transition to 'green energy' is considered as one of the solutions. Green energy is any energy generated from natural sources, such as wind, water or sunlight [8]. Energy plays an essential role in our lives. However, using electricity is one of the largest sources of greenhouse gas emissions, of which two-thirds is related to burning fossil fuels for energy to be used in transport, electricity and heating[9]. Therefore, to avoid the worst impact of climate change, a change to greener, more sustainable energy sources is needed, such as reducing overall energy consumption through energy savings and energy efficiency gains [10].

Even though scientific discoveries have significantly improved the human experience, industrial and academic research has a considerable carbon footprint. As Houghton et al. [11] state in the article 'Taking a LEAF out of the green book', scientific research does not only have to be reproducible and reliable. Therefore, to combat this problem, many universities worldwide have started to apply changes to their laboratories to make them greener and thus reduce their carbon footprint and energy consumption.

The University of Groningen, for example, has started a program called "FSE (Faculty of Science and Engineering) is going green", a laudable initiative to reduce energy consumption by 30% within the next three years. This program is based on the English program LEAF (Laboratory Efficiency Assessment Framework), a program developed by the University College London (UCL) to help scientists conduct their lab work more environmentally friendly way [12]. A LEAF pilot in the UK occurred throughout 235 lab groups (across 23 institutes), which were reported to have saved around 641K pounds and 648 tCO2e of avoided emissions [13].

As part of this program, the FSE Green Labs Initiative has identified several root causes of the high energy consumption within its labs. One of these is the Ultra-Low Temperature Freezers (ULT). ULT freezers are major energy-intensive equipment that stores samples for various scientific fields at extremely low temperatures, typically ranging from -40 and -80 degrees Celsius [14]. Researchers at the University rely on ULT freezers to preserve biological material, such as tissues or DNA samples, ensuring their long-term viability and integrity. However, even though many have addressed energy consumption within laboratories, there is a lack of knowledge regrading ULT freezers. As a result, the FSE initiative raises a crucial question about the high energy consumption costs and large carbon footprint of such freezers.

Therefore, this research study will explore the potential benefits of cost savings, sustainability and environmental impact regarding ULT freezers. By investigating the barriers to user acceptance and adoption of high-efficiency ULT freezers and providing detailed recommendations to reduce energy consumption, this research aims to contribute to the transition of the Faculty of Science and Engineering (FSE) towards a more sustainable future. It has the capability to improve energy efficiency in laboratories as well as contribute to global efforts to mitigate climate change through the adoption of green practices and technologies.

1.1 Problem Statement

The problem statement for this research is formulated as follows:

"FSE consumes a significant amount of energy, and therefore a solution is required to reduce this. This thesis specifically deals with the case of ULT freezers and what can be done to reduce their energy consumption within the FSE laboratories."

1.2 Stakeholders Analysis

First, it is helpful to recognise the whole system. The system researched is the laboratories within FSE, specifically the ULT freezers that store research samples. This system focuses on finding solutions to reduce the energy consumption of ULT freezers. Several external factors could have an impact on the system. These factors include government policies related to climate change or energy consumption, technological advancements related to energy-efficient ULT freezers, funding, and lab user's attitude towards changes in freezer management.
The stakeholder analysis aims to evaluate all relevant parties involved in the process and identify the role of the most involved (third) parties. In Figure 1.1, all stakeholders are presented. The problem owner of this research is the FSE Green Labs Initiative, as they are the authors of the idea and responsible for implementing the programme.

https://www.overleaf.com/project/6479d7a2a6f0e5b2e4546e00 **FSE Green Labs Initiative:** The primary stakeholder responsible for implementing and succeeding the "FSE is going green" program is the FSE Green Labs Initiative. This group is responsible for setting the program's goals, developing strategies, and coordinating with other stakeholders.

FSE Management (Faculty Board): FSE Management is responsible for overseeing the overall operations of the FSE and ensuring that the program aligns with the organisation's goals and objectives. They are responsible for providing the necessary resources and support to ensure the program's success.

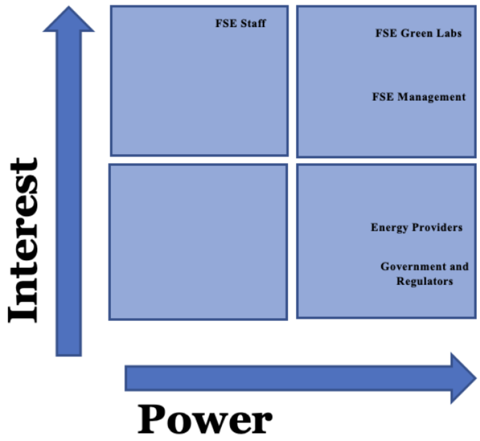

Figure 1.1: Stakeholder analysis model

FSE Staff (Lab users): FSE Staff includes all individuals working within the FSE whom the program will directly impact. This group includes scientists, researchers, lab technicians, and other support staff. The program's success will depend on this group's cooperation and participation.

Government and Regulators: Government agencies and regulators may significantly impact the program's success, particularly regarding implementing energy policies and regulations that may affect the FSE's operations and energy consumption.

1.3 Research Questions & Objective

Main Question: What is the optimal strategy to reduce energy consumption in ULT freezers while also considering the environmental impact?

To address the challenges outlined and contribute to the ongoing effort of the 'FSE Green Labs Initiative', this research seeks to answer the following questions:

1. **What is the inventory of the current ULT freezers in FSE?**
   To assess the potential impact of energy-saving strategies for the University, there must first be a clear understanding of the number and types of ULT freezers.

2. **What are ULT freezers' current energy consumption levels in FSE?**
   By quantifying the current energy usage of the freezers, conclusions can be made to evaluate if there is a need for new equipment or other potential energy-saving measures.

3. **What cooling and refrigeration system do the current ULT freezers use?**
   Investigating the specific cooling and refrigeration system will provide insights into the operational mechanisms and efficiency levels.

4. **What are the environmental impacts of the current cooling and refrigeration systems?**
   Assessing the current systems' environmental consequences can help evaluate the carbon footprint or potential environmental harm and how to reduce such.

5. **What are alternatives in technology and management of ULT freezers that can reduce energy consumption?**
   Identifying alternative ways to reduce energy consumption with the current ULT freezers.

This research aims to provide insights into the optimal strategy for reducing energy consumption in ULT freezers while also considering the environmental impact associated. Addressing these five research questions will help give a clear overview for the FSE Green Labs Initiative to achieve significant energy savings and move towards a more sustainable laboratory environment.

1.4 Methodology

A thorough methodology provides a clear outline for the FSE Green Labs initiative and thus achieves the research objectives outlined above. Such consisted of several key components.

Firstly, a comprehensive literature review is conducted to gather insights into the mechanical workings of a ULT freezer, such as the type of cooling system or refrigerants used and how these could affect the freezer's energy efficiency or carbon footprint. The review also included analysing several managerial changes to the current ULT freezers that could be adapted to reduce costs and carbon emissions.

Data is collected to obtain information on ULT freezers' energy usage patterns and characteristics within the FSE laboratories. This involved collecting energy consumption data from several ULT freezers and information on the model, volume and set temperature of the freezers to analyse their correlation. To understand the willingness to cooperate in lowering energy costs and the adoption of highly-efficient energy freezers, interviews were conducted with laboratory personnel. These interviews aimed to explore the perspective and experiences related to the maintenance of ULT freezers and the attitude towards adopting energy-efficient models.

Consequently, the combination of both qualitative and quantitative methods allows for a thorough understanding of ULT freezer's energy consumption and the factors influencing efficiency. Hence, providing a recommendation grounded on both empirical and theoretical research.

Chapter 2

Literature Review

2.1 ULT Freezers

A mechanical refrigeration system is designed to move heat from one location to another. Such a refrigeration system is composed of the following components: a compressor, cabinet to store the biodegradable product, condenser, refrigerant and evaporator [7]. ULT freezers store drugs, enzymes, chemicals, viruses, bacteria, cell preparations and other samples of critical biological research [15]. Figure 2.1 below depicts a standard upright ULT freezer used in many laboratories. These freezers operate at a temperature between -60C to -86C and have a service life of 12 to 15 years, depending on the manufacturer [16]. Studies show that a ULT freezer consumes the same energy as a family home (around 20kWh per day) [17]

Figure 2.1: Standard upright -80 degree ULT freezer [1]

One of the biggest challenges is finding a solution for the ULT freezers. Several factors can affect the efficiency of the freezers, such as the operating temperature, shelf racking, door openings, and other elements [6].

Nonetheless, as stated in the report for the U.S. Department of Energy by Rebecca Legett, there are several barriers to adopting high-efficiency ULTs [18]. First, Legett mentions the relative lack of information on ULT efficiency. Information such as the actual lifetime cost and ownership of a ULT freezer. Thus, looking beyond the initial purchase price of the freezer and thinking strategically about other costs it might encompass [2]. Figure 4.2 exhibits, through a pie chart, the typical per cent of lifetime costs of a ULT freezer.

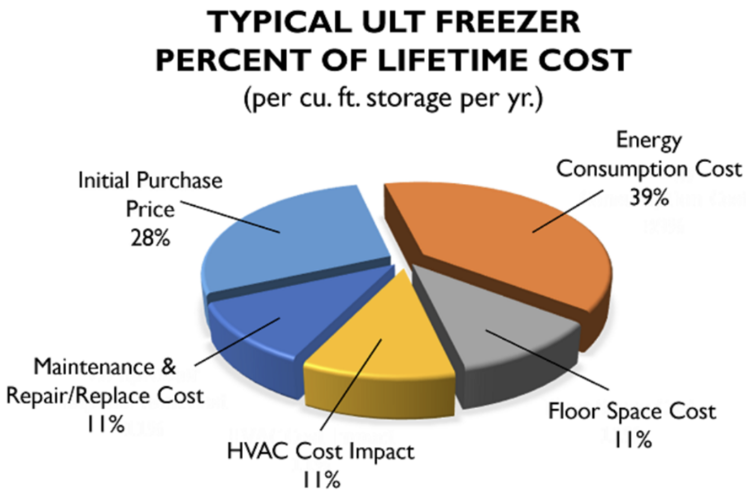

Figure 2.2: Pie chart conveying the results of the percentage of lifetime costs of a conventional ULT freezer[2],

2.1.1 Cooling Systems

To understand a ULT freezer's environmental impact and energy consumption, one must examine the composition and type of cooling system used. All sixty freezers owned by the University of Groningen utilise a cascade system. Specifically, a two-stage system uses two refrigeration systems working in tandem to achieve extremely cold temperatures of -80C [19]. The **cascade system** is the most standard refrigeration system that consists of the following components: a compressor, a condenser, an evaporator and a drop device. Figure 2.3 below depicts the components of a two-stage cascade cooling system.
As stated by Thermo Scientific [19] in their technical note about ULT freezers, the compressor is used to change the pressure of the working fluid. Next, the condenser converts a high-pressure gas into a high-pressure liquid. On the other hand, the pressure drop device helps reduce the liquid's pressure and temperature. Finally, the evaporator absorbs heat from the cabinet, changing the fluid from a low-temperature and low-pressure liquid to a low-temperature low-pressure gas.

Furthermore, Figure 2.3 shows that the freezer uses two stages to produce freezing temperatures. The first stage is known as the "high" stage system, which gets the working refrigerant to -45c. Consequently, the second stage, known as the "low" stage, gets the working refrigerant to -90c.

However, although the cascade system is the most utilised and shared, it is not the most efficient or environmentally friendly. With time, technology has steadily

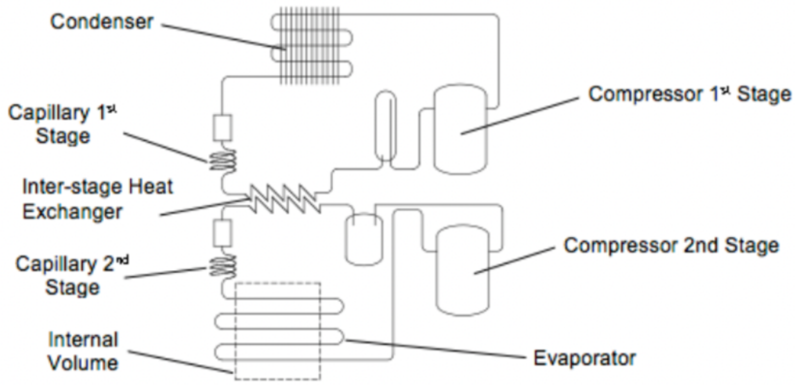

Figure 2.3: Schematic showing the components of a two-stage cascade cooling system [3]

improved, and thus, a new cooling system has become more popular and taken over the ultra-cold storage market [20]. Such is the **Stirling** cooling system, notably more efficient and simpler than the traditional cascade freezers. Figure 2.4 below shows the cooling system of a Stirling machine.

The Stirling engine is a closed-cycle engine and thus does not require a phase change of the working medium, which is helium gas. The basic functioning of the engine is based on the cycle, which expands and compresses the gas to provide a cold heat acceptor and a warm heat rejecter. Thermal transport is obtained through the thermosiphon, which contains the refrigerant. In the case of the Stirling, the refrigerant used is ethane. Unlike the cascade system, it uses no oil [3].

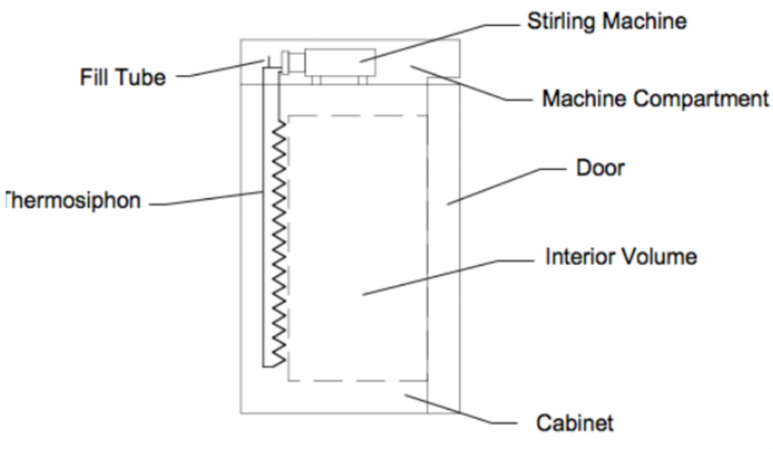

Figure 2.4: Schematic showing the components of a Stirling system [3]

Several factors can be used to compare both cooling systems. Two important ones for this research are the coefficient of performance (COP) and the Total Equivalent Warming Impact (TEWI). The COP, as defined by the research [3] is the ratio of the heat removed from the system to the input energy. In the case of the cascade system, the ratio is around 0.25 at a temperature of -80c. Nonetheless, the system

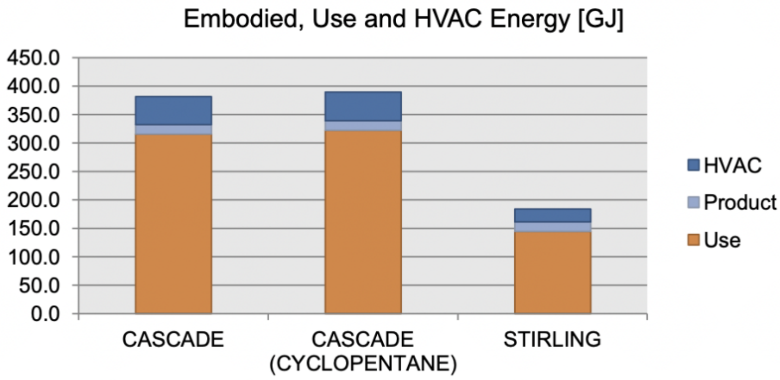

Figure 2.5: Embodied, use and HVAC CO2 for a 10-year life ULT [3]

adjusts to its capacity by switching on and off, causing its performance to drop to 0.2.

On the other hand, the Stirling system has a COP of 0.39 at the same base temperature, and as it runs continuously, there is no loss of efficiency. This dramatic difference in COP causes the average energy consumption of the cascade system to be more than twice that of the Sterling for a 780-litre cabinet [3]. Figure 2.5 below depicts the use and Heating Ventilation and Air Conditioning (HVAC) energy over a 10-year life period of cascade and Stirling systems. Notice that the cascade system uses HFC refrigerants, while the cascade (Cyclopentane) HC refrigerants.

As mentioned previously, another critical factor to consider when evaluating the different cooling systems is the TEWI. Such considers the refrigerant released during the lifetime of the equipment, plus the unrecovered losses on the final disposal and the impact of the co2 emissions used to generate the energy during its lifetime [3]. The same study provides an overview of the CO2 emissions which each cooling system emits. This is valuable to the current research, as the energy efficiency and environmental impact are analysed. Both can have a significant influence on the buying decision of the University. Figure 2.6 shows the TEWI of the different cooling systems and a typical household refrigerator over a lifespan of 10 years. One again notice, that the cascade system uses HFC refrigerants, while the cascade (Cyclopentane) HC refrigerants.

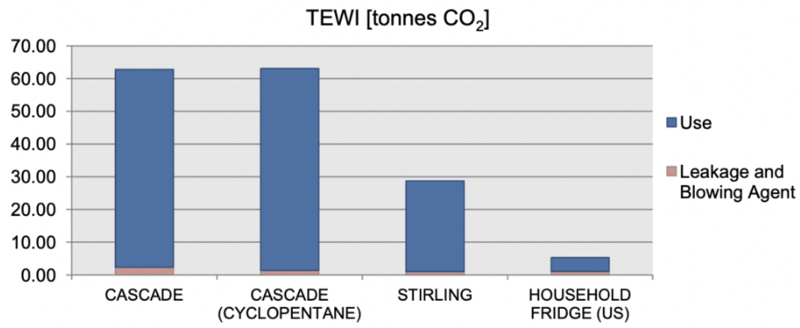

Figure 2.6: Total Equivalent Warming Impact (TEWI) over a 10-year Life [3]

2.1.2 Refrigerants

Another of the main topics of the research is the environmental impact of ULT freezers. As mentioned, all University freezers have a two-stage cascade system and thus use two different refrigerants. Their manufacturer categorises some of these freezers as 'energy-efficient'; however, this does not mean they are environmentally friendly. More than half of the freezers use refrigerants that contain hydrofluorocarbons (HFC) with very high Global Warming Potential (GWP). Such HFCs have been shown to harm the environment due to their chemical structure. Therefore a transition has started towards hydrocarbons (HC), known as green gases [21]. Cleaner HF refrigerants such as propane and ethane are now being used (R290 and R170). Such promotes lower pressures and temperatures in refrigeration systems and improves overall performance [19].

In 1995 the European Union adopted legislation banning the use of HCFC. Five years later, they banned using CFCs, as these refrigerants have ozone-depleting properties [22]. Therefore, more environmentally friendly alternatives started being used after these were phased out, such as HFCs and HFOs. While these do not harm the ozone layer, they have significantly higher GWP than other refrigerants. Thus, in April 2014, the European Union established an F gas regulation which banned all nonhydrocarbon liquids for new cooling systems (EU_517/2014) by 2020 [23].
Nonetheless, cooling devices that run at temperatures below -50C, such as ULT freezers, are an exception to this law. Therefore, technically ULT freezers can still make use of HFCs. However, to counteract global warming, buyers (such as the University) should consider this and thus invest in new ecologically-friendly coolants.

According to [24], research of environmentally friendly refrigerants for the commercial level is at an early stage of development, as right now, there is more focus on energy efficiency. The research mentions that the transition from high GWP refrigerants will depend on the application and the possibility of using refrigerants with some degree of flammability. If flammability is not a concern, the recommendation is to use HF refrigerants R170 and R1150, which have a low environmental impact. Figure 2.7 below depicts the three different refrigerant types depending on their chemical composition and characteristics to counteract global warming.

	HFCs	HFOs	HCs
GWP	1400 – 10000 (relatively high)	< 5 (greenhouse effect: low)	< 3 (negligible)
Flammability	nonflammable	slightly flammable	highly flammable
Toxicity*	low	low	low
Ozone depleting potential	0	0	0

* Low toxicity conforms to ASHRAE Class A.
Some substances may have Class B toxicity.

Figure 2.7: Table of the refrigerants generally used in freezers [4]

Furthermore, from the inventory research, it has been concluded that many of the ULT freezers from the University contain HFCs—particularly R508b and R404a, which have a very high GWP. R404a, for example, has a GWP of 3,922, meaning that 100g of this substance has the same GWP as 392kg of CO2 equivalent [5]. Figure 2.8 below shows the GWP values of several commonly used cooling liquids. Therefore, even though, legally, it is still possible to use HFC refrigerants for ULT freezers, it is not a long-term solution, and thus the University should start a transition towards greener refrigerants.

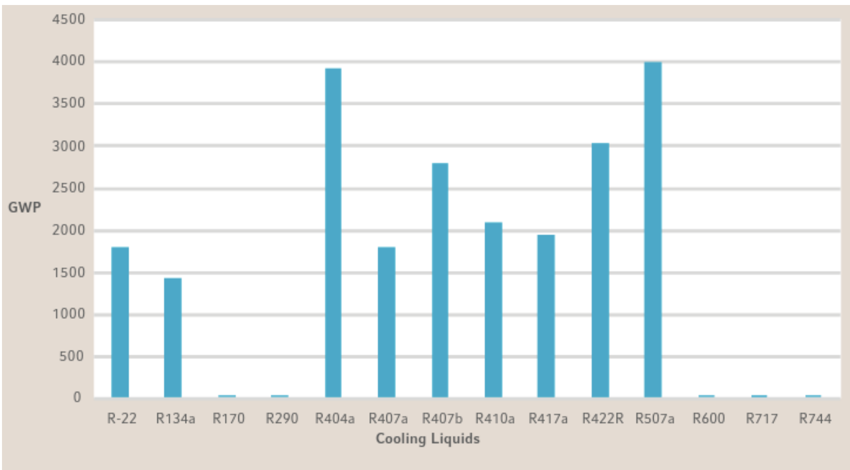

Figure 2.8: Glowbal Warming Potential (GWP) of different cooling liquids [5]

2.2 Freezer Management

The main objective of this research is to provide advice and recommendations to the FSE working group to reduce the energy consumption of ULT freezers within the University. Even though some of the most impacting changes refer to the manufacturing and functioning of the freezer itself, such as the cooling system mentioned previously and other energy-efficient characteristics, many other small changes can substantially reduce energy consumption and environmental impact. Simple changes, ranging from temperature adjustments to cleaning and organisational practices, can significantly impact the functionality and longevity of ULT freezers. By exploring these minor modifications, researchers can enhance sample storage conditions, improve energy efficiency and streamline workflows.

The functional changes can be implemented to optimise the operation and management of ULT freezers, ultimately ensuring the integrity and longevity of samples. Several research facilities worldwide have started to make such changes to reduce energy consumption and environmental impact.
Nonetheless, it is essential to mention that the exact energy use of a ULT freezer depends on several issues, such as the freezer models, the time the freezer is in use, freezer capacity, ambient temperature, dust, ice and how each freezer content is organised [25].

The three main changes that the University can focus on, are the following:

- Temperature adjustments from -80C to -70C
- Cleaning schedules
- Optimal storage organisation

2.2.1 Temperature adjustments

When setting the temperature for ULT freezers, there is often a discussion about whether to set it at -70c or -80c. The Radboud [25] study *"-70 is the new -80"* from 2020 states that before the 1990s, freezers were sold to function at a temperature of -65c or -70c. Only years after, freezer companies started advertising the lower temperatures. No concrete evidence was provided if the lower temperatures improved sample stability. Therefore, in recent years, many labs have set back their ULT freezers to the original temperature in order to meet sustainability objectives and save money. The same study names several other benefits for reducing the temperature, such as the longer compressor lifespan, which is because of the less strain on the compressor and thus potentially leading to longer equipment life.

Furthermore, several laboratories worldwide have increased the temperature of their freezers due to the lack of evidence that -80/85C storage is better than -70C and has indicated no loss of sample integrity [25].
An example of the impact that the temperature change can have on energy consumption can be seen in the figure below. Figure 2.9 shows the output data gathered by the University of Edinburgh in 2015[6]. Four different set temperatures were examined (-85C, -75C, -70C, -60C) and how such impacted the energy consumption for one year. As figure 2.9 shows, increasing the temperature to at least -70C can decrease energy consumption by 20%.

Another study that analysed ULT freezers' performance, energy consumption and carbon footprint from Leo Angelo M. Guampas in 2013 [26] also raised the question regarding the internal temperature of the freezers. Using electricity metres, they measured and evaluated the energy consumption of sixty-four ULT freezers. Aside from several other conclusions, such as the effect of age, capacity or spacing,

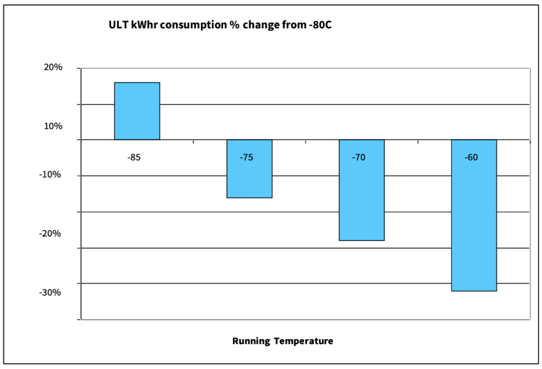

Figure 2.9: Graph of ULT energy consumption percentage variation from -80C [6]

the following figure depicts the effect of set point temperature on energy consumption. Figure 2.10 shows the amount of energy consumed depending on the set point temperature of the freezer. It was concluded that increasing the ULT freezer's set point lowers the ULT freezer's duty cycle, which in turn lowers the ULT freezer's energy consumption. On the other hand, lowering the duty cycle can also extend the freezer's life [7].

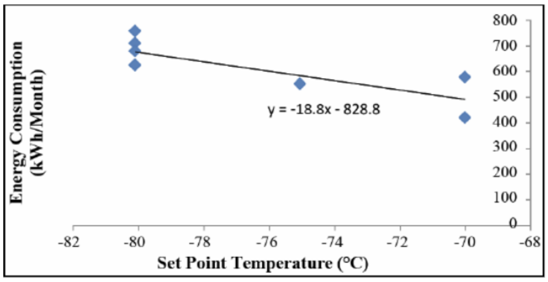

Figure 2.10: Energy consumption versus set point temperature of ULT freezer [7]

Thus, as can be seen from the graph, the linear regression line establishes a correlation between the set point temperature and monthly energy consumption. Based on the data, raising the freezer's temperature by 5C would reduce the daily energy consumption by 3 kWh and avoid 1.54 kg of CO2e of emissions. Hence, lowering the set point temperature by at least 5C lowers energy consumption by 14%. The same study [7] mentions several other researchers who came to the same estimates regarding reducing energy consumption when increasing the set point temperature of the freezers.

Consequently, the management of ULT freezers at the University must address these factors and evaluate when a freezer can be set at a higher temperature when there is no specific reason to be below -70C. Raising the temperature can reduce energy consumption by 2-4Kwh a day and, thus, reduce the energy cost for the University [27].

2.2.2 Cleaning schedule

Maintaining a cleaning schedule for ULT freezers is vital for ensuring equipment negativity and preserving sample integrity. Regular cleaning helps prevent ice build-up, frost, dust and other containment affecting negatively the freezer's performance. Dust accumulation on the condenser coils is particularly problematic as it insulates them and causes the compressor to work harder, increasing energy consumption by up to 25%.To mitigate this, cleaning the condenser filter every two to three months and the coil at least once a year is recommended to maintain efficiency and extend the freezer's lifespan [27].

Thoroughly defrosting the freezer chamber at least twice a year is also recommended. Such involves transferring all contents to another ULT freezer, switching the unit off, and cleaning it with a non-chloride detergent once defrosted [28]. An annual clean-out of unwanted samples from researchers no longer affiliated with the research group can help free up space [29].

Consequently, research conducted by Leo Angelo M. Guampas supports the importance of these cleaning practices and their impact on energy consumption. It was concluded that dust accumulation on the filter could increase energy consumption by 14%. However, when dust accumulates on the condenser coils as well, it can rise by 25%. Additionally, a positive correlation exists between the amount of frost and increased energy consumption, as frost reduced heat transfer efficiency [7].

2.2.3 Optimal storage organisation

Another way to avoid ULT freezers' high energy cost and consumption is by having an optimal storage organisation. For example, having a map or picture of the freezer's interior on the door will minimise the time it takes to find a sample and unnecessary door opening [29]. Minimising the amount of time the freezer door is open reduces temperature fluctuations and saves energy.
The Harvard University Sustainability Guide recommends using sample inventorying guidelines. Inventorying methods can range from a simple freezer map or database programs like Labrepco, Crytotrach or Freezerworks. This helps keep track of the freezer's contents and the time period of each sample. Thus, making it easier to throw away unused samples [29].

Furthermore, a study conducted by the University of Edinburgh about the effect of door opening times on the internal temperature of the freezer concluded that cooler operating temperatures lead to greater temperature variations during door opening, as well as opening a freezer door for longer will expose samples to more significant increases in temperature. However, the positioning within the ULT freezer also influences the samples. Those on the top shelf experience a more remarkable rise in temperature compared to the bottom shelf when opening the door [6]. Another way to reduce the temperature changes is to fill the fridge's space with empty boxes to act as a buffer against these changes [30]. Figure 2.11 below depicts how the average temperature varies depending on when the door opened in seconds.

Averages	Bottom Shelf △	Middle Shelf △	Top Shelf △
60 sec	+1.2 °C	+1.65 °C	+4.7 °C
30 sec	+0.77 °C	+0.3 °C	+3.4 °C
15 sec	+0.83 °C	+0.47 °C	+2.8 °C

Figure 2.11: Table on the average temperature variation depending on the shelf[6]

Chapter 3

Data Collection

3.1 Inventory Review (Audit)

At the start of the year, the Green Labs working group started documenting the number and condition of the ULT freezers on campus, specifically the ones in FSE. Such consisted of an inventory Excel which stated the following:

- The location of the freezer (room and department)
- The contact person in charge of the freezers
- The model and brand
- Purchase year (if known)

The inventory audit listed an amount of 60 freezers within FSE. Nevertheless, the ones used for this study were only a portion (41 freezers), most located in the biology department in Linneausborg or the chemistry department in Nijenborgh.
Furthermore, the information gathered, such as the model and brand of the ULT freezer, can indicate how energy efficient the freezer is or if it's environmentally friendly. It can be seen by analysing each freezer's manufacturing or vendor brochures. Such depicts which cooling system or refrigerants are used.

Additionally, several conclusions can be made after all the ULT freezers have been analysed. Such as if they are energy efficient and use environmentally friendly refrigerants. The energy measurements of each model can later refute it and if these correlate. The analysis will help provide a clear overview of the urgency the University must replace freezers. To keep track of the situation, each row of information of a particular freezer is highlighted with a different colour, depending on their characteristics.

1. **Green:** If the freezer is energy efficient and it's refrigerants or cooling system are environmentally friendly. Thus, no need to be replaced at the moment. *(Ex: the cooling system is Stirling or cascade with green refrigerants).*

2. **Orange**: unsure if the freezer is energy efficient because of the lack of information, and it uses refrigerants that are not environmentally friendly.

3. **Red:** if the freezer is not energy efficient and contains refrigerants with very high GWP *(Ex: CFC & HCFC, or HFC: R134a, R404A and R410A)*. The urgency to replace.

3.2 Energy Measurements

ULT freezers' energy measurements are essential to asses accurately the current energy consumption levels and associated costs. These measurements provide valuable insights into necessary changes to achieve energy reduction within FSE.

Figure 3.1: Energy meter used for measurements

Several ULT freezers were measured with members of the FSE working group. This report only analyses the energy measurements of 41 ULT freezers. Basic energy meters, such as the one depicted in Figure 3.1, were used for the measurements. The energy meters were connected between the freezer plug and the electric socket to measure wattage and voltage simultaneously. The recorded data was in watts per hour. The meters were left for at least seven days, including working days (Monday to Friday) and days off (weekend). This was done to capture variations in energy consumption over weekdays and weekends, ensuring a representative sample of energy usage patterns. The figure 3.2 below shows a table with the data gathered to assess within-day variations. The measurement difference's overall averages (highlighted in yellow) are minor, but they are not considered.

		1	kwH/h	diff from	2	kwH/h	diff from	3	kwH/h	diff from	4	kwH/h	diff from
Thursday	30/03/2023 08:00	0		mean	0		mean	0		mean	0		mean
	30/03/2023 16:40	4.5	0.519231	-0.01486	4.9	0.565385	0.00887	7.3	0.842308	0.001097	6.6	0.761538	0.011726
Friday	31/03/2023 08:14	12.1	0.488223	0.016153	13.6	0.558887	0.015368	20.6	0.85439	-0.01099	18.7	0.777302	-0.00404
Monday	03/04/2023 10:05	49.2	0.50237	0.002006	55.8	0.571429	0.002826	83.2	0.847664	-0.00426	76.1	0.777251	-0.00399
Tuesday	04/04/2023 17:16	64.9	0.503474	0.000902	73.6	0.570818	0.003437	109.7	0.849813	-0.00641	100.3	0.776056	-0.00279
Wednesda	05/04/2023 08:13	72.4	0.501672	0.002703	82.1	0.568562	0.005693	122.3	0.842809	0.000595	111.9	0.77592	-0.00266
	05/04/2023 16:42	76.6	0.495088	0.009287	87.2	0.601179	-0.02692	129.4	0.836935	0.006469	118.5	0.777996	-0.00473
Thursday	06/04/2023 08:04	84.2	0.494577	0.009799	96.1	0.579176	-0.00492	142.4	0.845987	-0.00258	130.3	0.767896	0.005368
	06/04/2023 17:09	89	0.52844	-0.02406	101.4	0.583486	-0.00923	149.9	0.825688	0.017716	137.3	0.770642	0.002622
Monday	11/04/2023 08:09	145.2	0.506306	-0.00193	164.6	0.569369	0.004885	243.7	0.845045	-0.00164	223.3	0.774775	-0.00151

Figure 3.2: Table from Excel that shows the deviation between the measurements of different days

The measurement process involved the following steps: First, the energy meter was plugged with the freezer. Then, the energy meter was reset, and the 'start time' (date and specific time) was logged into Excel. One week later, the energy meter information was recorded in Excel, including the 'stop time' (date and specific time). Additionally, the amount of energy usage recorded was divided by the exact hours the freezer had been monitored for, typically 168h (7 days), to calculate the average daily energy use. This data will help determine the ULT freezer with the highest energy consumption, enabling appropriate actions.

3.3 Survey - Interviews

In addition to collecting quantitative data about the ULT freezers, several lab technicians were also interviewed. The topics that were covered were mainly the following:

- Responsibility for purchasing ULTs in the laboratory, and what were the factors that affected their decision.
- Willingness to purchase energy-efficient freezers even if they are more expensive
- Willingness to participate in short-term changes such as temperature lowering, cleaning schedule and proper freezer organisation.
- Details of the ULTs, precisely, if they think they are too old or have had any issues with them.

The complete questionnaire sent to the laboratory personnel can be found in the Appendix.

Chapter 4

Results

The results section provides a comprehensive analysis of the data collected. It presents the key findings that address the research questions in this study, supported by figures and data. It gives an overview of ULT freezers within FSE, including their inventory, energy consumption measurements, cooling and refrigeration systems, and the survey responses from lab users. Such results contribute to a better understanding of the current situation of ULT freezers in the faculty and provide insight into possible energy-saving strategies.

4.1 Inventory

Understanding what the University currently owns is essential to assess the potential impact of energy-saving strategies. For this specific research, only 41 ULT freezers were analysed from the 60 found within FSE. The inventory table (Figure A.1) depicts an inventory of the ULT freezers, including the model and department within FSE. The table is found in the Appendix.
Knowing the model and brand of the ULT freezer can give an insight into the mechanics of the freezer itself and thus provide information about its cooling system and refrigerants.

4.1.1 Refrigeration and cooling system

The refrigeration and cooling systems of the ULT freezers are also assessed. As mentioned previously, such is crucial to understand the operational mechanisms and efficiency levels. This section includes which freezers are marked as 'energy efficient', the specific refrigerant used, and if it uses a cascade or Stirling system.

Those explicitly labelled 'energy-efficient or high efficiency' freezers are designed to consume less energy than the standard models without compromising storage capabilities. Moreover, the refrigerant characteristics determine the environmental impact and efficiency. The most commonly used refrigerants include HFCs with high GWP. However, newer models are transitioning to "greener" options, such as HFOs or natural refrigerants like HCs.
Furthermore, the cooling systems used in ULT freezers can be cascade or Stirling. Nonetheless, as shown in Figure 4.1, all of the freezers owned by the University have a cascade system.

Model	Energy efficiency	Cooling/Refigerant type	Cooling system
C542-85 (New brunnswick)	unknown	unknown	unknown
C660 HEF New Brunswick	Energy efficient	eco friendly HC	Cascade
Eppendorf / New-Brunswick freezer model U410	not specified	HFC (R404A, R508B)	Cascade
Eppendorf CryoCube FC570	Improved energy consumption	Green hydrocarbons	Cascade
Eppendorf F570 cryocube	Improved energy consumption	Green hydrocarbon based (R290/R170)	Cascade
Eppendorf F570n cryocube	Improved energy consumption	Green hydrocarbon based (R290/R170)	Cascade
Eppendorf/ Nw Brunswick U410	not specified	HFC (R404A, R508B)	Cascade
Eppendorf/ Nw Brunswick U725	not specified	HFC (R404A, R508B)	Cascade
Eppendorf/Nw Brunswick U570	not specified	HFC (R404A, R508B)	Cascade
Haier DW-86L628E	Energy saving	HC "low impact" (R290)	Cascade
Haier DW-86W420	Not specified	HFC and HC	Cascade
Innova C585 (New Brunswick)	Energy efficient	HFC (R404A, R508B)	Cascade
Innova U535 (New Brunswick)	Energy efficient	HFC (R404A, R508B)	Cascade
model C585 (New Brunnswick	Energy efficient	HFC (R404A, R508B)	Cascade
model U101 -86, New Brunswick	Not specified	HFC (R404A, R508B)	Cascade
model U410 -86, New Brunswick	Not specified	HFC (R404A, R508B)	Cascade
New Brunswick C340 Premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C340-86	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C340-86	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C340-86 (left)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C660 (center)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C660 (right)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C660 Premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C66085	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick High Efficiency C660 (left)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick Scientific C542-85	Unknown	Unknown	Unknown
New Brunswick Scientific, U570-86 EU	not specified	HFC (R404A, R508B)	Cascade
New Brunswick U725-86 (right)	not specified	HFC (R404A, R508B)	Cascade
New Brunswick, C340 premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick, C660 premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick, U410 premium	Not specified	HFC, R-407D and R-508	Cascade
New Brunswick, U410-86HEF	Not specified	HFC, R-407D and R-508	Cascade
Panasonic MDF- DC500VX-PE	not specified	HFC mixed	Cascade
Panasonic MDF-594-PE	Not specified	HFC	Cascade
Panasonic MDF-DC500VX-PE	not specified	HFC mixed	Cascade
Sanyo MDF-394	not specified	HFC, R-407D and R-508	Cascade
Sanyo MDF-594	not specified	HFC, R-407D and R-508	Cascade
Sanyo MDF-594	not specified	HFC, R-407D and R-508	Cascade
Sanyo MDF-794	not specified	HFC (R-407D and R508)	Cascade
Sanyo Ultra Low MDF-594	not specified	HFC, R-407D and R-508	Cascade
U570-86 premium	Not specified	HFC (R404A and R508B)	Cascade

Figure 4.1: Excel table that provides information about the current refrigerants and cooling systems of ULT freezers at FSE

As depicted, most ULT freezers still use HFC as refrigerants. This is probably due to the freezers being of old age and therefore have not transitioned to "cleaner/greener" refrigerants. Thus, even though they might not consume as much energy as those not marketed as 'energy efficient', they still are not environmentally friendly.
Furthermore, some ULT freezers have been highlighted orange since they did not specify which HFC was used. HFCs have high GWP; however, some are more than others. For example, R-404A, R-508A, and R-508B have extremely high GWP [31]. Those highlighted fully in green are the ones that are both energy and environmentally friendly.

Note that a bigger version of the figure can be found in the Appendix.

4.2 Energy consumption levels

To evaluate which freezers are the causes of the high energy consumption and what remedies can be applied, there is a need to quantify the current energy consumption levels of the ULT freezers in the FSE laboratories. As mentioned previously, the data was gathered by measuring the energy consumption of each freezer with an energy meter for seven days. This section presents the average energy consumption per day of each ULT freezer measured through several graphs. The data portrayed has been taken from 41 ULT freezers. The lab users set the freezer's temperature to -70,-75 or -80 degrees Celsius, depending on its contents.

Figure 4.2 is a pie chart representing the total percentage of energy consumed by each ULT freezer. On the other hand, the second figure is a column chart showing each model's energy consumption. The three different colours are used to differentiate the freezer's temperature. Blue determines the ULT freezer was set at -70C, pink at -75C, and green at -80C. Nonetheless, -75C will not be evaluated as a lack of validation data is available.

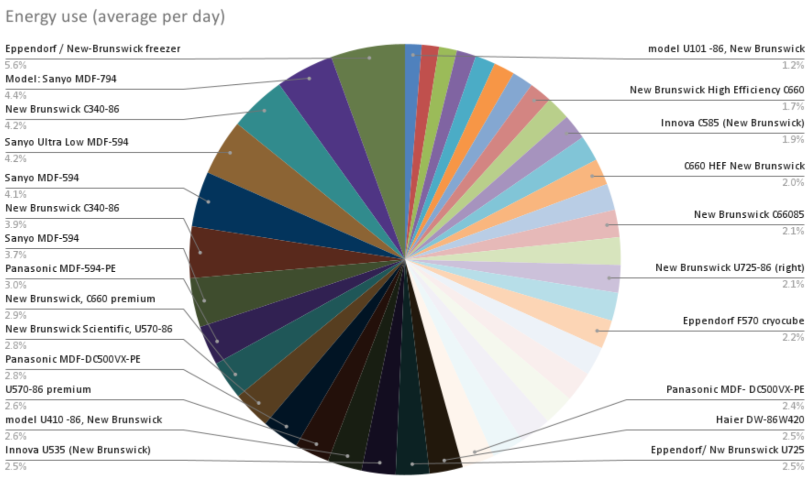

Figure 4.2: Pie chart with the percentages of daily energy use of each ULT freezer

Figure 4.3 shows that most ULT freezers (70%) have been set to -70C. This is due to the FSE working group's persistence in reducing energy consumption, and thus asking lab users to increase the freezer's temperature if there are no exceptional reasons to maintain the extremely low temperatures.
Furthermore, to evaluate the data gathered, a comparison is made with results obtained in other studies.

4.2.1 Temperature -80C

The following graph (Figure 4.4) depicts the ULT freezers' energy consumption at a temperature of -80C. 9 of 41 ULT freezers (21%) were set to -80C. The daily energy consumption tested ranged from 8.3 kWh to 21 kWh. The significant variation in energy consumption is because this research did not consider the room temperature at which the freezer was found, if the freezer was completely full, or how many times the doors were open. All of the aforementioned can increase energy consumption.
The average energy consumption of all is 13.4 kWh. Nonetheless, between the first seven freezers is 11.27 kWh daily. The eighth and ninth columns are nearly twice the average and thus are incredibly energy-consuming.

4.2.2 Temperature -70C

The following graph (Figure 4.5) depicts the ULT freezers' energy consumption at a temperature of -70C. The daily energy consumption tested ranged from 6 kWh to

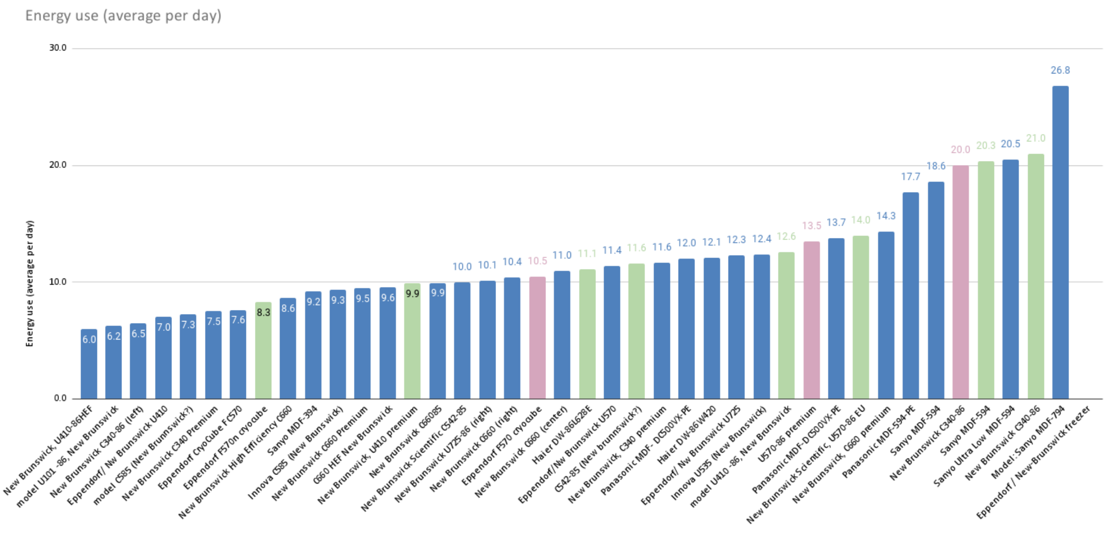

Figure 4.3: Column chart representing all 41 ULT freezer and their daily energy consumption

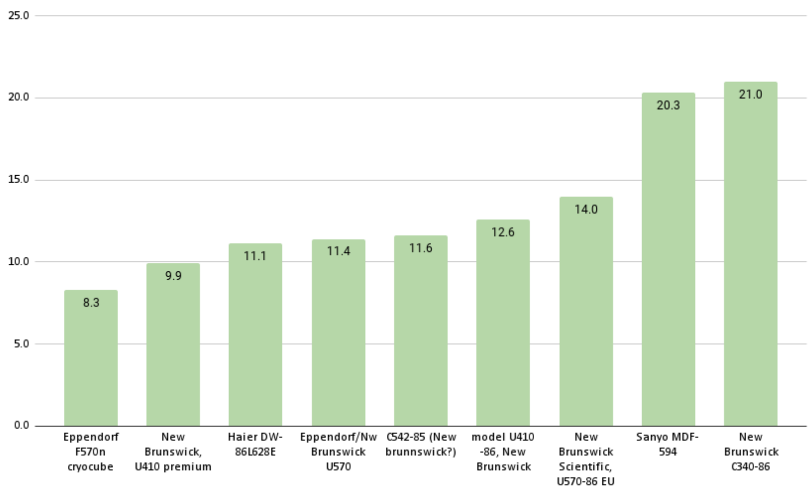

Figure 4.4: Column chart representing all ULT freezer that are set at a temperature of -80C and their daily energy consumption

26.8 kWh. Between the first and last column, there is a difference of nearly five times the first. As mentioned previously, this can be due to exterior factors that were not considered when taking the measurements of each ULT freezer. As researched by the University of California Riverside, freezers with an energy consumption between 6.12 and 7.92 kWh are energy efficient. Considering the external factors mentioned, there are still models that are incredibly energy-consuming, some consuming as much or more than a ULT freezer at -80C.

4.2.3 Overall result of both temperatures

Figures 4.6 and 4.7 include the daily energy consumption of each ULT freezer for both -80C and -70C, as well as the industry energy consumption of the freezer. The

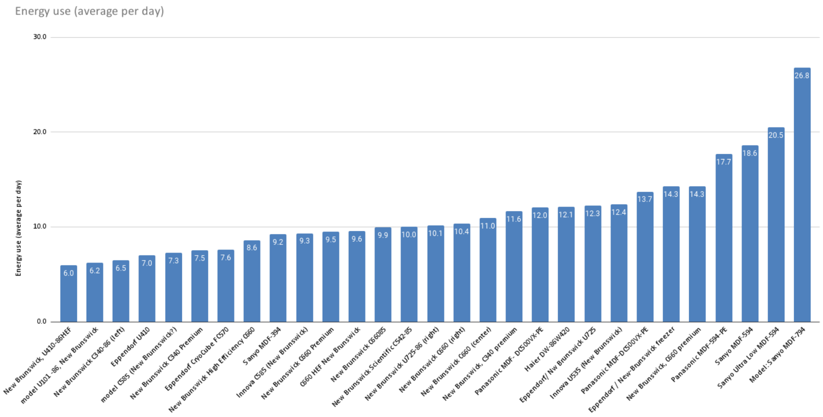

Figure 4.5: Column chart representing all ULT freezer that are set at a temperature of -70C and their daily energy consumption

comparison between both can tell if the ULT freezers are working adequately and if there is room for improvement. Those consuming more than the industry indicates that there is something wrong with the conditions of the ULT freezer.

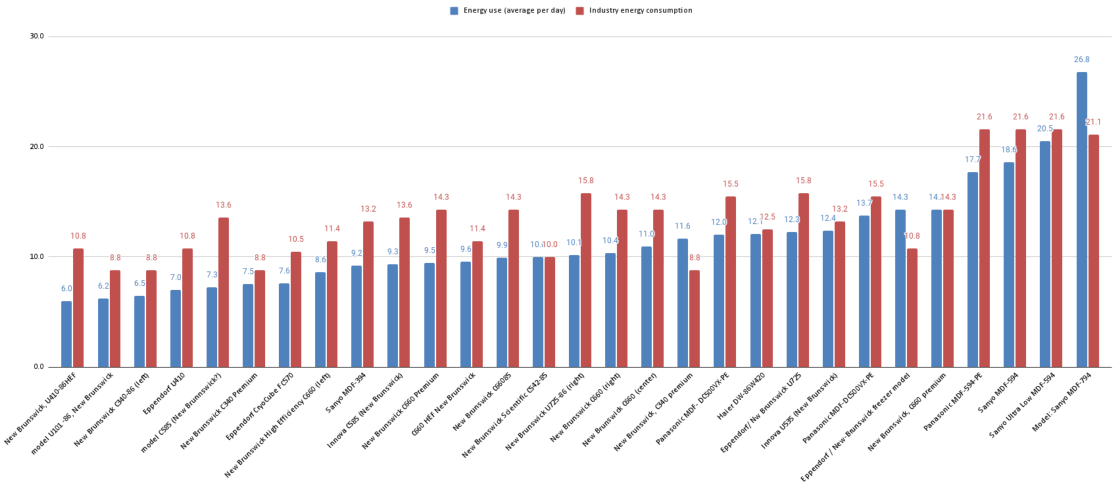

Figure 4.6: Column chart representing all ULT freezer that are set at a temperature of -70C, their daily energy consumption as well as their industry consumption

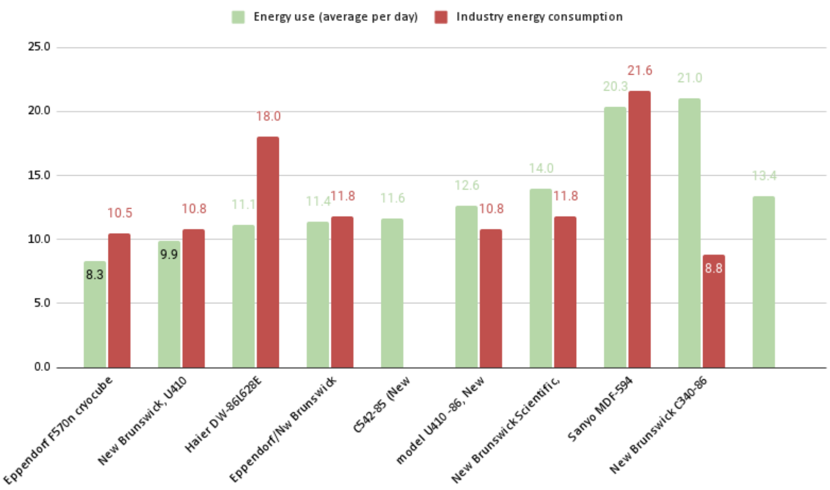

Figure 4.7: Column chart representing all ULT freezer that are set at a temperature of -80C, their daily energy consumption as well as their industry consumption

Consequently, it can also be analysed that the energy consumption also depends on the model and brand of each ULT freezer. For example, the 'Sanyo' ULT freezer is one of the most energy-consuming freezers in both temperatures. On the other hand, the 'Eppendorf' is one of the least energy-consuming.

4.3 Survey responses

Finally, a survey was conducted to gather insight into the functioning of ULT freezers within the FSE laboratories. The section presents the findings obtained through the questionnaire, designed to assess ULT freezers' current state and usage patterns.

The questionnaire consisted of 13 questions; the complete survey can be found in the Appendix. The questions were related to the ULT freezer used by each lab user and covered various aspects such as freezer, age, sharing possibilities, and key factors influencing purchase decisions.

Even though the survey had a limited number of responses (9 respondents), it still provided valuable insights into the perspectives and preferences of lab users regarding ULT freezers within the FSE laboratories. Lab users were not only asked to complete the survey questionnaire. However, they were also personally engaged in discussions while measuring ULT freezers.

An important finding was that most lab users did indeed find energy efficiency important when purchasing a new ULT freezer. This demonstrates a growing awareness of adopting energy-saving measures and reducing environmental impact. However, this was not the first key factor. Lab users prioritised freezer capacity above all else.

Additionally, cost was another significant factor. Respondents revealed they would be willing to allocate more budget for energy-efficient ULT freezers. Nonetheless, most expressed an interest in receiving financial incentives (approximately 30%)

from the University to support the purchase of the new energy-efficient ULT freezers.

The responses indicated a mixed perspective regarding the idea of sharing ULT freezers. While some were open to sharing, most lab users disagreed. Consequently, the survey shed some light on the practices related to ice removal and cleaning. While several mentioned performing ice removal every three months to a year, there was no clear, standardised schedule for these maintenance activities.

Chapter 5

Discussion

The discussion section provides a comprehensive analysis of the data collected. It presents key findings that address the research questions outlined in this study. It aims to interpret and explain the results concerning the current understanding of ULT freezers and their energy consumption.

5.1 Inventory Analysis

The inventory analysis provides a clear picture of what the FSE currently owns. Even though only 41 out of the 60 ULT freezers were analysed, it managed to portray critical information about the whereabouts of the freezers throughout FSE and the model employed by each laboratory.
The inventory information is crucial to answer all the research questions. It establishes the base for the analysis. Knowing the model and brand of the ULT freezer helps one understand the mechanics of the freezer, such as the cooling system and refrigerants used. Such can later be used to compare correlation with energy consumption measurements.

5.2 Refrigeration and Cooling System

As mentioned previously, the assessment of the mechanisms of each model and brand can give an insight into the cooling system and refrigeration used. Such can contain critical details about the ULT freezer, for example, if its energy-efficiency or environmentally friendly. The results show that most ULT freezers the University owns use high GWP refrigerants such as HFCs. On the other hand, five freezers used "green" refrigerants, such as HCs. Meaning that there is a positive trend towards the adoption of "greener" options.
Furthermore, all ULT freezers use a cascade cooling system. Although, this is not necessarily characterised as unfavourable. It is important that the University also looks into Stirling cooling systems as they are both energy efficient and environmentally friendly.

The findings answer several research questions, providing information about the cooling systems and how environmentally friendly each refrigerant is. The results highlighted the need for transitioning to greener options, such as natural refrigerants or low-GWP alternatives, to minimise environmental impacts. This data can be used as an indicator for the University (or lab users) when purchasing a new ULT freezer.

5.3 Energy consumption levels

Quantifying the energy consumption levels of the ULT freezers provided insights into their efficiency and identified potential areas for improvement. The results showed that there are indeed variations between models and brands. In both the ULT freezers set at -80C and -70C, there was a wide range of energy consumption, with some consuming significantly more than others. The findings also gave insight into the energy consumption depending on the two temperatures and how some freezers would consume much more when set to -80C.

Nonetheless, the results prove that many external factors must be considered, as there is a lot of variability. Factors beyond the interior temperature of the freezer, such as room temperature, maintenance and other characteristics of the freezer, also contribute to energy consumption. The University should use this data to evaluate which ULT freezers must be discarded or replaced because of their extremely high energy consumption and which should implement energy-saving measures to optimise energy consumption.

5.4 Survey Responses

The survey was conducted to shed light on the perspectives and preferences of lab technicians regarding ULT freezers. The results showed an increasing awareness of energy efficiency when purchasing new freezers. However, freezer capacity was still prioritised over energy efficiency in their decision-making process. Another vital topic for respondents was the price of ULT freezers. Most were willing to set aside more money to buy an energy-efficient and environmentally friendly freezer. Nonetheless, since these are usually significantly more expensive, a portion expressed interest in receiving financial incentives from the University to support the purchase.

Although the survey received a lower output than expected, it still brought valuable insights into the opinion of lab users towards their ULT freezers. The University can use this to evaluate the possibility of financial incentives to reduce the cost of energy consumption overall.

Chapter 6

Conclusion, Recommendation, & Limitations

This research project investigated ULT freezers within the FSE laboratories to provide insight into their inventory, energy consumption, cooling and refrigeration, and environmental impacts. This insight makes it possible to analyse the best measures to reduce the high energy consumption costs within FSE.
Therefore, the findings of this research contribute to a better understanding of the current situation at FSE and establish a foundation for developing changes to optimise energy consumption and reduce environmental impact.

Firstly, the inventory analysis revealed that there are currently 60 ULT freezers within FSE. Forty-one of them were included in this study. The information is vital for assessing potential strategies to reduce energy consumption.

The energy consumption assessment highlighted which freezers were the most energy consuming or efficient. Such provides a clear image of the ULT freezers' current energy usage patterns, making it possible to identify the areas of improvement.

Moreover, the analysis of cooling and refrigeration systems revealed which ULT freezers are energy efficient or environmentally harmful by looking into the operational mechanisms. Most freezers from the University use high-GWP refrigerants such as HFC. However, there is a positive trend towards adopting "greener" refrigerants. Additionally, identifying cascade cooling systems as the predominant mechanism highlights an opportunity to explore more energy-efficient and sustainable options, such as Stirling cooling systems.

The survey responses from the lab users shed light on their perspectives and preferences regarding ULT freezers. While capacity is still the most significant priority when purchasing a new freezer, there is an increasing awareness of energy-efficient ULT freezers. Respondents were willing to allocate more money towards an environmentally friendly and energy-efficient freezer. Nonetheless, many mentioned costs as a problem and would appreciate a financial incentive from the University to support the purchase.

In conclusion, this research emphasises the need for change towards using ULT freezers in research laboratories to reduce the overall energy consumption of FSE. While the results showed the eagerness to transition to "greener" alternatives, there are still several steps the University can take. Implementing energy-saving measures and the possibility of financial incentives can further stimulate the adoption of energy-efficient ULT freezers.

6.1 Recommendations

Based on the results of this research project, the following recommendations are proposed:

- **Implement energy-saving measures:** Apply energy-saving techniques to those ULT freezers that contribute to high energy consumption. These can be mechanical changes such as temperature adjustment or improving insulation. However, it can also include upgrading certain freezers to new, more energy-efficient models.
- **Raise awareness**: Increase lab users' awareness of the importance of energy efficiency and sustainable practices. Provide a clear outlook on which cooling systems and refrigerants to look for.
- **Financial Incentives**: Explore the possibility of supporting financial lab groups to purchase new ULT freezers. This incentives lab users to invest more in efficient equipment and promotes adopting sustainable practices while reducing energy costs at the University.
- **Regular maintenance and monitoring:** To improve energy efficiency and ensure optimal performance. Establish a policy for the University for laboratories to have standardised schedules for ice removal and cleaning ULT freezers.
- **Monitoring and evaluation:** establish that after a given amount of years, each laboratory group should assess their freezer's functioning and review its contents.
- **Investing in energy-efficient and environmentally friendly freezers**: Explore the possibility of substituting the most energy-consuming freezers for new energy-efficient ones that also take into account the environmental impact (such as the Stirling ULT freezer).

6.2 Limitations

It is essential also to acknowledge the limitations of this study. First, the inventory analysis was only done on two-thirds of the FSE ULT freezers (41). This was due to the lack of time to measure all freezers in a short period.

Furthermore, not all energy consumption measurements were conducted over the same period of time. Depending on the availability of the lab users, some energy meters were left for more than seven days. Those measurements of only seven days could not capture as many variations as the ones kept in longer. The analysis did not consider other external factors, such as the freezer contents, door opening, and room temperature. All of which could also impact energy consumption levels. Finally, the survey responses were limited to a few lab users. Therefore, it can be that other lab users have different opinions on specific topics.

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Appendix A

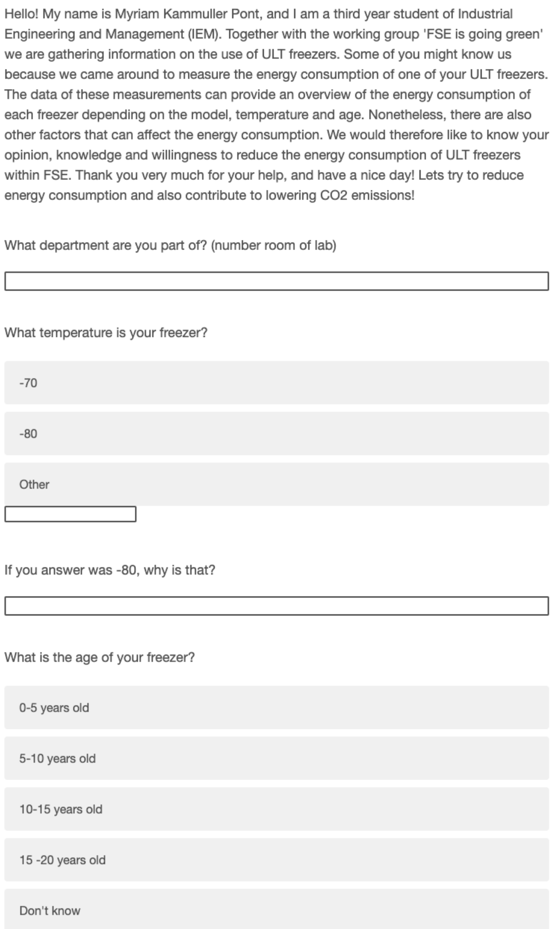
Appendix

Linneausborg	Room:	Department:	Model
5172	-128	Isotopenlab	New Brunswick, U410-86HEF
5115	0107	Molecular Biophysics	model U101 -86, New Brunswick
5173	0320A	MarBee	New Brunswick C340-86 (left)
	0103		Eppendorf/ Nw Brunswick U410
	0618	Micr. Fysiologie	model C585 (New Brunnswick)
	0673A	Mol. Microbiologie	New Brunswick C340 Premium
	0673A	Mol. Microbiologie	Eppendorf CryoCube FC570
	0773	Shared with FSE-Education	Eppendorf F570n cryocube
	0436A	Dierecologie	New Brunswick High Efficiency C660 (left)
	0161A	GELIFES/ Mol. Neurobiology (Robbert Havekes)	Sanyo MDF-394
	0514	Mol. Celbiologie	Innova C585 (New Brunswick)
	0673A	Mol. Microbiologie	New Brunswick C660 Premium
	0869	Chemical Biology 1	C660 HEF New Brunswick
	0717	Mol. Microbiologie	New Brunswick, U410 premium
	0161	GELIFES	New Brunswick C66085
	0681		New Brunswick Scientific C542-85
	0320A	Marine Biology	New Brunswick U725-86 (right)
	0436A	BPE ConsEco	New Brunswick C660 (right)
	0773	Molecular Microbiology	Eppendorf F570 cryocube
	0436A	BPE ConsEco	New Brunswick C660 (center)
	-128	Chronobiologie	Haier DW-86L628E
	0103		Eppendorf/Nw Brunswick U570
	0545A	Celbiologie	C542-85 (New brunnswick?)
	0782	Microbiele ecologie	New Brunswick, C340 premium
	0261	Behavioral Neuroscience / GELIFES (Gertjan van Dijk)	Panasonic MDF- DC500VX-PE
	0259a	Molecular Neuroscience / GELIFES (PKU vriezer)	Haier DW-86W420
	0103		Eppendorf/ Nw Brunswick U725
	0514	Mol. Celbiologie	Innova U535 (New Brunswick)
5115	0110	Molecular Biophysics	model U410 -86, New Brunswick
	0773	Molecular Microbiology	U570-86 premium
	0261	Behavioral Neuroscience /GELIFES (Martien Kas)	Panasonic MDF-DC500VX-PE
	0417	Plant Physiology	New Brunswick Scientific, U570-86 EU
	0773	Shared freezer Mol. Microbiologie en microbiele ecologie	New Brunswick, C660 premium
	0673A	Mol. Microbiologie	Panasonic MDF-594-PE
	0261	Mol. Neurobiologie / GELIFES (Eisel/van der Zee)	Sanyo MDF-594
	0618	GBB	New Brunswick C340-86
	0261	Mol. Neurobiologie / GELIFES (Eisel/van der Zee)	Sanyo MDF-594
	0681	Evol. Genetica	Sanyo Ultra Low MDF-594
	0618	Micr. Fysiologie	New Brunswick C340-86
5118	-0163	Bioproduct Engineering	Model: Sanyo MDF-794
5114	0123	Biomolecular Chemistry & Catalysis (Roelfes group)	Eppendorf / New-Brunswick freezer model U410

Figure A.1: Results- Inventory overview of ULT freezers

Model	Energy efficiency	Cooling/Refigerant type	Cooling system
C542-85 (New brunnswick)	unknown	unknown	unknown
C660 HEF New Brunswick	Energy efficient	eco friendly HC	Cascade
Eppendorf / New-Brunswick freezer model U410	not specified	HFC (R404A, R508B)	Cascade
Eppendorf CryoCube FC570	Improved energy consumption	Green hydrocarbons	Cascade
Eppendorf F570 cryocube	Improved energy consumption	Green hydrocarbon based (R290/R170)	Cascade
Eppendorf F570n cryocube	Improved energy consumption	Green hydrocarbon based (R290/R170)	Cascade
Eppendorf/ Nw Brunswick U410	not specified	HFC (R404A, R508B)	Cascade
Eppendorf/ Nw Brunswick U725	not specified	HFC (R404A, R508B)	Cascade
Eppendorf/Nw Brunswick U570	not specified	HFC (R404A, R508B)	Cascade
Haier DW-86L628E	Energy saving	HC "low impact" (R290)	Cascade
Haier DW-86W420	Not specified	HFC and HC	Cascade
Innova C585 (New Brunswick)	Energy efficient	HFC (R404A, R508B)	Cascade
Innova U535 (New Brunswick)	Energy efficient	HFC (R404A, R508B)	Cascade
model C585 (New Brunnswick	Energy efficient	HFC (R404A, R508B)	Cascade
model U101 -86, New Brunswick	Not specified	HFC (R404A, R508B)	Cascade
model U410 -86, New Brunswick	Not specified	HFC (R404A, R508B)	Cascade
New Brunswick C340 Premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C340-86	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C340-86	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C340-86 (left)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C660 (center)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C660 (right)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C660 Premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick C66085	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick High Efficiency C660 (left)	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick Scientific C542-85	Unknown	Unknown	Unknown
New Brunswick Scientific, U570-86 EU	not specified	HFC (R404A, R508B)	Cascade
New Brunswick U725-86 (right)	not specified	HFC (R404A, R508B)	Cascade
New Brunswick, C340 premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick, C660 premium	High efficiency	HFC, R-407D and R-508	Cascade
New Brunswick, U410 premium	Not specified	HFC, R-407D and R-508	Cascade
New Brunswick, U410-86HEF	Not specified	HFC, R-407D and R-508	Cascade
Panasonic MDF- DC500VX-PE	not specified	HFC mixed	Cascade
Panasonic MDF-594-PE	Not specified	HFC	Cascade
Panasonic MDF-DC500VX-PE	not specified	HFC mixed	Cascade
Sanyo MDF-394	not specified	HFC, R-407D and R-508	Cascade
Sanyo MDF-594	not specified	HFC, R-407D and R-508	Cascade
Sanyo MDF-594	not specified	HFC, R-407D and R-508	Cascade
Sanyo MDF-794	not specified	HFC (R-407D and R508)	Cascade
Sanyo Ultra Low MDF-594	not specified	HFC, R-407D and R-508	Cascade
U570-86 premium	Not specified	HFC (R404A and R508B)	Cascade

Figure A.2: Results - Overview of refrigerant and cooling system of ULT freezers



Hello! My name is Myriam Kammuller Pont, and I am a third year student of Industrial Engineering and Management (IEM). Together with the working group 'FSE is going green' we are gathering information on the use of ULT freezers. Some of you might know us because we came around to measure the energy consumption of one of your ULT freezers. The data of these measurements can provide an overview of the energy consumption of each freezer depending on the model, temperature and age. Nonetheless, there are also other factors that can affect the energy consumption. We would therefore like to know your opinion, knowledge and willingness to reduce the energy consumption of ULT freezers within FSE. Thank you very much for your help, and have a nice day! Lets try to reduce energy consumption and also contribute to lowering CO2 emissions!

What department are you part of? (number room of lab)

What temperature is your freezer?

- -70
- -80
- Other

If you answer was -80, why is that?

What is the age of your freezer?

- 0-5 years old
- 5-10 years old
- 10-15 years old
- 15 -20 years old
- Don't know

Figure A.3: Data Analysis- Survey Questions 1 to 4

Would you be open to share your freezer?

- Yes
- Maybe
- No

What are the key factors you look at when purchasing a freezer? (Rank them)

- Capacity
- Legacy/brand reputation
- Temperature range
- Energy efficiency
- New technology
- Price
- Environmentally friendly

Would you be willing to spend more of your laboratories budget for a freezer that is sustainable and energy efficient?

- Yes
- No

Would your answer for the previous question change if you had a financial incentive from the University? How much would you require to make that decision? (Answer in percentage)

How important do you consider energy-efficiency when purchasing a new freezer?

Not at all important		Slightly important		Moderately important			Very important		Extremely important	
0	10	20	30	40	50	60	70	80	90	100

Energy efficiency

Do you currently have a cleaning schedule? Explain why you do or do not.

Figure A.4: Data Analysis- Survey Questions 5 to 10

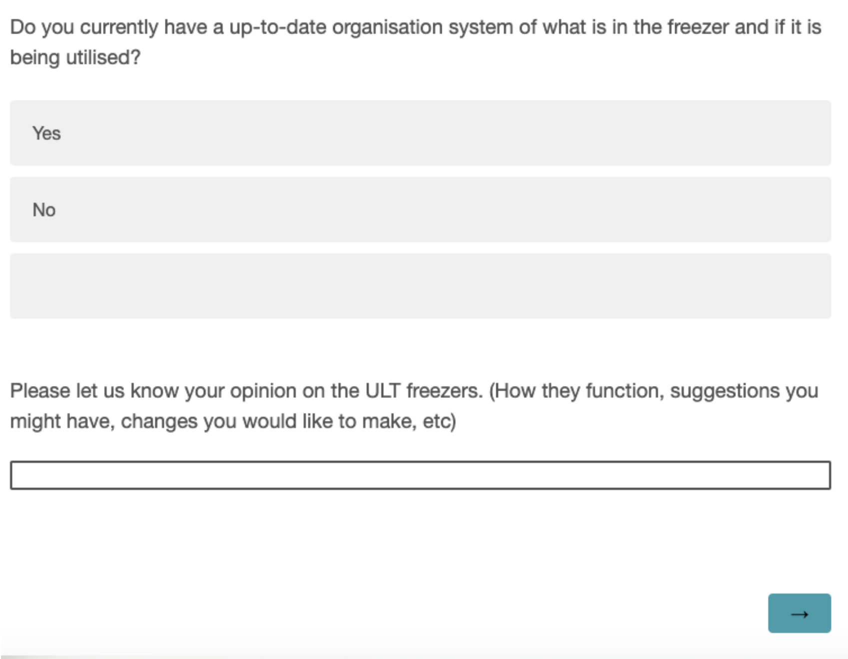


Figure A.5: Data Analysis-Survey Questions 11 to 12

What department are you part of? (number room of lab)
Molecular Biophysics
GELIFES
5172 05 23
GBB/Membrane Enzymology/NB4-16-113
BE & PPBBE (ENTEG)

Figure A.6: Results- Survey

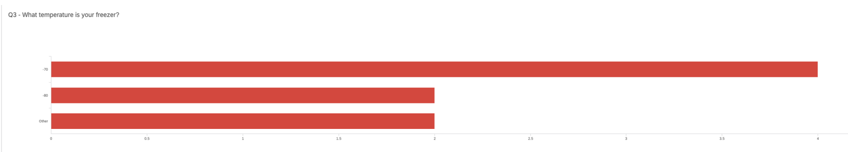


Figure A.7: Results- Survey

Q3_3_TEXT - Other

Other
both -70 and -80
-70 (twice) and -80

Page: 1 Of 1

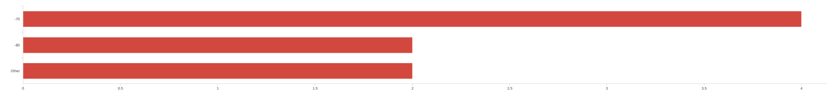


Figure A.8: Results- Survey

Q4 - If you answer was -80, why is that?

If you answer was -80, why is that?
We have -80 because of RNA samples. These would degrade at -70 degC.
we store dry-ice
Because of RNA samples which have to be kept at -80oC
In case of an emergency our cell strains will be damaged if the temperature goes higher then -65

Figure A.9: Results- Survey

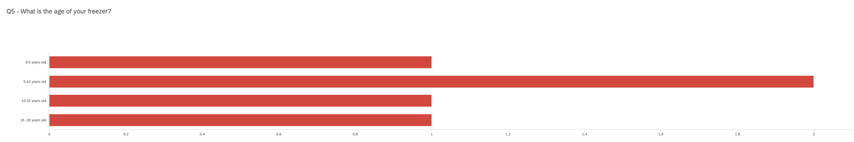


Figure A.10: Results- Survey

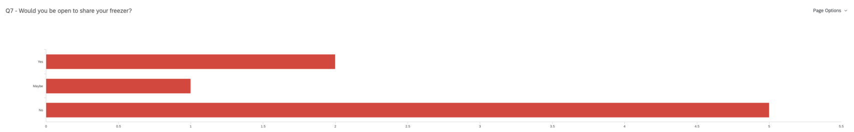


Figure A.11: Results- Survey

Figure A.12: Results- Survey

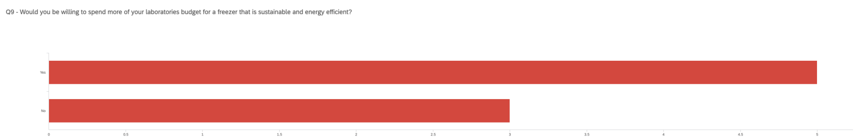
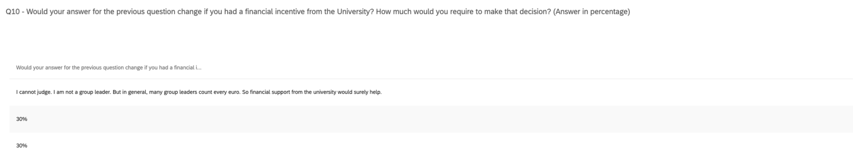


Figure A.13: Results- Survey


Q10 - Would your answer for the previous question change if you had a financial incentive from the University? How much would you require to make that decision? (Answer in percentage)

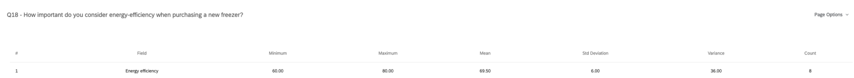
Would your answer for the previous question change if you had a financial i...

I cannot judge. I am not a group leader. But in general, many group leaders count every euro. So financial support from the university would surely help.

30%

30%

Figure A.14: Results- Survey


Q18 - How important do you consider energy-efficiency when purchasing a new freezer?

Page Options

#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Energy efficiency	60.00	80.00	69.50	6.00	36.00	8

Figure A.15: Results- Survey

Q14 - Do you currently have a cleaning schedule? Explain why you do or do not.

Do you currently have a cleaning schedule? Explain why you do or do not.
Yes, kind of. We clean all the labs, including freezers, once in 3 months.
Yes, to remove ice that gets in the way and keep an eye on inventory
once a year or more often when necessary
sure getting rid of to much ice
Yes we remove the ice; as a labtask

Figure A.16: Results- Survey

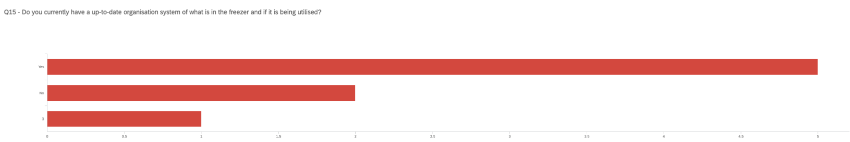


Figure A.17: Results- Survey

Q16 - Please let us know your opinion on the ULT freezers. (How they function, suggestions you might have, changes you would like to make, etc)

Please let us know your opinion on the ULT freezers. (How they function, su...
We have 3 ULT freezers. I put one up for replacement when moving to the new building. Problem is the way things are stored inside.For us it is important we can reuse the storage system so basically we are forced to buy Eppendorf/ Nw Brunswick systems, or compatible.Luckily the room we have the freezers has airco this realy helps preventing ice formation.
We already share the -80 freezer within 3 groups. We try to be efficient.
Very usefull
Silent and efficient.
NA

Figure A.18: Results- Survey