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Improving sustainability of ultra-low-temperature freezers at the School of Biosciences, Sheffield University

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Abstract

Ultra-low-temperature freezers (ULTFs) are an essential part of biological and medical research, but consume large amounts of energy. The School of Biosciences at the University of Sheffield has a fleet of approximately 80 ULTFs, which were operating at −80 °C until 2024, and contribute significantly to the School's electricity consumption—around 1300 kW h/d in early 2024, with correspondingly high electricity costs and carbon footprint. We therefore set out to manage the use of our ULTFs more effectively, while reducing risk to research, through a combination of extensive consultation with users, improved management, and increasing the set temperature to −70 °C. We have implemented a policy of consolidating and rolling out replacements for freezers, based on energy usage rather than age. Based on a pilot programme that achieved a 62% reduction in energy, we expect to reduce energy consumption by at least 50% and simultaneously save money while also mitigating risks to research, benefiting both the School and the University. This study provides details on how these results were achieved.

Keywords: *ultra-low-temperature freezer, sustainability, energy, efficiency*

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1. Introduction

There is an increasing awareness of the importance of sustainability in laboratory practice. This is supported by organisations such as My Green Lab, based in the USA [1], Green Labs in Europe [2], and LEAF in the UK [3]. These organisations provide support and resources and also offer certification of sustainable practices. Research funders are gradually adopting a requirement for certification to receive funding. Both Cancer Research UK [4] and the Wellcome Trust [5] have announced a requirement for LEAF, My Green Lab, or an equivalent certification to qualify for grant funding. Many laboratories worldwide are developing strategies for more sustainable research.

The University of Sheffield has an ambitious Sustainability Strategy, managed by a high-level management group, much of it based on centralised activities. Academic departments are also encouraged to take responsibility for reducing their carbon footprint. The School of Biosciences was formed in 2021 through the merger of three separate biology departments and comprises approximately 380 staff members. It is thus a large School. Soon after the School was formed, we established a Sustainability Committee, with the overall aim of becoming more sustainable, in line with the UN's sustainability goals [6]. Many of these goals are quite general, and it is not easy to see how they can be translated into practical actions at a local level. We soon agreed that the most useful activities for the School Sustainability Committee would focus on 'low-hanging fruit', i.e., those activities that bring a simple, rapid, and easily quantifiable improvement in sustainability, most obviously by reducing our carbon footprint.

We therefore began by surveying our activities and identifying those where the biggest efficiencies could be gained. Laboratory space occupies approximately 7% of the university's floor area but generates about 50% of all carbon emissions. The School of Biosciences has a base load of approximately 20,000 kW h/d. According to the UK energy regulator Ofgem [7], the average household energy consumption in the UK is roughly 2700 kW h/a (per annum), so the School's base energy consumption is equivalent to roughly 2700 average houses, or a large village. ULTFs form a significant part of this figure. A typical figure quoted for a ULTF is 14.4 kW h/d [8], implying that our fleet of 80 ULTFs would be expected to consume approximately 1150 kW h/d or 6% of the School's total energy consumption, at a cost of approximately 130,000 GBP/a, this being just the cost of running the freezers and not including downstream air conditioning and ventilation. It was clear that even fairly modest improvements in ULTF performance could translate into a useful reduction in energy consumption. We therefore established a ULTF Group as a subgroup of the Sustainability Committee, tasked with analysing the problem and generating a quantifiable reduction in the School's baseline energy usage. The group currently consists of four people: the School's Technical Manager, one member of technical staff, one academic, and a member of the Estates and Facilities Management (EFM) team. The group meets formally every two weeks, focusing on action rather than discussion. It has been very active in the roughly 24 months since its inception, indicating that making a significant and sustained improvement requires a major time commitment.

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Our aim has been to identify and implement changes in working practices that lead to a real and sustained reduction in energy usage from our ultra-low-temperature freezers. Here, we describe how these aims have been realised, resulting in at least a 50% expected reduction in ULTF energy consumption.

2. Materials and methods

Energy consumption was monitored by portable monitors that plug into the wall socket. Several models were considered, finally selecting the Multicomp Pro MP001186, with other (more expensive) monitors being less reliable. The monitors were left in place for 7 days. A comparison of different monitors suggested that they have an error within 5%, based on repeat measurements in consecutive weeks.

Most of the ULTFs in this study were housed in temperature-controlled environments, specifically in rooms equipped with heating and air conditioning. The overall room temperatures were monitored and showed no discernible change as a result of changes to the freezers (for example, changing their set temperatures). The environmental factors were thus roughly stable.

Statistical tests were calculated using Microsoft Excel or *R* (version 4.5.1 [9]). The significance of correlations was tested using the two-sided *t*-test where appropriate, or other tests as described.

The most effective communication and consultation on this project took place via face-to-face meetings with staff in the research clusters. We also compiled a collection of literature on ultra-low-temperature freezers, for example, studies on the longevity of biological samples stored at −70 °C versus −80 °C (e.g., [10–12]), which was the most common concern expressed in our meetings, and made these available via the intranet.

The defrost kit is stored in a large plastic tub and contains gloves, a paper roll, an ice scraper, a dustpan and brush, and a roll of foil, with an instruction suggesting to lay the foil in the bottom of the freezer, shape it into a spout, and direct the water into a suitable container (such as the plastic tub itself). Our Standard Operating Procedure for defrosting of ULTFs is available as Supplementary materials.

3. Results

3.1. Initial analysis

The membership of the ULTF Group was made up of volunteers from the School Sustainability Committee and, fortuitously, it has turned out to contain a good mix of skills. L.G. is the Environmental Projects Coordinator within Estates and Facilities Management (EFM), which is the University's professional services department responsible for campus services, engineering and maintenance, as well as Estates Development; he is part of Estates Development, who play an important role in planning and delivering the transition to net carbon zero on campus. He is thus the only member of the group whose formal role is directly focused on sustainability. As part of EFM, he has access to specialist resources and technical expertise, which has proven an essential underpinning of the group's work. M.H. is the Technical Manager for the School, overseeing all technical aspects of its operation, including buildings and equipment. Her enthusiastic support for the group's work has been essential. Due to her role, she is part of the Executive Team at the School and has therefore been able to bring the group's concerns to the attention of senior management. As discussed below, the group has engaged in a wide range of hands-on tasks, including defrosting ULTFs and shifting their contents, as well as talking to principal investigators (PIs), measuring energy input, and setting up the infrastructure described below. This has entailed a considerable effort from the technical staff on the group, not formally part of their job descriptions, but facilitated with the support of the Technical Manager. Finally, the senior PI on the group has provided strategic advice.

The first task of the group was information gathering. The School operated about 80 ULTFs. Most of these were purchased by PIs from grant income, meaning they were acquired piecemeal in a range of styles and manufacturers, and have a wide range of ages, with the oldest being 24 years old. There had been no School management of ULTFs, so a number were iced up and not well maintained; some have poor documentation regarding their contents; and some are shared between PIs, while others are used by a single PI. They are managed by the responsible PIs, which means that most of the day-to-day access is carried out by PhD students and postdocs, and there is no School-wide oversight. A few are used by research facilities and have more professional technical support. The School kept some ULTFs available for emergencies, particularly in the event of a breakdown, and for keeping samples cold during routine defrosting. In principle, anyone using an emergency freezer should vacate it promptly once the emergency has passed. This did not always happen, meaning that there was often uncertainty about which freezers were available in the event of an emergency. Many ULTFs had thermocouples fitted internally that were connected to a central monitoring system, providing automatic notification of freezer failure.

A few labs kept backup samples in a separate ULTF in a different location. This is good practice, for two reasons. First, if the main ULTF breaks down or is damaged by fire or flood, then the biological resource (cell line, seed) is not permanently lost. In some cases, these resources have taken years to produce, and the lab's research would be seriously curtailed in the event of sample loss. Second, the backup ULTF is used only for backup storage, meaning it is not often accessed, resulting in more efficient energy use and a lower risk of failure. It does, however, require a greater degree of organisation on the part of lab members.

We first documented the existing freezers and collected basic details about their capacity, condition, occupancy, and other relevant information. This was to assess the usage of emergency freezers and to discuss with users how they utilised their ULTF. An important early aim was to measure the actual energy usage of as many ULTFs as possible. We used simple monitors that plug between the wall socket and the ULTF. The installation of the monitor thus required a brief disconnection of the ULTF from its power supply, and we therefore notified all PIs in advance and asked them to inform us if they did not want their ULTF disconnected, even momentarily. Only one did, because the freezer was so old that they were concerned that it might not come back on.

3.2. Baseline performance

Monitoring of all ULTFs took about 3 months. Most of the ULTFs could be monitored (72 out of 79), which allowed a reasonably accurate estimate of the total energy usage as 1250 kW h/d, somewhat larger than the 'average' load expected for 80 ULTFs, which would be 1150 kW h/d [8], suggesting that our usage was slightly worse than average. For reference, the average energy usage of a UK house is 7.4 kW h/d. We then searched for correlations among the data. Despite a wide range in the data, there was a highly significant correlation with age (**Figure 1**): energy usage increased by approximately 3.6%/yr. This figure aligns with literature values, for example, 3% [13]. Interestingly there was no significant correlation with freezer capacity (**Figure 2a**) (that is, larger freezers did not use significantly more energy than smaller ones), and therefore a strong negative correlation of energy usage per litre vs. capacity (**Figure 2b**), i.e., larger freezers were markedly more efficient on a per volume measure. There are of course disadvantages in having a larger freezer (more floor space, harder to keep track of contents, takes longer to defrost, door will be opened more frequently, shared usage and therefore less clear management structure for the freezer), but the advantage in efficiency is clear.

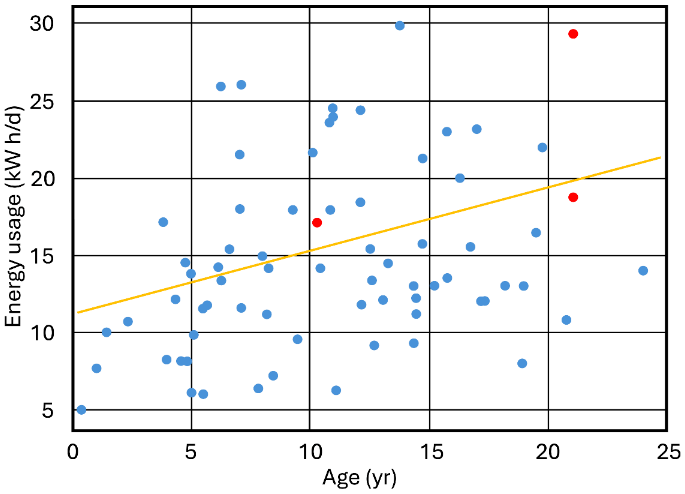

Figure 1 • Energy use of ULTFs in Biosciences as a function of age. The orange line is the line of best fit. There is a highly significant correlation with age: Pearson correlation coefficient $\rho = 0.32 \pm 0.11$, $p < 0.01$. The three ULTFs in red have been taken out of service: the one at top right because of its age and inefficiency, and the other two because they failed.

The energy consumption of freezers varied over a very large range, from 6.2 to 41.6 kW h/d. In addition to the factors of age and capacity described above, there were no other significant predictors of energy usage. For example, tests for the effect of door opening ($n = 25$) yielded no significant effect ($p = 0.17$), while a comparison of chest versus upright freezers provided no meaningful comparison due to the limited number of chest freezers in our sample ($n = 5$). Previous studies [14–16] have shown that more frequent door openings increase energy use and that upright freezers are more efficient. There is no reason to suppose that our results differ, and it is likely that tighter control of these variables would have produced similar results here. The energy usage increases significantly with age, but the overall effect is only 3.6%/yr, meaning that many older freezers had good energy efficiency (**Figure 1**). We therefore suggest that a blanket policy of disposing of freezers beyond a fixed age is not helpful, as previously suggested [12].

Most of the ULTFs were set to −80 °C, following what, until recently, has been standard practice in research labs [16], but some were set to −70 °C and a few at −75 °C. As expected from the literature [17], the energy usage of the freezers at −70 °C was considerably lower (**Figure 3**), with a median usage roughly 35% lower than those at −80 °C.

The literature reports a wide range of energy reductions for the comparison between −80 °C and −70 °C. Some values collected from the literature are reported in **Table 1**, together with the results obtained in this study.

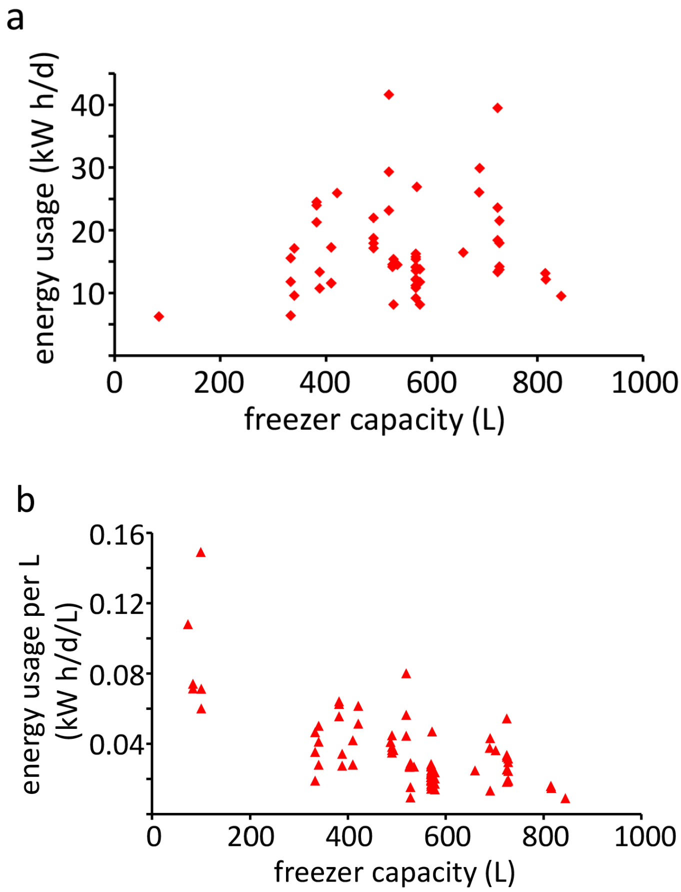

Figure 2 • Energy use of ULTFs in Biosciences as a function of ULTF capacity. (**a**) Usage of each ULTF: There is no significant correlation between usage and capacity ($p = 0.19$, two-sided t-test). (**b**) Usage per litre: There is a strong trend that larger freezers are more efficient per litre ($p < 0.001$, two-sided t-test).

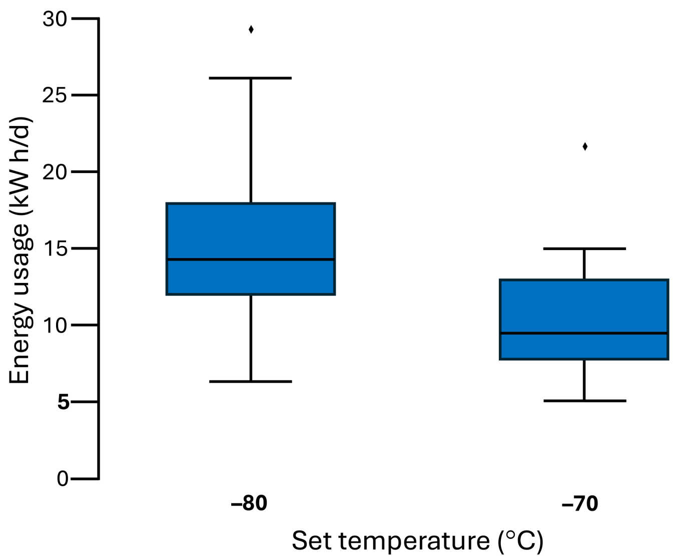

Figure 3 • Energy usage of all ULTFs in Biosciences at the start of the project by set temperature. The boxes show the first and third quartiles, with the horizontal lines showing the medians. Whiskers show the range, with outliers marked individually as rhomboids. A test for normality of the data suggested that the data were not normally distributed; therefore, the difference between energy usage at the two temperatures was analysed using the Mann–Whitney test, yielding a significant difference ($z = 2.51$, $n_1 = 17$, $n_2 = 51$, $p < 0.05$ two-tailed).

Table 1 • Percentage energy reduction on changing from −80 to −70 °C.

Change, %	Comment	Ref
35	Cross-sectional (median changes)	This work
29	PG&E, 71 freezers, cross-sectional	[16]
37	PG&E report, 7 freezers in controlled conditions	[16]
30	3724 labs, no detail available	[18]
28	NIH, 7 freezers	[13]
27	Uni Edinburgh, 3 freezers	[19]
24.9	Paired before/after, 38 freezers	This work
24.6	UCo Boulder, upright freezers	[14]
23	Thermofisher, 4 freezers	[20]
22	Uni Liverpool, 6 freezers	[21]
20–22	Uni Copenhagen, 4 freezers	[15]
20.5	UCa Riverside, 4 freezers	[22]
9–18	UCa Davis	[23]
12.4	UCo Boulder, chest freezers	[14]

The first two rows in **Table 1** are cross-sectional studies (a comparison of freezers at −80 °C and −70 °C at a single time point). The energy reductions for these studies both come at the upper end of the remaining intervention studies, suggesting that cross-sectional studies may not provide a realistic measure of the effect of changing freezer temperature. One can only speculate why this may be, but it is possible that labs using higher temperatures are already more conscious of sustainability issues and thus maintain their freezers in better condition.

The effect determined in this work (25%) was measured using many freezers in working laboratories (as compared, for example, to the PG&E study, which used carefully controlled conditions). Despite this, the effect is one of the larger ones observed, providing reassurance that significant energy savings can be achieved by increasing the working temperature, even in demanding work environments.

Research has been conducted on the impact of varying ULTF temperatures on sample quality [5]. Earlier freezers typically operated at −70 °C, but then manufacturing techniques improved, allowing ULTFs to run at −80 °C. The evidence suggests that there is very little difference in sample longevity when stored at −80 °C rather than −70 °C [11, 16, 17, 20, 24], and one paper even suggests that RNA stability is better at −70 °C than at −80 °C [25]. The only clear benefit of running at −80 °C is that if the freezer fails, there is more time to react before it warms up to a dangerous level. Several major institutions already adopt a policy of running ULTFs at −70 °C, as do some funding agencies (for example, the Wellcome Trust [5]).

Finally, we note that some manufacturers appeared to have more efficient ULTFs than others. Because ULTFs are typically purchased by the PI, there has been no oversight on which freezers are purchased. This suggests that a more centralised purchasing policy would bring significant benefits in terms of carbon footprint (as well as likely gain from stronger purchasing power).

3.3. Implementation of an action plan

As a result of these findings, the ULTF Group proposed a set of recommendations to the School:

- All ULTFs should be set to −70 °C.
- Set up a properly functioning set of backup freezers, with an identified person in charge.
- This person would also assist in de-icing and defrosting, labelling, and racking. The School should also implement regular cleaning of ULTF filters.
- Identify the least efficient ULTFs. Remove these and replace them with new ones on a rolling basis. A better-organised set of freezers will mean an overall reduction in the number of ULTFs, with more sharing of ULTF use.

- Purchase of new ULTFs should be organised centrally within the School. The main benefits are that we can buy more efficient ULTFs; we can use consistent racking configurations, so that exchange of racking will be simpler (for example, so that defrosting will not require removing all individual boxes from racks, simply moving an entire rack); and by buying "in bulk" we should be able to negotiate a better price. Where possible, we aim to move towards larger freezers with more shared use.

These proposals were presented to the School Executive Board for approval, which they received. The first four recommendations are not controversial, although they do require resourcing. However, the final recommendation represents a major shift from our normal policy, which is that each PI is responsible for selecting and ordering the equipment in their lab: this is the standard policy within UK universities. The proposal takes away control from the PI and gives it to the School. It therefore requires consultation, as discussed below. The recommendations were expected to result in a reduction in carbon footprint (and, consequently, a decrease in energy costs). However, they also require changes to working practices in labs. To facilitate this, the group talked to research groups using all means possible: at research cluster meetings; at School staff meetings; via a sustainability away day; on the School intranet site; and via emails. Of these, the face-to-face meetings at research clusters were the most effective as they involved more staff, and generated debate and engagement, with an overall very positive response. Members of the ULTF Group went to research cluster meetings, presented the results and recommendations, and engaged staff in the project. The research and consultation phase, overall, took about 12 months, and we believe that this extensive consultation was crucial to the project's overall success.

The simplest of these recommendations to implement was changing all ULTFs from −80 °C to −70 °C. Following considerable discussion, we agreed to implement this as an opt-out policy: all freezers were to be switched to −70 °C unless the responsible person objected. We announced the policy at a School meeting and sent out emails warning of the upcoming change, as well as attaching stickers to each freezer. In the end, we were pleasantly surprised that only one PI requested to retain the −80 °C temperature due to concerns over the reliability of the ULTF; and one freezer had to remain at −80 °C for regulatory reasons. We believe that the extensive consultation leading up to the development of this policy contributed to its ready adoption. We note, for example, that only half of the ULTFs at the University of Colorado Boulder have transitioned to −70 °C, despite the Green Labs initiative that began there in 2009 [24]; the implication is that leaving implementation to individual labs takes a very long time to produce change. The managerial decision to adopt an opt-out policy was critical to our success. The next simplest recommendation was to ensure that several backup freezers were kept empty and available. This was seen as essential in giving staff confidence in the new system. Information was signposted on the School's intranet.

Freezer temperatures were changed over in the summer of 2024. A comparison of energy usage before and after the changes shows a wide range in the reduction in energy usage (**Figure 4**), with a mean reduction of 4.0 kW h/d per freezer, or 153.7 kW h/d over the freezers for which a direct comparison could be made, representing a reduction in energy usage of 24.9%.

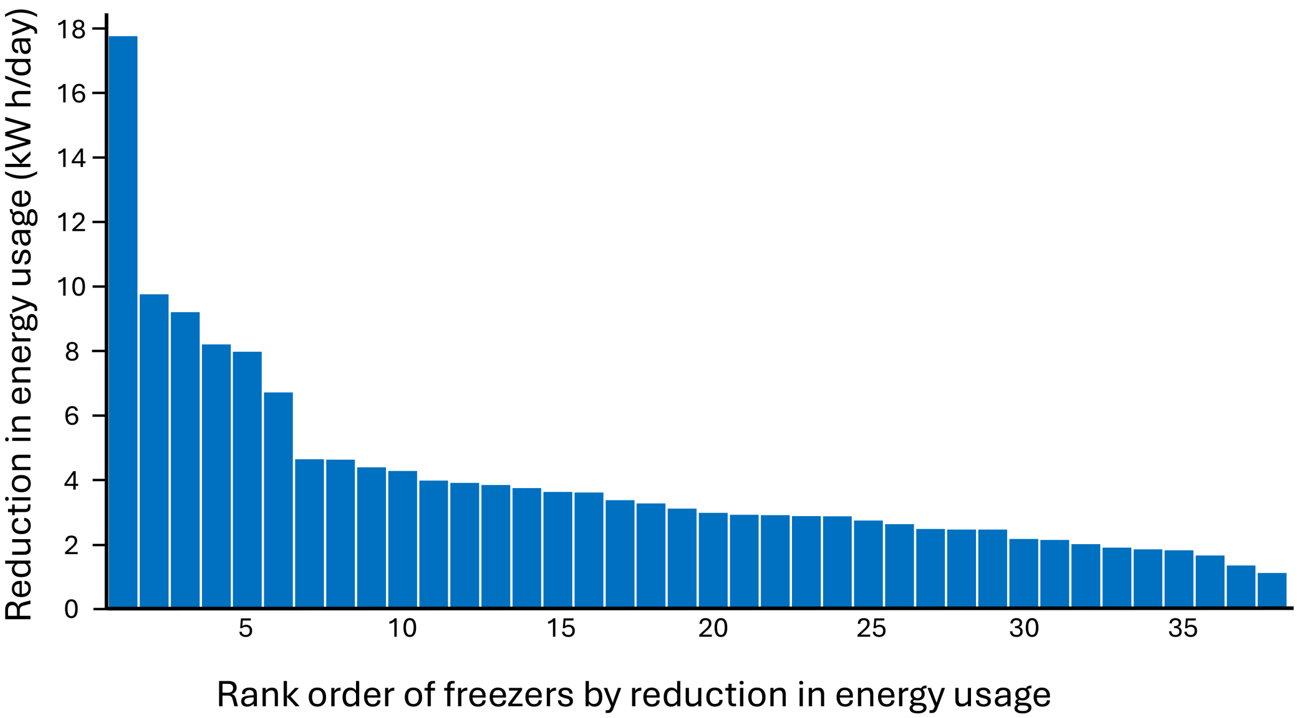

Figure 4 • Reduction in energy consumption as a direct consequence of changing the set temperature from −80 °C to −70 °C. The data are in rank order and include all freezers for which a direct comparison is available (i.e., the same freezer and monitor). The mean reduction in energy usage is (24.9 ± 10.2) %, with a big difference between different freezers. A paired t-test shows a very significant reduction ($p < 0.01$).

The other major change was the proposal to consolidate and replace the least efficient ULTFs. We initiated a pilot scheme with a group of eight PIs, whose lab spaces were clustered together and whose ULTFs were outdated and inefficient. All PIs readily agreed to participate, which was a pleasant surprise, particularly as the proposal involved a reduction in the number of ULTFs by one and an overall reduction in capacity of 17%. We engaged in a detailed tendering exercise, where ULTF sustainability and environmental impact were explicit criteria. In consequence, all new ULTFs were purchased from the same manufacturer (PHC) as part of a School-wide deal. Starting with six ULTFs within the group, we purchased four new ones and removed five old ones, leaving us with five freezers, one of which now serves as an archive. The archive freezer is opened less frequently and so is more efficient; it also gives us a second set of strains in a different location, and thus a major reduction in the risk of catastrophic loss of samples in case of failure, fire, or flood. The complete rehousing of samples acted as an incentive to throw away unwanted samples, resulting in a considerable saving in the number of samples retained. The overall effect was to reduce the total ULTF volume by 18%, with space set aside for new research groups (**Figure 5a**). The overall reduction in energy usage was 62% (**Figure 5b**). This also includes the saving by changing the temperatures from −80 °C to −70 °C, implying that the effect of consolidation into a smaller number of newer freezers alone was to reduce energy usage by about 49%.

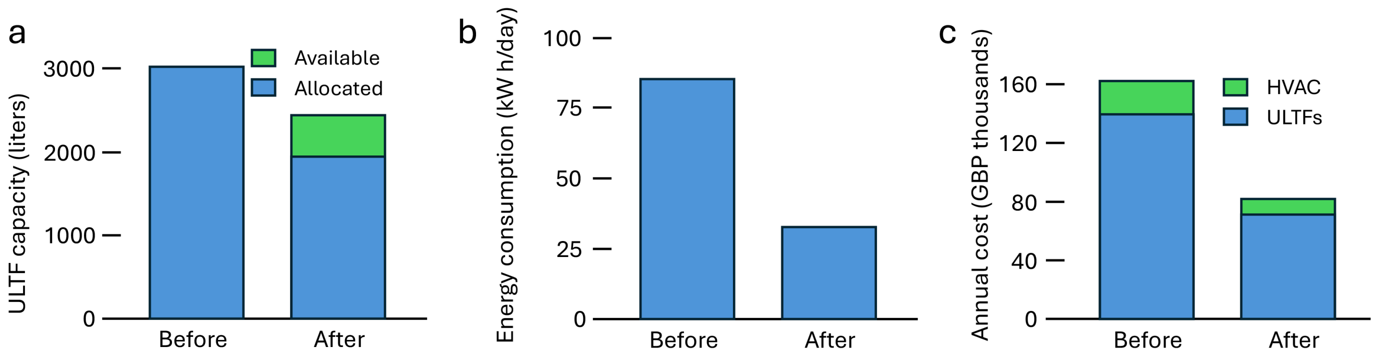

Figure 5 • (**a**) Freezer capacity and (**b**) energy consumption of ultra-low-temperature freezers used by the pilot group before and after replacement of freezers and change in temperature. (**c**) The estimated annual cost of ULTFs in the School once the programme was completed. There is a 5% error on the energy measurements, making the differences highly significant (unpaired *t*-test, $p < 0.01$). The expected costs are proportional to energy consumption and are therefore significantly reduced.

4. Discussion

Having demonstrated through this initial phase that the project is viable and relatively painless, we are now proceeding with replacing and consolidating the remaining ULTFs in the School, which we hope to complete within approximately 2 years. Overall, we expect to decommission about 30 further ULTFs and replace them with about 20 new ones. The expected saving is, conservatively, a 50% reduction in ULTF energy usage, based on the results from the pilot, and a corresponding reduction in energy costs (**Figure 5c**).

ULTFs generate heat, which must be removed, resulting in additional energy use, a carbon footprint, and financial costs. The efficiency of an air conditioning system is typically described by the EER (Energy Efficiency Ratio), which is around 12 for a good modern system. The overall effect of ULTF usage should therefore be increased by a factor of at least 1/12 (the 'at least' recognising that University buildings may not always have the most modern and effective air conditioning). The only studies cited here that considered the additional energy required for HVAC (heating, ventilation, and air conditioning) quoted figures of 33% [15] and 18.5% [16] for the additional energy required. We therefore use a reasonably conservative estimate of 15%. On this basis, we expect that the final effect of the ULTF project will be to reduce energy usage by at least 720 kW h/d (i.e., 50% of initial usage plus cooling requirements, namely 1440 kW h/d), which equates to saving 190 t/a CO_2 using the EPA calculator [26], or 82,000 GBP/a (110,000 USD/a). In our messaging to staff, this is often expressed in units of average household energy usage, meaning that we expect to save the energy equivalent of 97 average households. We note that the financial saving implies that we expect to recoup the capital costs of replacement freezers within 6 years (using current energy prices; if energy prices increase, the payback time will reduce).

The changes outlined here are expected to halve our energy consumption via ULTFs. This represents a reduction of 720 kW h/d, or approximately 3% of our total energy consumption in the School of Biosciences. We emphasise here that the changes represent a benefit for users, a reduction in risk to research continuity in the School, and a cost saving to the University, plus, of course, environmental benefits from the reduction in carbon footprint of approximately 190 t/a CO_2. There are no significant disadvantages: a change in research culture is required, which will become easier as more institutions make similar changes. If similar measures were adopted across the UK university sector, we estimate that this would reduce energy consumption by roughly 25 GW h/a, equivalent to 18 kt/a CO_2, or the equivalent of four wind farms.

Our experience so far is that roughly half of the space occupied in a typical ULTF is not needed. Many samples are unlabelled, or the labels are illegible; many are so old that they are not worth keeping. Many samples are stored in ULTFs when they could be stored equally well at −20 °C (plasmids, for example). It is therefore very possible that our eventual requirements will be less than currently projected.

As noted above, this project has required significant effort in monitoring, defrosting, de-icing, planning, and purchasing. We have written a Standard Operating Procedure (SOP) for defrosting (available as Supplementary materials) as well as a code of practice and guidance on storage and labelling, and provide a School support service. All these documents are readily available to PIs in the School via the School's intranet.

5. Conclusions

Overall, we expect that the measures described above will achieve a reduction in energy usage (and thus also in costs and carbon footprint) from our ULTFs of at least 50%. Significantly, this is a quantifiable change based on many freezers in a working laboratory environment and should therefore be applicable widely across the sector. A key element in the success of the plan has been attention to finance. ULTFs have typically been purchased by PIs from grant income as needed, which means that PIs naturally feel protective of the ULTFs in their care. However, the electricity bill and air conditioning costs are paid centrally by the University, and not by academic departments. Departments have generally kept clear of ULTF purchasing decisions. The data collected in this project have shown that the centralised purchase cost will be offset by cheaper running costs within less than 6 years on current energy prices. This was a sufficiently strong financial argument that the University were happy to pay for the ULTFs, particularly as the lower energy usage also helps them approach the University's net carbon zero target quicker. This naturally suits PIs, who can spend their grant money on something else. It is also a good outcome both for the central Facilities Management team and for management in the School of Biosciences.

We note that although freezer age is well correlated with energy usage, the increase is relatively small, especially when compared to the wide spread of energies seen (**Figure 1**). We therefore suggest that a blanket policy of replacing freezers beyond a certain age is not appropriate. We also note the very strong correlation between freezer capacity and energy usage per litre (**Figure 2b**), implying that larger freezers are much more efficient. This implies increased communal use of freezers and more centralised facilities, which are difficult to achieve and manage, but are by far the most efficient usage strategies.

A critical part of this project was the time allocated to consultation, both with PIs and with University management. Once PIs appreciated the rationale for changing practice, the implementation (for example, the opt-out policy for changing set temperatures) worked remarkably smoothly and resulted in an almost 100% adoption of new practices. Similarly, discussions with Facilities Management (who pay the cost of energy and have the responsibility for the move to zero carbon but have historically not been involved in freezer purchasing) convinced them that their paying for new freezers was economically sensible.

The changes are therefore positive for all parties. The new ULTFs represent a significant and sustained reduction in energy usage, in running costs, and in purchasing costs. The interchangeability of racking makes defrosting much simpler. New procedures should mean that emergencies are rarer and can be handled more effectively. One of the greatest risks in a University biology department is irretrievable loss of samples due to ULTF failure, flood, or fire. The new policy, particularly the more supported use of backup freezers, substantially reduces the risk. Due to improved labelling of ULTF contents, researchers now have a clearer understanding of what is in their ULTFs and where to locate the contents. This has numerous benefits, including reduced waste, enhanced sample security, and shorter door opening times. A better understanding of ULTF contents is also useful when engaging in discussions with insurance companies about insuring the contents of freezers. Similar changes are being planned for rollout across other parts of the University. We expect that similar changes can be implemented in other biological and medical research organisations, resulting in a significant and ongoing contribution to reducing energy consumption in labs. A new generation of more energy-efficient freezers is now available. They are more expensive to buy but have much improved efficiency [16]. It would be of interest to investigate whether there is a strong case for replacing current freezers with the new generation.

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Author contributions

Conceptualization, M.H.; formal analysis, M.P.W.; investigation, R.M.G., L.G., S.M. and J.-R.C.; data curation, R.M.G., L.G. and S.M.; writing—original draft preparation, M.P.W.; project administration, M.H. and L.G. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that they have no competing interests.

Data availability statement

The data supporting the findings of this publication can be made available upon request.

Supplementary materials

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Additional information

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