Everything You Wanted to Know about Running an Ultra Low Temperature (ULT) Freezer *Efficiently* but Were Afraid to Ask…

Updated: 3-8-2013

1 Introduction

Ultra-low temperature (ULT) freezers are typically designed to operate between -56°C and -86°C and they are usually operated at a set point of -70°C or -80°C (CBEA, 2012). When new, these freezers consume approximately 16 to 22 kilowatt hours (kWh) per day, which is about as much energy as an average family household. After years of service, many such freezers consume over 30 kWh per day, and typically at least 30% of the samples stored in them are out-of-date, unrecoverable, or otherwise not useful for research. ULT freezers may fill every nook in hallways and laboratories, making workspaces loud and hot, adding heat load to the building HVAC system. Optimizing cold storage is not a focus of most research departments and the numbers and types of them tend to grow organically without regard to space use or integration with the building HVAC systems. Proper freezer management is important to research institutions in minimizing operating costs, reducing freezer failure, and ensuring optimal freezer performance.

This guide describes procedures to operate ULT freezers efficiently and to improve sample access. It is based mainly on research and operational experience at the National Institutes of Health and University of California Davis, and it is designed for laboratory staff (lab managers, principal investigators (PIs), research staff, etc.), repair technicians, building operators, and procurement and property officers. It is meant to be valuable for a user of a single freezer, as well as site managers and policy makers. Typically, freezer management in the public sector has not been supported on a centralized basis, and this guide provides some opportunities for energy conservation and risk management.

To get you started at a campus level, first contact property custodians to obtain an inventory of the ULT freezers in operation. Information about the number, type, age, and location of ULT freezers can help you target and prioritize labs based on their energy savings potential. Then add about 10% to include freezers bought used or shipped in with recruited faculty. You may be surprised!

FOR ADMINISTRATORS TOO BUSY TO READ THIS WHOLE GUIDE

1. Create a Cold Storage Management committee with all your stakeholders.
2. Subsidize energy efficient freezers per cubic foot, and experiment with your own benchmark. See Appendix 1
3. Subsidize energy monitors for every ULT freezer. Beyond alarms, monitors may predict failure as well as preventative maintenance and save energy.
4. Subsidize a site license for an off-the-shelf sample database and incentivize or even *mandate* its use. It will improve sample access, data sharing, risk management and energy efficiency. Don't forget to mandate that expiration dates be included with every batch (renewable of course, but not perpetual).
5. Subsidize Room Temperature Sample Storage (Doyle 2011). It is still slow to be adopted, and once it takes off, it may save a lot of freezer foot print. Start with shipping—no dry ice!
6. For new buildings include process cooling with a chilled water loop and reliable backup power, then subsidize water-cooled ULT freezers.

The strategies here are complementary with the race to the first zero carbon laboratory on your campus (Watch, 2012).

2 ULT Freezer Purchase and Location

2.1 New Freezers

As a typical freezer user, you do not think much about total campus inventory - you just need another freezer. Before you bring an additional ULT freezer into your building, be sure to notify the building manager about the additional heat load you will introduce. Sometimes it makes sense to consolidate freezers together in one room; other times it is best to disperse them throughout a floor. Sometimes they may need to go into another building, or better yet, the old ones can be cleaned out so you do not have to buy another!

FREEZER FRIDAYS: CLEAR OUT INSTEAD OF BUYING NEW

Clear out freezers over a few weeks with the whole lab group. It's a tough job, and "Freezer Fridays" for a month can bring new order and better sample access, as well as increase freezer space by 30%. Sharing space with another lab group can resolve floor space issues as well. Several Centers for Disease Control (CDC) laboratories had great success using the Freezer Challenge contest to motivate laboratory managers for a freezer cleanout (Kuehl, 2013).

2.2 Freezer Replacement – Changing of the Guard

Technological improvements in cold storage have resulted in more energy efficient operation of ULT freezers. Advances in ULT freezer compressor design, insulation, and cabinet design have resulted in greater efficiencies to store samples. However, the efficiency of ULT freezers decreases over time, due to loosening seals, refrigerant loss, degraded lubricants, fatigue in mechanical systems, or poor maintenance. Each year of a ULT freezer's age translates in to approximately 3% increase in energy consumption, as indicated in Figure 1. Some ULT freezers age well; therefore, it is highly recommended to test every freezer to verify the need for replacement. While a compressor rebuild may cost \$3,000-\$4,000, many repairs are under \$400, or 5% of replacement cost. Many of these repairs are cheapest the sooner you attend to them.

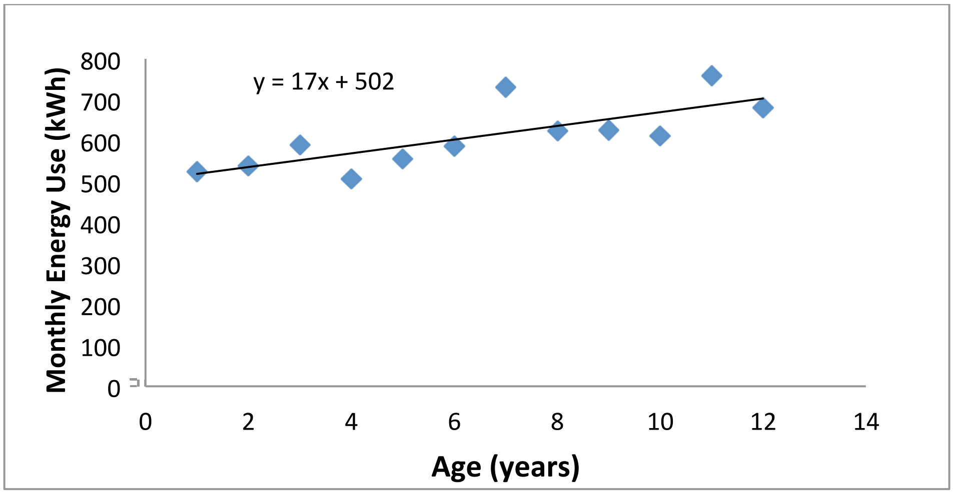


Figure 1 Energy consumption versus age for maintained 17.3 cubic foot (ft^3) ULT freezers at a set point of -80°C (Gumapas and Simons, 2013)

BE A ZOMBIE SLAYER

A zombie freezer may still run and appear "normal" like a living freezer, yet it may gorge itself with two to four times as much energy as its living peers or more, especially per cubic foot. It is often full of undead, perhaps forgotten, samples. A regular testing or metering program of freezers older than 10-15 years will reveal poor performers. Retiring or repairing the bottom quartile of inefficient freezers will protect precious samples and save a lot of energy.

True Story: Measurement of an under-counter ULT freezer (3.5 ft^3) discovered it was using more than a 22-ft^3 model. Its energy intensity was about 800% of other freezers. The irony was compounded with the laboratory's change in focus to DNA research, so a residential freezer replaced it for a 95% energy savings and under $400.

The most nimble testing could be with plug and play meters for 120 V or 208V. A 4-6 hour measurement will reveal zombies.

2.3 Capacity vs. Efficiency – Size Matters

Smaller ULT freezers have much higher energy consumption per cubic foot (intensity) than larger freezers; they have a larger surface-volume ratio and smaller compressor motors are less electrically efficient and smaller compressors are less mechanically efficient than larger ones. A 3-ft^3ULT freezer can be six times as *intense* as a 23-ft^3 freezer. Figures 2 and 3 show that even for freezers of the same size class, the worst performers are four times as *intense* as the best.

Based on the break point in energy intensity shown in Figure 2, purchase ULT freezers 20 ft^3 or larger. To maximize efficient use of large freezers, it is important for a university or research department to acknowledge and support sharing of resources; this can be encouraged through appropriate incentives at each site. Many research groups already share freezers, thus gaining floor space, and decreasing energy consumption. Some PI's are wary of sharing due to security or space hogging, and examples of successful sharing are important to highlight. Some faculty will share shelves with 3-5 other research groups, while others are very concerned for the security of their samples, and sprawl of guest storage.

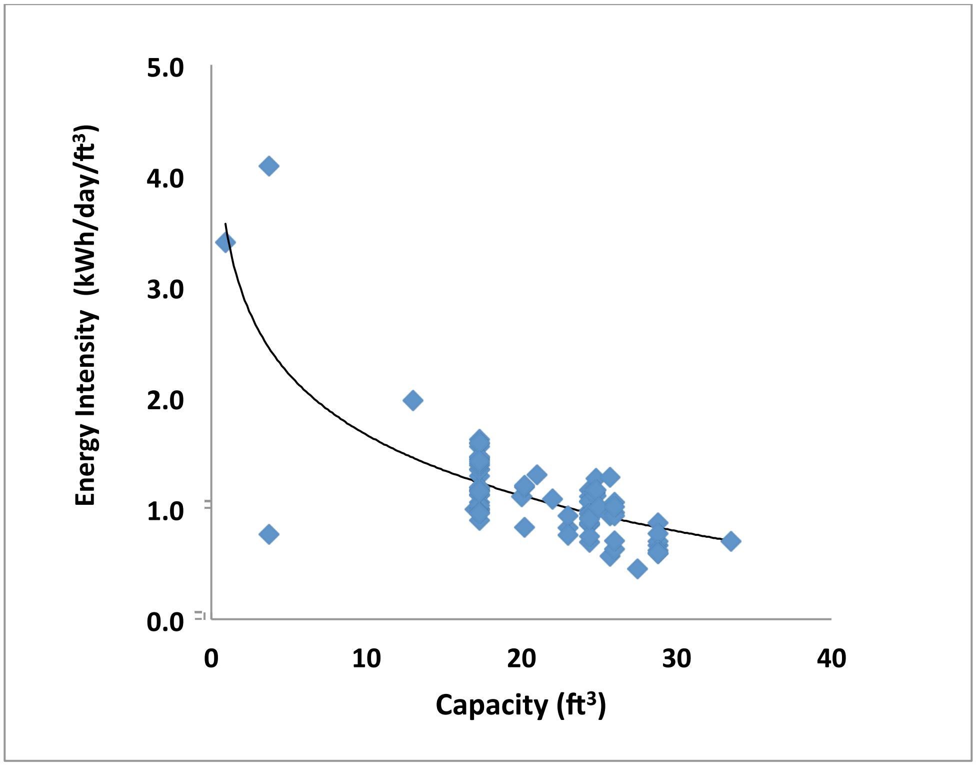


Figure 2 *Energy intensity of existing ULT freezers. Freezers smaller than 15 ft^3 use up to three times more energy per volume than 20-25 ft^3 ULT freezers. (Gumapas and Simons, 2013)*

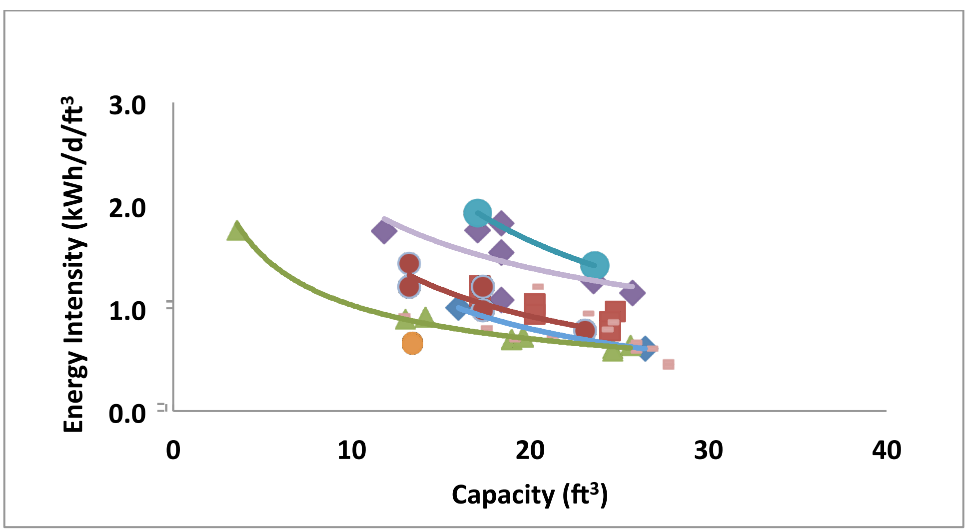


Figure 3 *Energy intensity of new ULT freezers from data supplied by manufacturers to the University of California. Each symbol represents a different manufacturer and they show greater disparity than volume relationships, although values have not been independently verified. Differences may result from efficiency or measurement methods.*

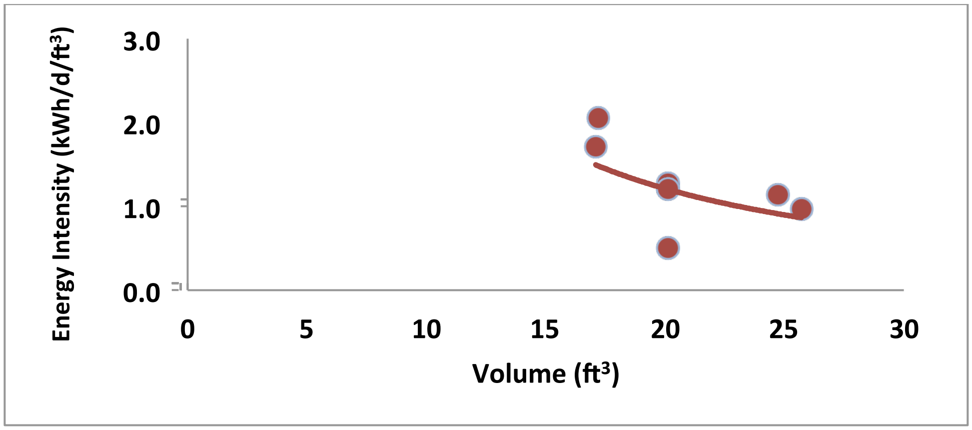


Figure 4. *ULT Freezer energy intensity versus volume at University of Manchester, United Kingdom (Nicholas, 2012). The lowest energy intensity freezer uses hydrocarbon refrigerants.*

3 ULT Freezer Operation and Maintenance

3.1 Freezer Maintenance and Efficiency – Take care of me and I'll take care of you

Regular maintenance improves the operation of ULT freezers by reducing its energy consumption and assisting the unit to achieve its set point temperature on a consistent basis. An unmaintained freezer can use 12% to 25% more energy than a maintained freezer and costs up to an additional $280 per year to operate. Comprehensive monitoring of complete freezer inventories has shown that one third to one half of freezers are wasting one third of their energy (Kriss, 2011), thus leading to at least 10-15% wasted energy (e.g. 0.33 x 0.33 = 0.11)

Figure 5 clearly depicts the importance of routine maintenance; it shows the amp draw over time for a significantly dusty ULT freezer (red) and a dust-free ULT freezer of the same model (blue). Both freezers have a set point of -80 °C and operate in ambient temperatures from 23°C to 25°C. The dusty freezer amperage cycles between 7.5 amps to 17.0 amps and has a duty cycle of 99%. The dust-free freezer amperage cycles between 0.1 amps to 13 amps and has a duty cycle of 70%.

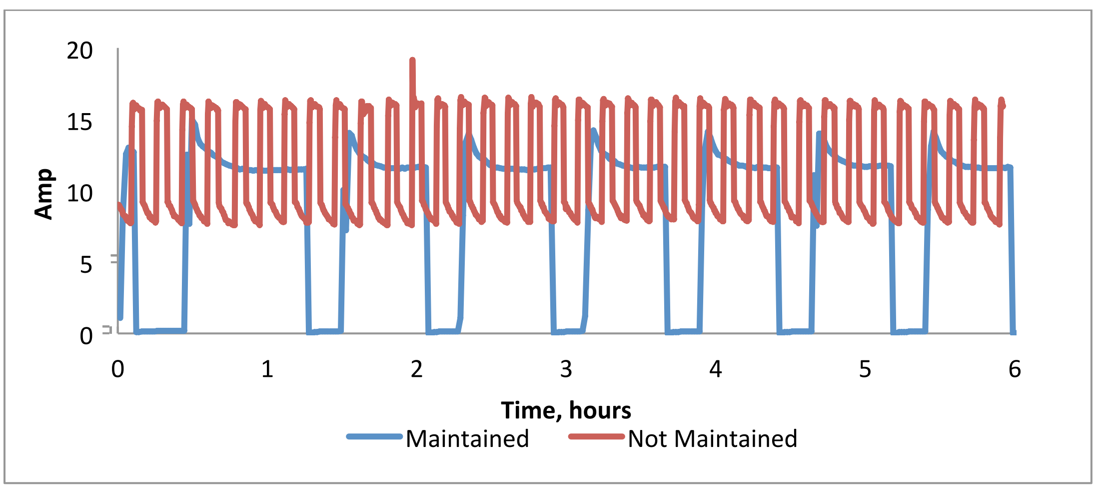


Figure 5 *The influence of dust accumulation on ULT freezer filters and condenser fins on amperage for ULT freezers at a set point of -80°C operating in ambient temperatures from 23°C to 25°C (Gumapas and Simons, 2013)*

Dust Buildup

Dust or grime buildup on the filter (Figure 6) blocks the normal air flow through the condenser, which reduces the ability of the ULT freezer to effectively dissipate heat. Any air flow that bypasses the clogged filter will result in air carrying dirt to deposit on the condenser. Dirt on the condenser increases energy used in the compressor to transfer heat to the ambient environment.

Figure 6. Dust build up on filter

Check on filters on a monthly basis, cleaning or replacing filters as needed. Clean freezers located in high traffic areas such as hallways more frequently than ULT freezers located in labs or repositories. Clogged filters make it more difficult for air flow to cool the freezer coils. To clean a filter, remove and rinse it with water (choosing the direction carefully so lint is pushed off filter). It is okay to place a wet filter back on the freezer. To clean coils, gently vacuum or brush in the direction of the lines on the coil, or take a wet paper towel and gently move the towel in the direction of the lines. Be careful not to bend metal lines.

DESIGN SUGGESTION

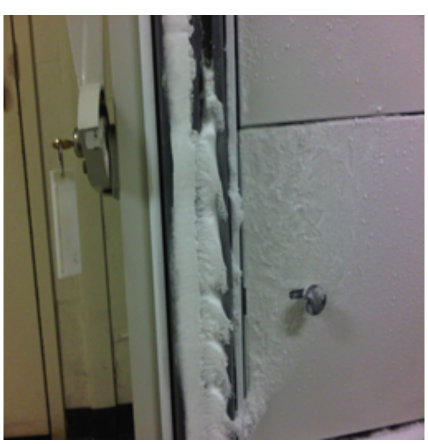
Air flow, on purpose: What good is a clean filter if a new one cuts down 80% of air flow?

While it is important to keep condenser coils clean, the intended air flow through the mechanical space under a ULT freezer appears, well, unintentional. Closing the door with a brand new filter can block 80% of air flow. While 300 ft^3 per minute may be flowing across the condenser and then the hot compressor, intake airflow may be10% or less of this value and the mechanical space can be 10-15°F hotter than room temperature. As reported by Cavallaro and Bullard (1994) about kitchen refrigerators, circulation is compromised with unintended gradients, escape, and recirculation. Cooling fans are often not engineered, there are no cowls or air blocking panels, and lots of hot back flow goes across the condenser coils. While fast circulation of room air through intake would maximize condenser cooling, a room full of 300 ft^3 per minute freezers could overwhelm the room exhaust, leading to a hot room. Specific airflow for the "sweet spot" of direct cool air across the coils versus overwhelming HVAC returns air needs to complement room cooling and air flow. Cooling fans need to have cowling and blocking panels to avoid backflow.

Some manufacturers use a plastic wire grid to electrostatically attract lint and dust, but their loading effectiveness has not been widely published. If good at dust collection, then this grid has minimal air flow resistance.

See Appendix B, Hot Aisle Compatibility Scorecard.

Frost Accumulation



Frosting occurs on any surface with a temperature that is below the dew point of freezing air and below the freezing point of water. Frosting is generally observed on the evaporator coils and the outer gasket seals of the ULT freezer (Figure 7). Frost accumulation inside the freezer or around the freezer door creates gaps in seals, which allow cold air to leak out and warm air to enter the freezer. Frost can also damage the seals on the freezer.

Figure 7. Frosting on ULT freezer door. This may start from a leaky gasket or inadequate cleaning of frost from seals, or one time leaving the door ajar. Gasket tubes may fill with ice, so be sure they are pliable. Defrost if solid.

When defrosting a ULT freezer, place absorbent materials (pads, paper towels, etc.) around the unit and monitor periodically to prevent water from collecting on the floor, thus preventing slips and falls. Also consider having a pan near the freezer to collect water.

Do not use sharp equipment to remove ice/frost buildup in the freezer, as this can permanently damage the freezer, rendering it unusable. Use appropriate tools (Figures 8 and 9) to:

- Minimize the risk of personal injury
- Prevent damage to the gaskets and seals
- Minimize the risk of releasing refrigerant chemicals

If seals collect a lot of frost frequently, have a ULT freezer technician look at the freezer to see if a door adjustment can help with a better seal or if the seal needs to be replaced.

DEPARTMENT OF FROST PROTECTION

Frosty Friends: The campus or institution can promote good frost hygiene by distributing frost brushes or soft cloth wipes branded with their conservation program. A short handled bucket brush has lots of bristles, while a long handled auto windshield brush reaches into the back of ULT freezers and has a scraper built into it. Both can be obtained for $3-$5 when purchased in bulk. Rubberized gloves can make this frosty chore easier.

Figure 8 (left). Simple tools for frost build-up prevention.
Figure 9 (right). Blunt defrosting tools are very important, and can be made from soft Polyvinyl Chloride (PVC) or Polypropylene (PP) plastic and used with gentle hammering if needed.

3.2 Proper Spacing – I Can't Breathe Without You

Proper cooling of an ULT freezer allows the condenser fins to effectively dissipate heat, but what is "proper cooling", and where should the heat go?

Vendor "Advice": In order to provide "proper" ventilation around the ULT freezer, manufacturers recommend keeping at least 8" of clear space on the top, and a minimum of 5" of clear space in the rear and on both sides.

Figure 10. Some Vendors show freezers in tight packed arrangement, and they include hinges that allow this.

What You Should Not Do: Having air swirl around a ULT freezer is not managing the reject heat, and is sloppy thinking. Some recent vendor catalogs are showing freezers close side-by-side spacing, and with door hinges that allow flush opening. However, most freezer hinges are not like this.

An important principle is to take the cooling where it is needed and remove the heat. Data center operators began designing server racks into solid walls with cold aisles in front where people walk, and hot aisles behind where the reject heat can either be pulled away by return ducts or cooled in place with water cooling, for example.

To the relief of scientists who have stuffed as many ULT freezers as they could in a room, there needs to be no space <u>between</u> freezers (figure 10). In fact, a good freezer farm would have panels between freezers to prevent the warm air coming forward and getting re-entrained in the intakes. There does need to be space <u>behind</u> the freezers and on top to let warm air reach return registers. If a room still gets hot, the ventilation capacity of the air flow and air handling unit may have been exceeded.

DESIGN SUGGESTION

These wheels were made for walking: Because ULT freezers "walk" with repeated opening the doors, it would be helpful for hot aisle design if freezers could be locked to the floor, to their neighbors, or had standard spacers of about 10-15 cm.

EZ Stores It—*NOT*

Boxes stored on the top of a ULT freezer (figure 11) pose a safety hazard according to National Fire Protection Association (NFPA) 1:10.20.2. The standard states at least 18" of clearance is required below sprinkler head deflectors to ensure adequate water distribution from the sprinkler in the event of a fire.

Boxes also choke off rising heat and force it back into aisles and ULT freezer intakes. Remove items that have fallen behind or are pushed up against your unit blocking airflow underneath or above your unit. Be especially careful not to block air intake or exhaust grills.

Figure 11. Boxes stored on top of a ULT freezer pose a safety hazard

3.3 Ambient temperature – Is cool better?

Many operating manuals say the ambient temperature range is about 15-30 °C, so why should operators worry about room temperature? Does savings in room cooling outweigh higher plug load? For one, failures start to go up as room temperature goes up, so there is likely some mechanical strain on the cascade compressors.

According to Figures 12 and 13, we can see that plug load for ULT freezers increases slightly with room temperature, about 2% per °C.

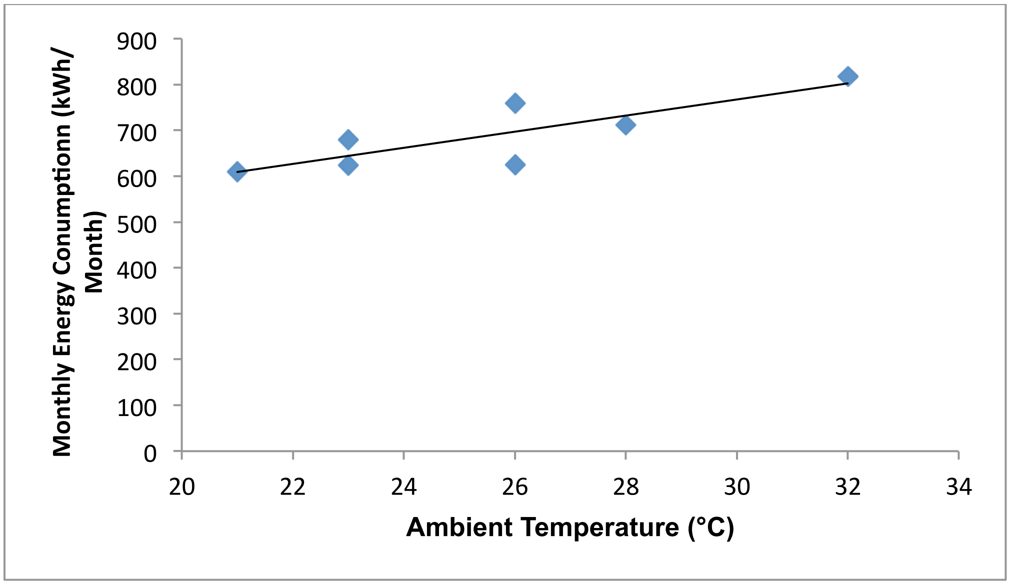


Figure 12 *Energy Consumption versus Ambient Temperature for 17.3 ft^3 at set point -80°C for maintained ULT freezers (Gumapas and Simons, 2013)*

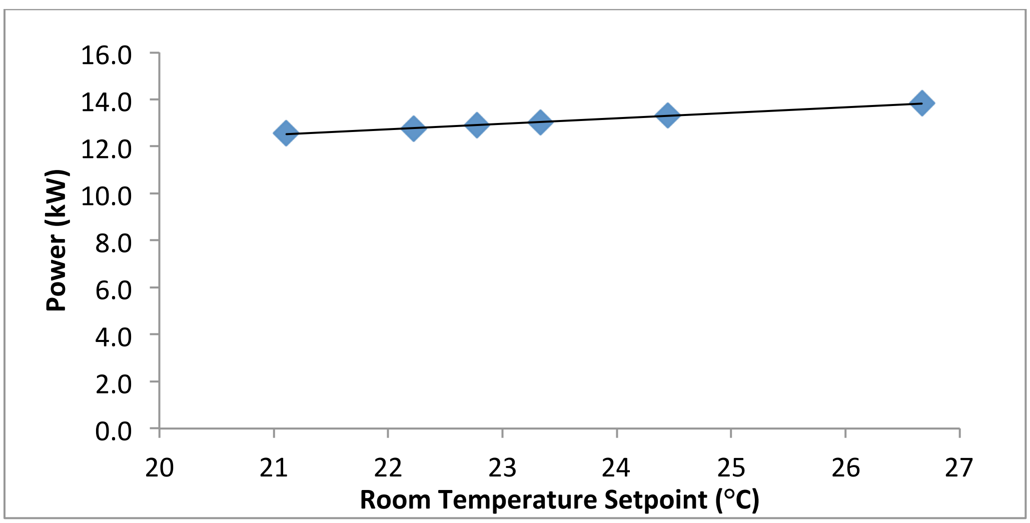


Figure 13 *Energy Consumption measured at the electrical panel versus Ambient Temperature for ten ULT freezers (University of California, Davis).*

DON'T COP OUT: ROOM COOLING VS FREEZER REJECT HEAT

Q: Is it worth it to cool the room versus the extra strain on the HVAC system? Many ULT freezers are rated to perform up to 30 °C.

A: Maybe yes, maybe no. More analysis needed

Building and District Cooling Efficiency vs. Appliance scale compressors.
Large Heating Ventilation and Air Conditioning (HVAC) systems, especially campus scale central plants, are generally much better at cooling than small compressors. A small compressor is generally less efficient at removing heat than a chilled water loop served by a central plant. Definitive studies on this energy trade off still need to be documented.

Freezer Consolidation – Get Freezers Out of Hallways

Each ULT freezer occupies 20-30 ft^2 of valuable space. Due to space constraints in labs, numerous ULT freezers are stored in hallways (figure 14). Most hallways are not designed not effectively remove heat generated from ULT freezers; therefore, ambient temperatures can be as high as 90°F (32°C). Operating ULT freezers at these ambient temperatures increases energy consumption by as much as 24% and increases the risk for a ULT freezer to fail, which puts samples at risk.

Figure 14. Hallways are not effective locations for freezers. What else is wrong with this picture?

3.4 Air Management

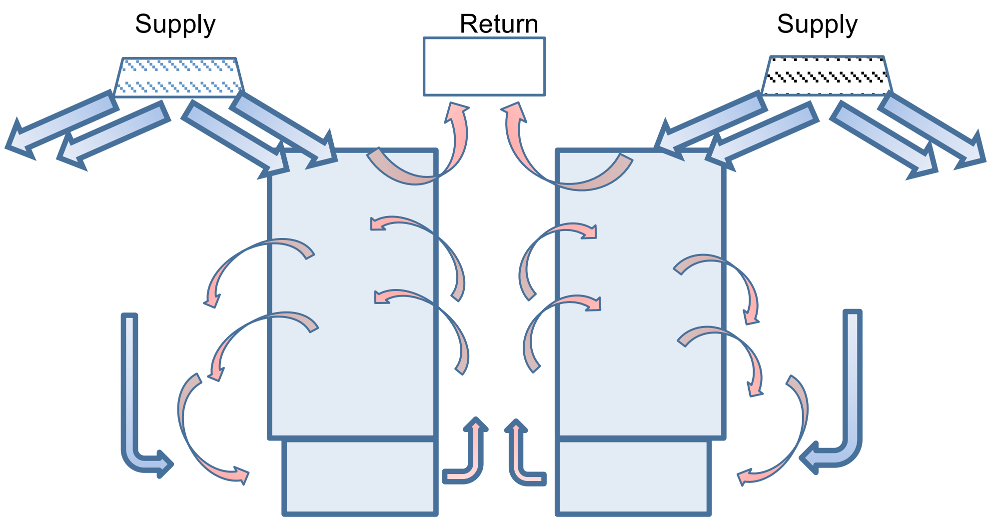


Figure 15 Reject heat dissipation and removal through swirling air. Note that warm air can be entrained into freezer intakes.

The alternative to the standard practice of swirling air (figure 15) is to induce stratification and directed convection (figure 16). By closing off the back of freezers to create plenums or chimneys, the hot air will rise to the ceiling. Rather than have diffusers on supply registers, they should be removed or directed straight down in front of freezer in the cold aisle, thus bringing coldest air to the freezer intakes. With relatively little retrofit effort, freezer plug load and HVAC cooling can be reduced.

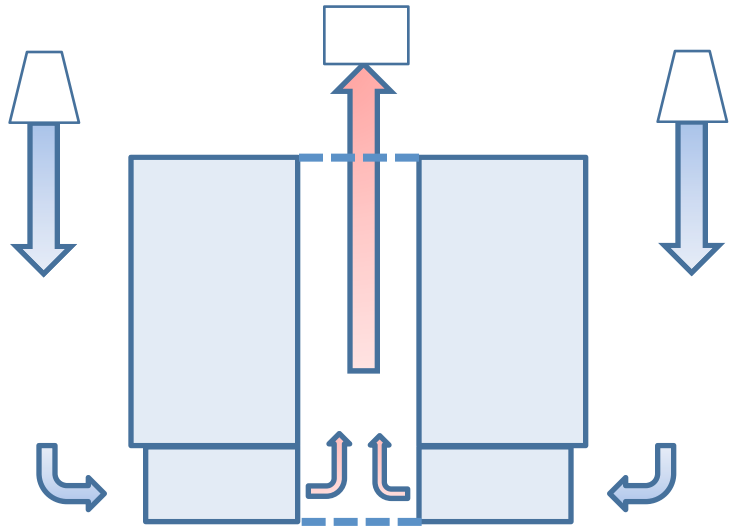


Figure 16 Reject heat management with panels and stratification.

Think "Stratification". Removal or downward directing of supply diffusers will drop cold air to freezer intakes and improve freezer and HVAC efficiency, much like a well-designed data center. The space behind freezers can be paneled off to create a chimney, plenum, or hot aisle, thus sending reject heat directly to the returns. The gaps between freezers need to be blocked as well, while allowing easy access for maintenance. If the sum of freezer through-put air flow does not exceed the return air flow, the room should not over heat. This stratification strategy can be used for freezers against a wall in a hallway if necessary and pull away reject heat.

Freezers and "Reject Heat"— Integrating your appliance with building cooling
Freezer farms and equipment rooms can be the "tail-waggers" that drive the supply air temperature (SAT) for a zone, and thus requiring a lot of reheat for the rest of the zone. The impact will vary depending on the location of the freezer relative to exhaust grilles and other thermal loads in the space. Don't forget you may be better off dispersing freezers instead of consolidating them, or moving them nearer to an AHU instead of at the end of a duct run where air supply is weakest, especially in older constant air volume systems. Freezer vendors give very limited advice on integrating their equipment into your building.

While excess reheat should be avoided, there are some cases where it could be used and ULT freezers can be integrated into airflow and conditioning. Equipment rooms can be hot, while adjacent laboratories or hallways may be cold. Here's how you might tune your supply and exhaust dampers to push some reheat into those rooms. Table 1 shows how air delivery can be adjusted to push warmed air into adjacent spaces if needed.

Table 1. Air flow adjustment to push warmed equipment room air into adjacent rooms. In the easiest case the rooms would already have an open doorway between them. Removing doors is not acceptable for fire code or air balance considerations.

Room Type	Air Delivery	Before ft^3/min	After ft^3/min
Equipment Room (200 ft^2	Supply	200	200
	Exhaust	210	50
Adjacent Lab 2000 ft^2	Supply	2000	2000
	Exhaust	2100	2260

3.5 Maintain Sample Inventory – Sample, Sample, Where Art thou Sample?

Every minute an upright ULT freezer door is open, it takes approximately 10 minutes for it to recover its temperature back to set point. Keeping a well-organized inventory reduces the time needed to search for an item, and it will decrease the risk of compromising the sample integrity by exposing it to high temperature.

Inventory Tips:

- Keep all samples labeled and spot check inventories on a regular basis
- Utilize a barcode system
- Radio frequency identification (RFID) is another useful option, though more expensive than bar codes
- Secondary containment (i.e., plastic storage box) provides sample security and an extra layer for lab safety
- Properly dispose of samples that are not labeled, unknown, or no longer in use
- Work with Environmental, Health, and Safety personnel on questions on the proper disposal of unwanted samples.

Disposing unused samples frees up valuable space in ULT freezers, which reduces the need to operate additional ULT freezers. In the private sector, some companies mandate logging of all samples before placement in ULT freezers. While there is some start-up time investment, the time savings down the road and under pressure are worth the effort.

Filling a Freezer—when the cupboard is bare
For a brief period, your ULT freezer may have some empty space in it, and little thermal mass or baffles to hold in cold air when the door is open. Two remedies can help: 1) Put in plastic bottles full of ice to hold thermal mass 2) place spare foam coolers behind the doors on partially full shelves. This will block some of the cold air "falling out" when the doors are opened, and this will maintain cabinet temperature.

URBAN LEGEND?

A full freezer takes less energy to operate: An ostensible reason for this idea is that the thermal mass takes longer to warm up, so the compressor doesn't have to work as hard.

Think about it: while the contents take longer to warm up, it also takes longer to cool down so the compressor works just as long every day. The fundamental insulating factors of wall thickness and gasket integrity do not change with a full or empty freezer, so why should it make a difference to heat transfer? While cycle frequency will go down, cycle duration will go up. The heat entering the cabinet will not change. There is a nominal power spike at the beginning of each compressor cycle, so more cycles could plausibly increase energy use a little bit. Data has not been widely shared, so it remains in urban legend status for now.

Over-Filling a Freezer—when every corner is filled
A "properly" filled freezer may lead to wide temperature variations. Because ULT freezers have no circulation fans, overfilling a ULT freezer can lead to very wide temperature variations in some freezers by passive natural convection. One study found 40-50°C span inside one cabinet, and the evidence they provide indicates cabinet uniformity would be served by leaving one rack out of each shelf. (Moore et al., 2004)

DESIGN SUGGESTION

I can't believe I filled the WHOLE thing: freezer testing for uniformity is done on empty freezers, while the normal status is full, and that is the most vulnerable scenario for wide temperature heterogeneity. ULT freezers design needs to insure uniformity when full with OEM racks and owner-supplied containers.

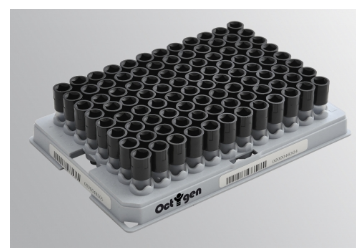
3.6 Sample Management: Maximize container efficiency

Keeping large volumes of samples for a long time is very expensive. What's large?
If your sample protocol involves collecting many samples and then subsampling, then set up collection protocol to immediately fill the smallest vial possible and then place it in an ULT freezer. If it involves extracting large volumes, then do your best to make sure you have the equipment and staff to meet your sample flow. Even 15 mL tubes in foam trays take up a lot of room. Fifty milliliter (mL) or larger should be kept in ULT freezers only for brief periods of time. Minimize sample volume as soon as possible.

REVERSING HVAC CREEP: TRADE A FREEZE DRYER FOR A FREEZER

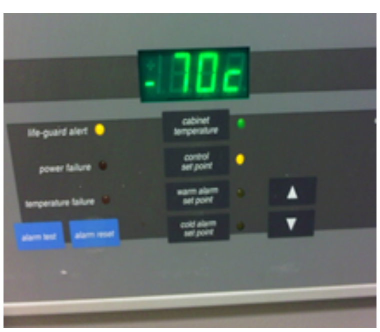
Meeting sample flow: a milk biochemistry laboratory at the University of California, Davis bought another ULT freezer when a new project promised more samples. When their equipment room overheated, energy managers increased cooling airflow by 500 ft^3 per minute and "solved" the problem. The next step was a ventilation estimator to install more ducting. Green laboratory liaisons were alerted and a few questions revealed that the samples needed freeze drying, but the department freeze dryer was often in use. With a few emails, the liaison found a surplus freeze dryer in the Chemistry Department, and the owner loaned it out. The milk researchers were able to return the freezer for a complete refund, and laboratory airflow was returned to its original value.

Sample Vials: Size matters and Tiny Wins.
Is a 2" box space-efficient? For samples under 0.5 mL, a cardboard box 2" tall full of 2 ml screw cap vials may be enormously wasteful. Consider this arithmetic: A standard 2" (5 cm) box has this total volume: 5 x 13.25 x 13.25 cm = 860 mL. With 100 cells per box, each cell has a volume of 8.6 mL, therefore a 1 mL sample is only 12% space efficient, and a 0.2 mL sample is only 3% space efficient.



Lab or facility managers may encourage or subsidize micro-vials and 96-well plates that can increase the number of samples by 60%. They have a capacity of 0.5 mL and are available from standard distributors.

3.7 Increase ULT Freezer Set Point – Temperature Tuning & Back to the Seventies



A proven and instant way to save energy and money (~$100/y) is to "Chill Up", or increase the set point 10 °C. This lowers the energy consumption of ULT freezer by 2 to 4 kWh per day (Gumapas and Simons, 2013, I^{2}SL Wiki). Lowering the duty cycle also gives your ULT freezer new life by decreasing how often the compressor cycles on and off. While sample stability is not broadly documented, ULT freezers used to be called "minus seventies"; that was the default temperature for decades. Some studies have shown that DNA, RNA, antigens and viruses are stable at -70°C (Miller, et. al. 2008). In general, DNA extracts may be kept at 4°C to -20 °C (Wu, et. al., 2011) for an 80% energy savings.

3.8 Meltdowns: Preparation and During the Catastrophe

Backup freezers are essential, and can be run at -40 to -60 °C at considerable energy savings and then turned down when needed. That will also discourage squatters from moving in when they find available storage space, which has been known to happen in research environments!

> **DESIGN IDEA: UNIFORM RACK SIZE??**
> **When samples need to be transferred in a hurry, having different rack sizes adds to the chaos.** Having to scramble for different racks as well as available freezer space can obliterate a sample inventory system as well. It would be fantastic if manufacturers made racks the same size. Meanwhile, have your back-up plan in order. Wouldn't bar coding on every box be wonderful about now?

3.9 On-Site Operation Incentives and Continuous Improvement

Consider developing a rebate program for freezer replacement (See appendix A for more information on how to calculate rebates). Consider participating in the freezer challenge, which is an effective way to engage all the key stakeholders – lab users, managers, facilities personnel and energy managers - in a collaborative effort to reduce energy use. See (Store Smart 2012) for more information. Two prizes in Freezer Challenge are motivational: the Frostiest Photo and Rip Van Winkle Awards for the most ice-impacted freezer picture, and the oldest discarded sample, respectively. Both of these campus awards can be fun ways to engage users.

4 References

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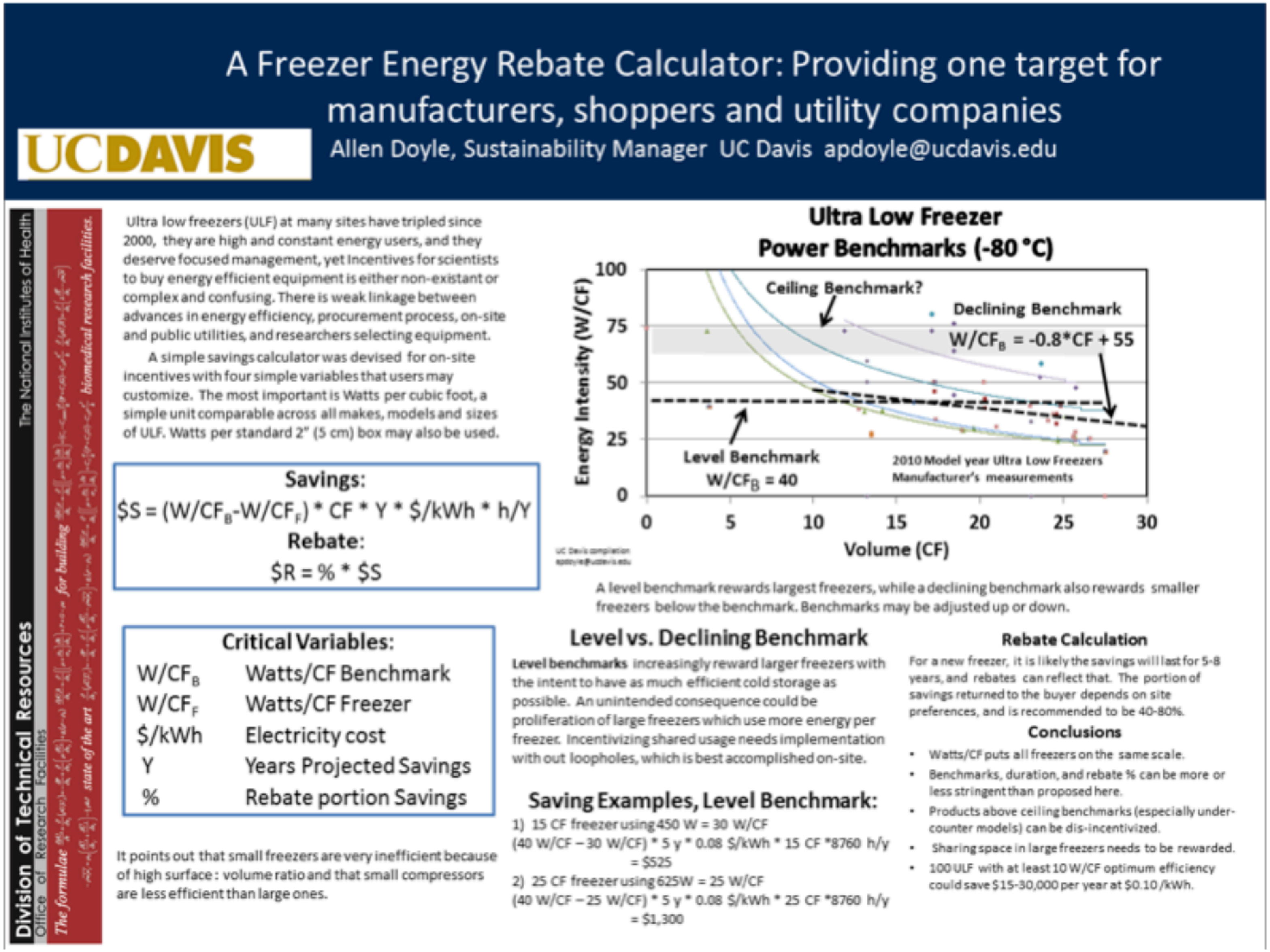
Appendix A Benchmark incentives at your site. Poster given at NIH conference, December 2012.



Appendix B. Proposed Scorecard: Hot Aisle Design Compatibility.
For manufacturers, building designers and operators.

Intent: make ULT design compatible with Hot/Cold Aisle air management or in situ cooling similar to data centers

Not all specifications may be valid or the right magnitude, as this scoring system needs to be optimized.

Contact the authors for input as these parameters are still in draft form.

Points	Description	Method
2	Front-Back Circulation	Airflow from front to back.
1	Fan shroud	This controls air from front to back and reduced side spillage and short cycling.
1	>100 CFM intake	Brings adequate room air to cool condenser. (Estimate ONLY of sweet spot.)
1	< 150 CFM intake.	Too high overwhelms HVAC. (Estimate ONLY of sweet spot.)
1	Engineered Blades	vs pressed sheet metal with unknown air flow.
1	Low resistance air filter	Such as electrostatic grid, if adequate dust loading.
2	Ease of filter cleaning	Promotes user PM
1	Exhaust delta T <10° (sweet spot?)	IR therm. front and rear grates
1	Airflow ratio w & w/o grate	Without front panel or filter, 1:1 ?
1	No Side Vents	Prevents uncontrolled circulation
1	Side and Bottom Blocking	Prevents air flow underneath and around sides
2	Duct Mounting Fittings	Mounted ducts would allow direct heat removal, and bolt holes or brackets would make this easy
1	Intake & Exhaust Temp Sensors	Sensors allow comparison of intake and exhaust
1	I/E sensor direct output in mV	Allows user monitoring using third party devices.
2	Cabinet temp sensor output (mV)	Allows user monitoring using third party devices.
1	Waste Heat Harvesting	Is there provision to direct reject heat into HVAC as reheat or other useful heat.
	Bonus Points; Your ideas here	
20	**Total Possible Points**	