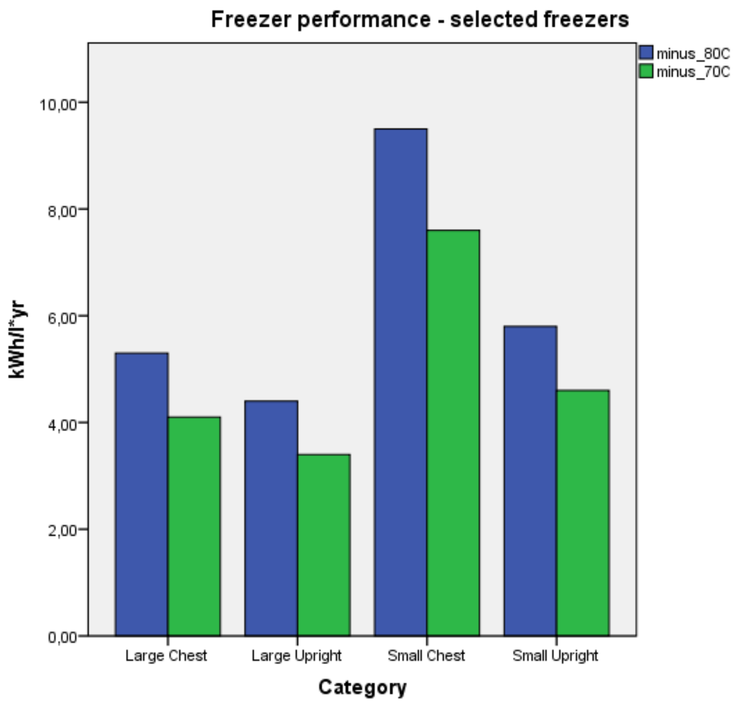
Plug load test for ULT Freezers: 20-22% lower energy consumption at -70 ºC compared to -80 ºC

Highlights:

- New ULT (Ultra-Low Temperature) freezers tested in the fall of 2017 consume between 4.4 and 11.9 kWh per liter of inner volume.
- One new large upright ULT freezer consumes between 3,500 and 8,000 kWh per year. This corresponds to a yearly expense approx. 800 – 1,750 EUR in Denmark.
- Upright ULT freezers are in average 22% more energy-efficient per liter of inner volume than chest freezers.
- Large freezers are in average 13% more energy efficient per liter of inner volume than small freezers.
- The total plug load of a ULT freezer is 20 – 22% lower at -70 ºC compared to -80 ºC.
- The temperature inside a ULT freezer is more stable at -70 ºC than at -80 ºC.
- No scientific documentation was found indicating that sample storage at -80 ºC is safer than -70 ºC.
- Labs in a number of American universities successfully store samples at -70 ºC.

Green Campus, together with the procurement department at the University of Copenhagen tested the plug load of four new ULT freezers at both -80 and -70 ºC. The results show that the total energy consumption of a ULT freezer is 20 to 22% lower, i.e. its energy efficiency per unit of inner volume is 20 to 22 % higher, at -70 ºC than at -80 ºC. This difference has a great impact in the case of heavy power consumers such as ULT-freezers. Even brand-new eco-friendly ULT freezers consume between half and one-and-a-half times as much power as 4-people home in Denmark[1].



Furthermore, the test results show that temperature inside the freezer is more reliable when the freezer is run a little warmer: the average daily temperature inside all freezers deviated less than one degree Celsius from the -70 ºC mark (which is less than the margin of error of the measurement) but as much as 4.5 ºC when set to -80 ºC.

For the four freezers that were tested, the savings in running at -70 ºC instead of -80 ºC fall between 650 and 800 kWh per year, which translates into more than 130 EUR and up to 200 kg of CO2-e per year per freezer[2]. These savings are likely to be greater in older, less efficient units.

Potential for UCPH as a whole

A mapping of laboratory appliances in 2013 counted over 500 ULT freezers in total at UCPH. It is expected that since then the number of freezers has increased to around 600 units in 2017. It is estimated by the procurement department at UCPH that the university purchases 50 new ULT-freezers every year[3], the majority of these replacing older units.

A conservative estimate of a complete change to sample storage at -70 ºC at UCPH shows, based on our test results, yearly energy savings of 400 to 480 MWh. These savings, approx. 0.6% of the university's energy budget in 2017, correspond to 85,000 – 105.000 EUR given current electricity prices in Denmark. This would mean as well a reduction in the university's total GHG emissions of 80 to 100 tons CO2-e just from the reduced electricity consumption.

With a service lifetime of 15 years, the TCO (Total Cost of Ownership) of an ULT freezer set to -70 ºC would be over 2,000 EUR lower due to smaller electricity bills alone. To this must be added that when set to -70 ºC the unit's compressor works less often (most freezers control temperature by changing how often or how long they run instead of varying their power output)[4,6], which results in less wear and thus potentially lower maintenance costs.

Furthermore, ULT freezers shed a large amount of waste heat to their surroundings, which often makes it necessary to acclimatize freezer rooms. Reduced freezer energy consumption means also less waste heat, which in turn means a reduced load on the room/building's cooling system. One of the newer ULT freezers in the market produces, according to the manufacturer, 0.9 kWh/day less waste heat when set to -70 ºC compared to -80 ºC[10]. This difference translates into approx. 300 kWh/year less waste heat per freezer. Even with district cooling[a], this means a reduction of 100 kWh/year in the power consumption of the cooling system itself for every freezer of this kind that makes the change to -70 ºC.

Many American universities run their freezers at -70 degrees

At a number of universities, especially in the U.S., laboratories have been working to make the change to -70 ºC. Among these are Stanford University, University of San Francisco and Harvard. At Colorado University Boulder, as much as half of all the ULT freezers in campus already run at -70 ºC[4].

CU Boulder, together with University of California Riverside, San Diego and Davis, and University of Alabama Birmingham, maintain a database of all the samples –from entire animals to peptides, DNA and RNA- that their laboratories store at higher temperatures[5]. This database is free to access, and contains data on how long any particular group has kept their samples at a particular temperature, as well as contact information for the people involved.

No documentation that -80 ºC is necessary

A couple decades ago the standard for low-temperature sample storage was -60 ºC. The gradual decrease to -80 ºC occurred only as freezer manufacturers began marketing ULT freezers that could reach lower and lower temperatures, but there are still laboratories in the world that never actually shifted towards -80 ºC [4,7]. There is, to the best of our knowledge, no

[a] Municipal cooling typically has a coefficient of performance greater than 3. This means that it is capable of removing over 3 times more energy than it consumes itself. Other cooling and air conditioning methods are typically less efficient.

consistent scientific documentation that -80 ºC is the optimal storage temperature for the vast majority of research samples.

Further information on changing over to -70 ºC and sustainability in the laboratory in general can be found at CU Boulder's sustainability center (https://www.colorado.edu/ecenter/greenlabs/lab-energy-efforts/freezers/70-0c-efforts)[4], my green lab (https://www.mygreenlab.org/)[7], International Laboratory Freezer Challenge (https://www.freezerchallenge.org/)[8] and I2SL (http://www.i2sl.org/)[9] online.

Test parameters for the ULT freezer plug load test

In the fall of 2017, the plug load of 18 new ULT freezers was tested at the current standard of -80 ºC. From these, four randomly-selected freezers were selected for an additional plug load test at -70 ºC.
The selected freezers fell one in each of four categories: small and large chest freezers, and small and large upright freezers.

All measurements in both test runs were performed by a certified laboratory. The tests were held under the following parameters:

- Accurate measurement of the unit's inner volume (capacity).
- Accurate measurement of the unit's inner temperature and plug load for a period of 24 hours under controlled ambient temperature (daily average of 25°C).
- The unit was kept closed for the duration of the test.
- All temperature probes inside the freezers were mounted, and the access holes for cables sealed, 24 hours before commencing the test. During this preliminary 24-hour period the unit remained closed and sealed.
- The allowed margin of error was set at ± 5 % for the inner volume measurements, ± 1 °C for the inner temperature, 2.5 °C for the average ambient temperature, and ± 5 % for the unit's total plug load.
- Small and large chest freezers are defined as units with an inner volume of 100-375 and 500-820 liters, respectively. Small and large upright freezers are defined as units with an inner volume of 420-570 and 725-949 liters, respectively.

References:

1. En dansk 4-personshustands elforbrug ligger på 14,2 kWh/døgn. DONG energy, ”Elforbrug”. https://www.dongenergy.dk/privat/f%C3%A5-en-lavere-energiregning/tjek-dit-energiforbrug/gennemsnitsforbrug/elforbrug

2. ”Miljødeklarering af 1 kWh el”, Energinet.dk, Dok. 16/19206-10. 1. juli 2017

3. ”Grøn indkøbsaftale”, *Grøn Campus*, 2013. http://groencampus.ku.dk/detgoervi/konkreteprojekter/groenindkoebsaftale/

4. ”-70 ºC Efforts”, *Environmental Center University of Colorado Boulder*, 2017. https://www.colorado.edu/ecenter/greenlabs/lab-energy-efforts/freezers/70-0c-efforts

5. “Biological Samples Stored Long Term at -70C or Warmer” (Google Sheets). https://docs.google.com/spreadsheets/d/13UvBeoXAhwSHshSYoUDHwcxWiW7qYLnUb-eLwxJbCYs/pubhtml

6. “Ultra-Low Temperature Freezer Performance and Energy Use Tests”, Office of Sustainability - University of California, Riverside, juni 2016.

7. “-70 is the new -80”, *my green lab*. https://www.mygreenlab.org/-70-is-the-new--80.html

8. “International Laboratory Freezer Challenge”. https://www.freezerchallenge.org/

9. ” 2012 Centers for Disease Control and Prevention Lab Freezer Challenge”, International Institute for Sustainable Laboratories. http://www.i2sl.org/conference/2013/abstracts/b2_york.html

10. “Thermo Scientific TSX”, presentation by Samantha Cramer, Thermo Scientific – New England Region, September 30th, 2016.

Annex 1. Plug load test results

Category	Freezer code	INTERNAL VOLUME [liter]	Test -80 C				Test -70 C				Difference			
			Average outside Temp. [Celsius]	Average inside Temp. [Celsius]	kWh/day	kWh/l*yr	Average outside Temp. [Celsius]	Average inside Temp. [Celsius]	kWh/day	kWh/l*yr	Average outside Temp. [Celsius]	Average inside Temp. [Celsius]	kWh/day	kWh/l*yr
Small chest	1	367,0	24,0	-78,7	9,8	9,7								
Small chest	2	366,9	24,4	-78,9	9,5	9,5	24,9	-69,6	7,6	7,6	0,5	9,3	-1,9	-1,9
Small chest	3	357,6	25,0	-76,4	10,8	11,0								
Large chest	4	715,3	24,7	-78,7	19,8	10,1								
Large chest	5	666,8	24,1	-78,2	9,6	5,3	24,1	-69,0	7,5	4,1	0	9,2	-2,1	-1,2
Large chest	6	831,5	25,3	-75,7	21,7	9,5								
Large chest	7	560,2	24,6	-75,8	13,3	8,7								
Large chest	8	559,5	25,6	-75,5	12,6	8,2								
Small upright	9	507,3	25,0	-77,0	16,6	11,9								
Small upright	10	559	24,9	-78,8	8,5	5,5								
Small upright	11	587,7	24,9	-82,5	14,8	9,2								
Small upright	12	550,9	25,4	-76,9	8,7	5,8	24,8	-71,2	6,9	4,6	-0,6	5,7	-1,8	-1,2
Small upright	13	550,9	25,4	-77,3	9,1	6,0								
Large upright	14	841,5	24,6	-79,7	17,8	7,7								
Large upright	15	704,8	24,7	-80,1	12,2	6,3								
Large upright	16	841,2	24,8	-75,9	22,2	9,6								
Large upright	17	818,4	25,2	-76,8	9,8	4,4	25,0	-70,3	7,6	3,4	-0,2	6,5	-2,2	-1
Large upright	18	818,4	25,0	-77,1	10,2	4,5