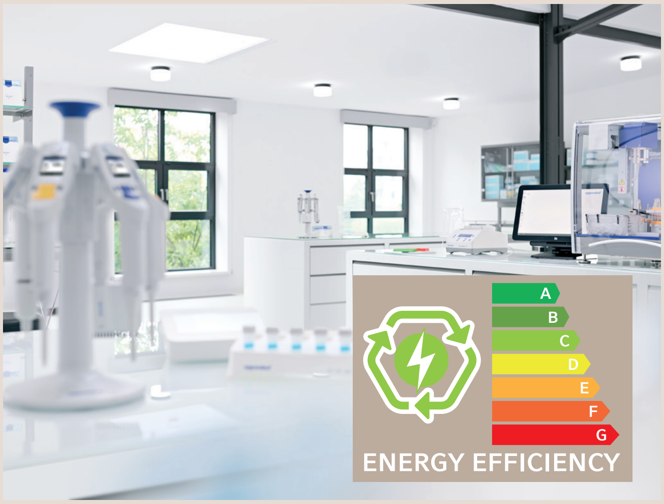
WHITE PAPER No. 110

Energy Consumption in Laboratories – How to Make Sense of an Intricate Topic?

Patrick Penndorf, Re-Advance

Executive Summary

Laboratories are among the most energy-intensive building types. However, education on laboratory equipment's electricity consumption is often lacking, even as regulatory frameworks tighten and electricity costs continue to rise. The challenge is compounded by a lack of detailed data and missing experience in crafting effective energy-saving strategies. This White Paper addresses these gaps by offering an intuitive understanding of electricity consumption alongside practical guidance for generating high-quality energy measurements. Through specific examples of energy consumption and savings reduction strategies, it uncovers rarely discussed yet essential insights to drive meaningful change.



Introduction

The overlooked impact of energy consumption
Plastic waste poses a highly visual problem in laboratories. In contrast, energy consumption is often overlooked as a significant cause of carbon footprints due to its invisible nature. Still, averaged over a year, the electricity needed to operate a single fume hood can equal the energy consumption of an entire single-family home. In fact, for many groups electricity consumption presents a greater opportunity for reducing carbon footprints than plastic waste. Current advances in sustainable practices are driven by both, changing habits and technological innovations. For example, the net energy consumption of ultra-low freezers has decreased by more than 45% over the last few decades. Moreover, switching temperatures in ULT freezers from -80 °C to -70 °C can save an additional 30% (see Table 1).

	CryoCube® F740hi	CryoCube F570h	CryoCube F440h	CryoCube F101h (2G)
Capacity	740 L	570 L	440 L	101 L
-80°C per day	10.5 kWh	7.4 kWh	6.8 kWh	4.7 kWh
-70°C per day	7.5 kWh	4.9 kWh	4.8 kWh	3.2 kWh
-80°C -> -70°C Savings	-28 %	-34 %	-29 %	-32 %
Power savings/ anno	1,095 KWh	913 KWh	730 KWh	548 KWh

Table 1: Average energy savings in kWh/ day when changing the set-point of an Eppendorf ULT freezer from -80 °C to -70 °C. The data are based on Eppendorf-external tests with 3 empty units (230 V) in parallel and 20 °C room temperature.

Recognize Energy as a Resource

Inside most laboratories, energy is generally not considered as limited resource. As a result, awareness and motivation to drive change is limited. Furthermore, concrete information about consumption is missing, thereby, complicating progress. Beyond general tips on how to save energy, more advanced strategies are seldom developed.

To identify safe and impactful solutions, a more thorough understanding is required. Therefore, it is crucial to delve into informative data and statistics, which are rarely discussed. To develop an intuitive understanding of how electricity consumption can be reduced, one has to start by discerning the processes that require energy.

Centrifuges

While centrifuges serve a singular purpose, their energy consumption in their use phase is caused by multiple processes, namely A) rotating, B) cooling, and C) in some models, vacuum generation. Below is a comparison of two models of different sizes and their energy consumption:

Figure 1: Common microcentrifuges like Centrifuge 5427 R provide a FastTemp option for fast and energy efficient pre-cooling

Microcentrifuge:
Centrifuge 5427 R (with 30-place rotor)

> Using the FastTemp to cool it down from RT to +4 °C requires 60 Wh

> A spin for 20 minutes at 20,000 x g at 4°C with 10 tubes takes 130 Wh

If we assume that a lab group cools down this centrifuge once and runs five spins every working day, this results in an annual power consumption of in total 50 kWh. This is comparable to ca. 60 runs of a washing machine.

Tabletop Centrifuge:
Centrifuge 5910 Ri (6x 50 mL fixed-angle rotor)

> Using the FastTemp to cool it down from RT to +4 °C requires 1,000 Wh

> A spin for 60 minutes at 15,000 x g at 4 °C with 4x 50 mL tubes takes 640 Wh

Assuming a similar usage for the larger centrifuge, we end up with 4.2 KWh per day or 1,050 kWh/ year, enough to fully charge an electric vehicle 15 times. The spinning alone has a quite low impact, demonstrating the high impact of cooling down the centrifuge.

More detailed information about the power consumption of centrifuges is available in White Paper 115. When talking about energy consumption, one must also be precise about the mode of operation, i.e., how many tubes are loaded, at which speed, at which temperature, and how long the centrifuge is run. This is important since accelerating the rotor consumes more energy than maintaining the spin.

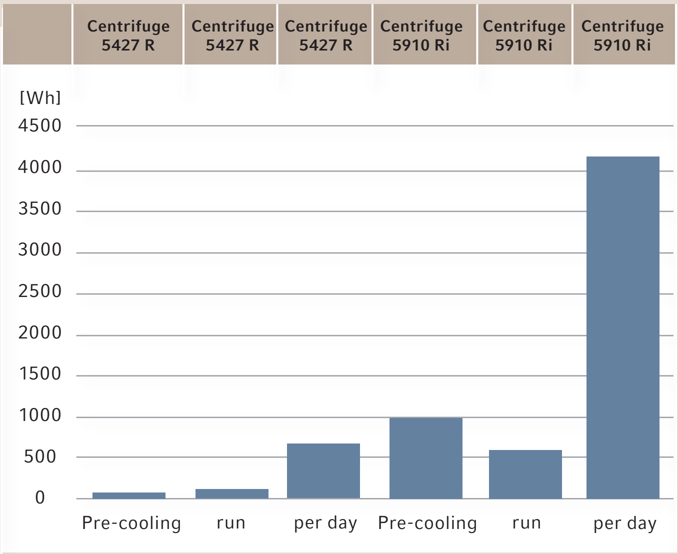


Figure 2: Power consumption of different centrifuges based on one pre-cooling and 5 runs per day (please note that speed and time of each run differs between the two models given their unequal size)

Heating / Mixing

Since temperature-controlled incubation is a common step within protocols, many laboratories keep their instruments switched on throughout the day, in some cases not turning them off at all.
To quantify the resulting energy consumption, we can use the Eppendorf ThermoMixer® C as an example. Essentially, we have to differentiate shaking and heating. If a Thermomixers runs for 5 hours at 65 °C without being used, it consumes as much energy as a 110 Wh, equivalent 10 phone charges.

Figure 3: ThermoMixer C for sample incubation and mixing

Here, another important point becomes evident:
It should be noted that changes in energy consumption are not linear. On the one hand, electricity use grows with higher temperatures. On the other hand, at higher temperatures, shaking adds more to the electricity consumption than at lower temperatures. These differences are due to internal mechanics.

More detailed information about the power consumption of thermomixers is available in White Paper 107.

Operating at	Mixing	Power Consumption
16 ˚C	0 rpm	8 Wh
16 ˚C	1,000 rpm	13 Wh
37 ˚C	0 rpm	11 Wh
37 ˚C	1,000 rpm	16 Wh
65 ˚C	0 rpm	22 Wh
65 ˚C	1,000 rpm	29 Wh

Table 2: Power consumption data of the Eppendorf ThermoMixer C with different running parameters (SmartBlock 1.5 mL and 10x 1.5 mL tubes filled with 1.0 mL of water)

To reduce energy consumption, turning it off is best practice, also decreasing the operational load, which will in turn, increase lifetime. Quite often, multiple instruments of these compact units are located in the laboratory: Any savings in usage patterns can be made on multiple units in parallel. However, repeatedly turning it on and off will significantly reduce the savings if the instrument is cooling out and it needs to be heated up every time again. This makes proper planning essential. In other equipment, changing settings is the preferred option to save energy consumption.

PCR Cycler

The energy consumption of PCR cyclers depends on the exact settings of the given program that is run.
To estimate average consumption, the ACT Label Team from My Green Lab® has co-operated with Eppendorf to define a standard protocol. Therein, a PCR-foil sealed unskirted 96-well plate (total volume: 250 µL, 48 wells filled with 30 µL water in columns 1, 3, 5, 8, 10, 12) was used to run the following cycle at the fastest ramp speed. The average working time is set to 8 h/ day and 4x PCR runs.

Figure 4: PCR cycler require energy due to constant heating and cooling steps

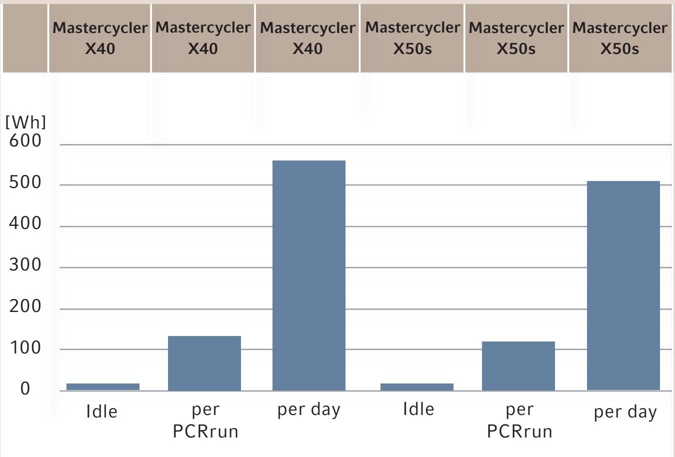


Figure 5: Power consumption of two different PCR cyclers based on 4 runs a day and idle (8 hrs day)

When comparing two different PCR Mastercycler models, we see that the size/ speed of a certain model not necessarily allows to draw conclusions about energy consumption. The Mastercycler X50s has a max. heating rate of 10 °C/ min and a cooling rate of 5 °C/ min. The Mastercycler X40 has a max. heating rate of 3.3 °C/ min and a cooling rate of 1.5 °C/ min.

95 °C	95 °C	60 °C	72 °C	72 °C	4 °C
2 min	15 s	15 s	30 s	1 min	10 min
30x					

Table 3: Standardized PCR program for power consumption comparison, developed with the My Green Lab/ ACT label Team.

The detailed calculation is:

PCR Mastercycler X40 (Slower Model)

> Standard PCR run: 135 Wh (73 min)
> Idle: 10.5 Wh
> 8 hours (480 min) a day = 4 runs (292 min) + idle (188 min) = 540 Wh + 33 Wh = ca. 575 Wh

PCR Mastercycler X50s (Faster Model)

> Standard PCR run: 113.4 Wh (55 min)
> Idle: 11.8 Wh
> 8 hours (480 min) a day = 4 runs (220 min) + idle (260 min) = 454 Wh + 54 Wh = ca. 510 Wh

Although the Mastercycler X50s is larger and faster, the instrument is equipped with an efficient heating and cooling system which results in a 15% lower power consumption per standardized run compared to the smaller X40 which provides a slower ramp rate.
Traditionally, holding temperatures after the completion of the PCR program is set to +4 °C. To save energy, settings for the steady state can be changed to +10 °C, significantly reducing the power consumption.

Mastercycler X40:

> +4 °C: 34 Wh
> +10 °C: 23 Wh (savings of >30%)

Mastercycler X50s:

> +4 °C: 68 Wh
> +10 °C: 35 Wh (savings of >45%)

That means if the Mastercycler X50s is programmed at 10 °C for sample conservation after the PCR run instead of 4 °C overnight (14 h in total), one could save ca. 460 Wh or approximately ca. 45 phone charges. This number doubles to more than 95 charges if the work planning allows to turn of the machine overnight (952 Wh). Advanced planning can enable savings also in instances where change is otherwise challenging.

Electronic Pipettes

Given the benefits of improved ergonomics, user-independent reproducibility and added versatility, electronic pipettes find an ever-larger adoption. But has this change an impact on the power consumption of the laboratory? The battery of the electronic pipette must be charged, which means introducing another energy-consuming piece of equipment. Fully charging the battery of an Eppendorf Xplorer® electronic pipette (single-channel, 1,000 µL) requires 5.5 Wh and enables approximately 1,400 pipetting steps.

The Multipette® E3* an electronic multi-dispenser has a battery capacity of 4.4 Wh. The number of steps to be achieved strongly depends on the liquid type to be dispensed. Ostensibly, energy consumption of those pipettes is comparatively small. Still, options to save energy are limited to optimizing pipetting schemes. In contrast, for other machines saving options are closely linked to best practice.

*in USA/Canada: Repeater®

Figure 6: Eppendorf Xplorer electronic multi-channel pipette

CO_2 Incubators

Similar to ULT freezers, cell incubators run 24/7, disabling energy savings through shutdowns or standby modes. The Incubator CellXpert® C170i requires about 37 Wh at steady state at 37°C. This means that if we never opened the doors, it would consume approximately 324 kWh each year - enough to run an average 2-Person household for a month.

Figure 7: Cell incubators like the CellXpert C170i run 24/7

In order to limit power consumption, adherence to best practices, similarly to freezers, is most effective:

> Limit the door openings
> Check and clean door seals
> If possible, select a unit with segmented doors. This will keep the heat inside (less power consumption) and directly saves CO_2 as well due to the smaller opening area

A single heat sterilization cycle requires approximately 3, 250 Wh. This number seems surprisingly high, yet, to ensure proper sterility, the incubator must be heated to 180°C for about 14 hours; otherwise, entire experimental series could be contaminated. By comparison, conventional 230 V household ovens consume about 1,000 watts per hour when operating at 200°C.

A Major Consumer of Electricity: HVAC

Surprisingly, it is not laboratory equipment that leaves the biggest footprint. The biggest consumer of electricity across laboratories is Heating, Ventilation, and Air Conditioning (HVAC), given the need to exchange air frequently and maintain steady temperatures (see Box 1). Given that HVAC consumes often up to 50% of electricity of all laboratory processes, changes can have a significant impact but require involvement of facility management and ventilation specialists.

Box 1

HVAC refers to Heating, Ventilation, and Air Conditioning. These systems provide temperature control and air quality management. In some institutions, HVAC systems have been shown to account for more than 60% of total energy consumption. The reason is that -by law- a specific air exchange rate per hour should prevent the accumulation of (toxic) chemicals. Additionally, the need for constant temperatures makes continuous heating or cooling of fresh air drawn from outside necessary. Nevertheless, unnecessarily high air exchange rates can often be reduced and air conditioning settings be reviewed. Of note, change is often complicated in older buildings, where HVAC systems frequently lack the ability to be differentially regulated, for example, at night. Also fume hoods significantly impact energy consumption. However, the extent of energy savings by shutting sashes largely depends on the air ducting and ventilation design. Thus, implementing changes in air ventilation often requires the cooperation of various stakeholders, including scientists and facility management.

Finding More Numbers

Unfortunately, data on the energy consumption in laboratories is seldomly discussed, leaving scientists unaware of how much energy their equipment actually consumes.
Insofar as suppliers and manufacturers report on consumption, there are standardized methods for measuring electricity use. For instance, the German Institute for Standardization (DIN) provides guidelines for energy measurement. Similarly, the ACT (Accountability, Consistency, Transparency) label by My Green Lab offers a standardized protocol. These protocols define how measurements should be conducted, including factors such as turn-on times, active running times, operating modes, and the load, among others. Accordingly, the data generation on power consumption for PCR-cyclers, mixers, and centrifuges presented above were based on ACT protocols. Thereby, enabling transparency and comparability.
To estimate individual energy consumption, numbers for other pieces of equipment like Mass Spectrometers (≈19 kWh/ day), Glassware Washers (4-9 kWh/ day), and Sterilizers (≈49 kW/ h) are available on the ACT-Label database (https:// actdatabase.mygreenlab.org/). The measurement protocols as well as an overview of other impacts are listed in the database as well.
Knowing about these numbers can be crucial when reporting is required. They can also help to trace reduction although laboratories not always have a direct financial stake in their energy bills.

Why Measuring Electricity Matters

To engage colleagues, generating tangible numbers through measuring energy consumption directly is often an effective strategy that can also help to quantify monetary saving for administrative staff. On top, most companies have adopted sustainability pledges and emission goals that require substantial action going forward. Future regulations such as the CSRD (Corporate Sustainability Reporting Directive) will also require companies to quantify their energy consumption and develop strategies to reduce use over time. For academic laboratories, a growing number of funding bodies requests statements and plans to enhance sustainable practices. Although often necessary, lab internal quantifications can easily be confusing by providing variations between institutions and numbers provided by manufacturers. Most often, these discrepancies are due to variations in measurement setups that can be swiftly explained and finally avoided.

Reliable Quantification

When measuring energy consumption, a set of parameters must be clearly defined to assure reliability and transparency. In other words, there is no single value for “the energy consumption” of a piece of equipment; it depends on the specific setup. Thus, a few guiding questions prove helpful in designing reliable measurements:

What concretely is measured?
As discussed previously, running times, operating modes, room temperature, and other factors must be defined and protocolled to put results into perspective. As a result, the pressing question “How much energy does this centrifuge consume?” cannot be definitively answered unless the rotor type, spinning speed, temperature setting, load, and brake ramps are specified.

Does the measurement provide the information sought?
For example, measuring the idle energy use of a freezer during the weekend might not be as useful as monitoring its energy consumption during active use, which includes door openings as well as changes in the number of stored samples.

Which state is the equipment in?
Energy consumption during first use and for older equipment is often different due to inner mechanics and wear, respectively. Obviously, size and load are two other factors that can heavily influence consumption.

Is a proper measurement plan developed?
One-time assessments do not inform about measurement mistakes or variations that might arise from differences in use over time. Also, proper measurement equipment is essential since otherwise over- or underreporting is possible. Energy consumption correlates but does not determine environmental impact.

When it comes to environmental footprints, the type of electricity source (e.g., coal, nuclear, solar, wind, or hydro) is an important factor that can significantly affect the environmental impact. This becomes especially clear when measuring emissions to determine Scope-related-impacts, given that consumed quantities are multiplied by region-specific emission factors (see Box 2).

Box 2
As many institutions aim to reduce their environmental impact, lowering their Scope 1 and 2 emissions largely dependents on decreasing energy consumption.
Scope 1 emissions refer to direct greenhouse gas (GHG) emissions from sources that are owned or controlled by an organization. These include natural gas burned to operate boilers and Bunsen burners within the lab, as well as emissions produced by institution-owned vehicles.
In contrast, Scope 2 emissions represent indirect GHG emissions that result from the purchase of electricity, steam, heat, or cooling by an organization. These emissions occur off-site but are still associated with an organization’s energy consumption.
The calculation of these impacts is straightforward: After quantifying consumption of these factors, multiplying by an emission factor results in the released carbon dioxide equivalent (CO_2e).
To illustrate the impact of Scope 2 emissions, consider a laboratory that requires 5,000,000 kWh of electricity in a year. Using an emission factor of 0.258 kg CO_2e per kWh (EU average 2022), the calculations for Scope 2 emissions would be as follows:
Emissions (CO_2e) = 5,000,000 kWh * 0.258 kg CO_2e/ kWh
= 1,290,000 kg CO_2e = 1,290 t CO_2e

After impacts are quantified, it remains essential to translate these insights into actions. Besides the previously discussed options, three simple yet impactful strategies are often overlooked:

Reviewing and Optimizing Settings:
Adjusting parameters is a powerful way to align the reduction of electricity consumption with good scientific practice. For example, reviewing laser and area settings when scanning with microscopes or optimizing HPLC gradients can save time while enhancing precision. Similarly, double checking settings and pre-running a control to check parameters can prevent costly mistakes. As previously discussed, increasing the holding temperatures of PCR cyclers will lower energy use and reduce wear due to less condensation water.
However, power savings must be balanced with safe sample handling and time management. As described previously, doubling the run time to cut the spinning speed of centrifuges half does not automatically save significant amounts of energy while conflicting with time-sensitive steps. Therefore, prioritizing the use of a smaller centrifuge will be safer and more impactful.

Maintenance
Routine maintenance and cleaning of laboratory equipment are often underappreciated yet sustainable practices. For instance, regularly defrosting freezers prevents failure, ensures constant temperatures and saves energy. Similarly, cleaning filters and fans in equipment like fume hoods can improve airflow.

Reprioritizing Purchasing Decisions
Finally, when purchasing new equipment, energy efficiency should be taken into account when comparing models. Together with factors like heat dissipation, significant amounts of money can be saved in the long term. Of note, equipment that generates less heat, requires less air conditioning, creating a compounding effect in energy savings. Still, energy savings have to be aligned with best practice experimental success. For instance, fast pulldown times for freezers or precise temperature set-points in a PCR run should not be sacrificed for small energy savings, as maintaining sample quality remains top priority. In the end, saving energy is not just beneficial for the environment; it saves money, time, and motivates the optimization of processes. Appreciating energy as a limited resource is still uncommon but might help transform your laboratory for the better.

About Eppendorf

Eppendorf is a leading life science company that develops and sells instruments, consumables, and services for liquid-, sample-, and cell handling in laboratories worldwide. Its product range includes pipettes and automated pipetting systems, dispensers, centrifuges, mixers and DNA amplification equipment as well as ultra-low temperature freezers, fermentors, bioreactors, CO_2 incubators, and shakers. Associated consumables like pipette tips, test tubes, microtiter plates, and disposable bioreactors complement the instruments for highest quality workflow solutions.
Eppendorf was founded in Hamburg, Germany in 1945.

Your local distributor: www.eppendorf.com/contact
Eppendorf SE · Barkhausenweg 1 · 22339 Hamburg · Germany
eppendorf@eppendorf.com · www.eppendorf.com

www.eppendorf.com