Technical Overview

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Comparing the Energy Consumption of Different UHPLC Systems

Abstract

Laboratories are indisputably one of the most resource-intensive industry spaces. A way to reduce energy consumption is to use analytical instruments that operate economically. Depending on the sample load and method requirements, however, it might be inevitable to run a UHPLC system all day. To better judge the energy consumption of a UHPLC system per day and per processed sample, this technical overview compares equivalent UHPLC systems of four different vendors. For practical relevance, different operational states (idle, waiting for samples, running) are distinguished.

Introduction

Energy consumption of analytical instruments is a major contributor to the overall environmental footprint of a laboratory. Using HPLC systems in an economic way is key to becoming more environmentally sustainable. This strategy includes the selection of a system most suitable for the number of samples to be expected on a typical day. A previous publication compares the energy consumption of different Agilent InfinityLab LC systems directed at different application needs—from a compact, integrated LC to a modular, high-throughput UHPLC system.[1]

Fast UHPLC systems are a common choice of contract laboratories with established high-throughput workflows and the need to analyze huge amounts of samples per day. Their systems probably remain switched on all day, mainly processing sample queues or waiting for the next sequence to be submitted. To judge the energetic efficiency of these laboratories, it is more appropriate to measure the energy consumption per sample processed, instead of the mere consumption of a UHPLC system running all day. The energy consumption of the system in different states (idling, waiting for sample submission, running) can, however, make a difference to the overall consumption per working day.

This technical overview compares the energy consumption of four UHPLC systems of different vendors, assessing the consumption over different operational states and sample loads per day. As in a previous comparison of Agilent InfinityLab LCs[1], the method was not optimized to the lowest energy consumption possible but intended to represent a realistic use case.

Experimental

Instrumentation

Energy consumption of different UHPLC systems was measured using a CLM 221 power meter (Christ Electronic Systems, Memmingen, Germany) and an ALMEMO 2590 data logger (Ahlborn, Holzkirchen, Germany). All measurements were conducted at room temperature (23 ± 2 °C) using UHPLC systems of different manufacturers, each system representing the upper end of the performance range. All systems were well-maintained and fully functional.

1. Agilent 1290 Infinity II LC
   - 1290 Infinity II Flexible Pump (G7104A)
   - 1290 Infinity II Multisampler (G7167B)
   - 1290 Infinity II Multicolumn Thermostat (G7116B)
   - 1290 Infinity II Diode Array Detector (G7117B)
2. Shimadzu Nexera LC-40 X3
   - LC-40B X3 Binary Solvent Delivery Module
   - SIL-40C X3 Autosampler
   - CTO-40S Column Oven
   - SPD-M40 Photodiode Array UV-Vis Detector
   - SCL-40 System Controller
3. Thermo Scientific Vanquish Flex
   - VF-P20-A Quaternary Pump
   - VH-A10-A Autosampler
   - VH-C10-A Column Oven
   - VH-D10-A Diode Array Detector
4. Waters Acquity H-Class Plus Bio
   - Acquity H-Class Bio Quaternary Solvent Manager
   - Acquity H-Class Bio Sample Manager FTN
   - Acquity Column Manager
   - Acquity TUV Detector

Column

Agilent ZORBAX RRHD Eclipse Plus C18, 2.1 × 50 mm, 1.8 µm (part number 959757-902)

Software

The Agilent, Thermo, and Waters LCs were controlled using Agilent OpenLab CDS, revision 2.6, with Thermo Scientific SII for OpenLab CDS 1.2.0.359 and Waters Acquity drivers 2.4.21. The Shimadzu LC was controlled using Shimadzu LabSolutions software, version 5.97 SP1.

Solvents

LC-gradient-grade methanol was purchased from VWR (Darmstadt, Germany). Fresh ultrapure water was obtained from a Milli-Q Integral system equipped with a 0.22 µm membrane point-of-use cartridge (Millipak).

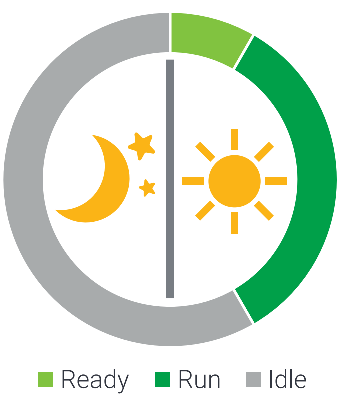
Sample

Agilent RRLC checkout sample, part number 5188-6529.

Method settings

Energy consumption of each instrument was measured during three states of operation over a day in the laboratory: idle, ready, and run (see Figure 1 for exact conditions). A typical day in the laboratory was assumed to comprise 8 hours of actual analysis time on each system ("run"), with an additional 2 hours for priming, purging, column temperature equilibration, as well as waiting for samples to be submitted ("ready"). For the remaining time of the day, the system was presumed to be in standby, meaning pumps, column oven, and detector lamp were switched off, but the sample thermostat was still cooling the samples ("idle").

The LC systems were switched on and left in idle state overnight to allow homogeneous cooling of the samples. In addition to the sample, each autosampler held 64 vials filled with 1.5 mL of pure water to simulate a realistic fill state. On the following day, energy consumption during idle state was measured for two hours.



	Idle	Ready	Run
Mains	ON	ON	ON
Sample Thermostat	ON	ON	ON
Column Thermostat	OFF	ON	ON
Pump	OFF	ON	ON
Detector Lamp	OFF	ON	ON
Autosampler	OFF	OFF	ON

Figure 1. Assumed operational states of an LC system over the course of a typical lab day.

After measuring the energy consumption in idle state, the pump, column thermostat, and detector lamp were switched on. During this ready state, the energy consumption was again measured over two hours.

Finally, a sequence of 30 injections was submitted. During this run state, the chromatographic conditions listed in Table 1 were applied on each system to separate the sample. These conditions represent typical UHPLC applications employing fast gradients, short run times, and high pressure (around 800 bar). The energy consumption was measured over the entire sequence of 30 injections. For the final evaluation, however, only the number of samples completed within two hours and the energy consumed during this time was recorded.

Table 1. Chromatographic conditions of analytical and preparative runs.

Parameter	Value
Mobile Phase	A) Water B) Methanol
Flow Rate	0.8 mL/min
Gradient	Time (min) %B 0.00 30 2.00 95
Stop Time	3 min
Post Time	1 min
Injection Volume	1.25 µL
Needle Wash	Water/acetonitrile, 1:1 (v/v)
Column Temperature	40 °C
Sample Temperature	4 °C
UV Detection	DAD 280 nm Peak width 0.005 to 0.0063* min (0.10 to 0.15* s response time) 40 to 50* Hz data rate

*The settable values differ among the different system manufacturers.

Results and discussion

The Agilent RRLC Checkout Sample was separated on four different UHPLC systems. Method parameters and the separation column were the same on each system.

The energy consumption of each system during idle, ready, and run states was measured for two hours each. Figure 2 compares the energy consumption per hour in the different states of operation.

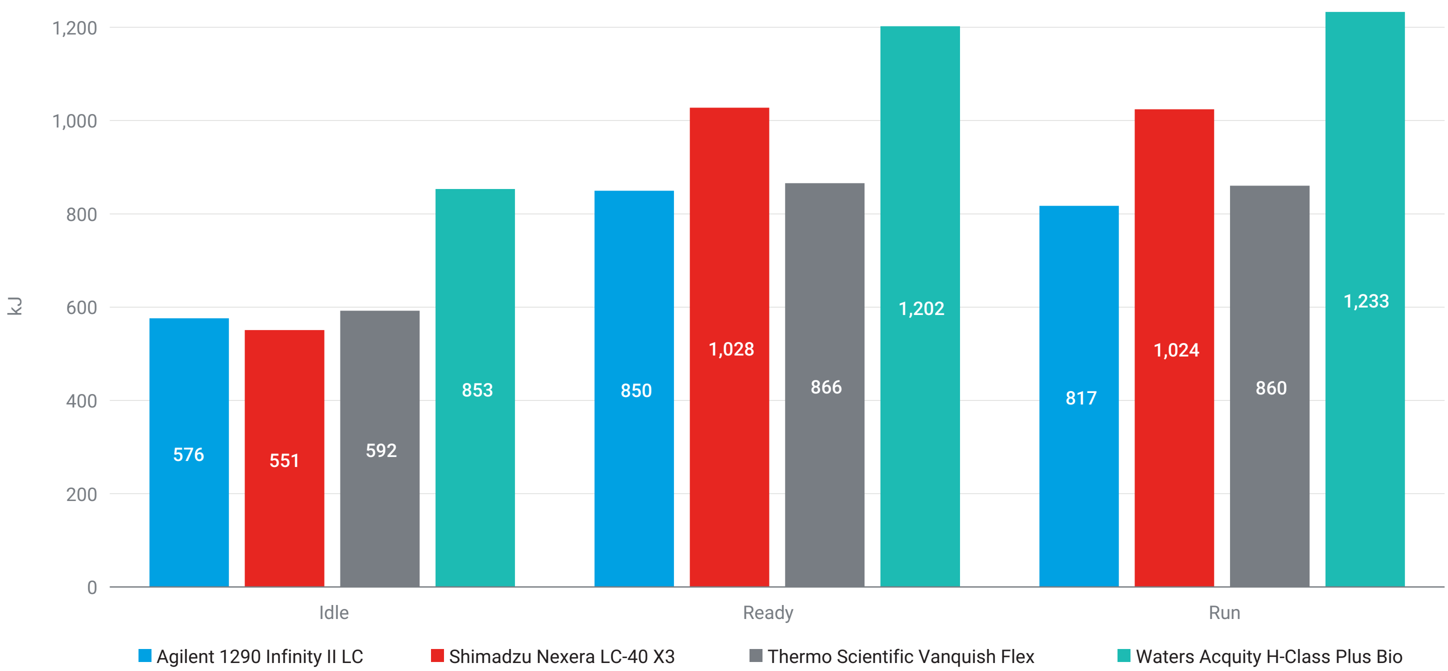


Figure 2. Energy consumption of four different UHPLC systems per hour in different operational states.

The Agilent and Thermo LCs consumed similar amounts of energy in all three states. The Shimadzu LC was slightly more economical than Agilent and Thermo in idle state but consumed more energy during ready and run. The Waters LC consumed significantly more energy than the competition in all operational states.

To get a realistic overview of the energy consumption per day, the measured values were extrapolated to represent a working day of 8 hours in run, 2 hours in ready, and 14 hours in idle state (see Figure 3). The results for the Agilent, Shimadzu, and Thermo LCs were again very similar, with an energy consumption of 4.5 to 5.0 kWh. Although the Shimadzu LC had a slight edge over the competition in idle state, the higher consumption during ready and run put the Shimadzu in third place, albeit very close to Agilent and Thermo. Again, the Waters LC was on the high end of the consumption scale.

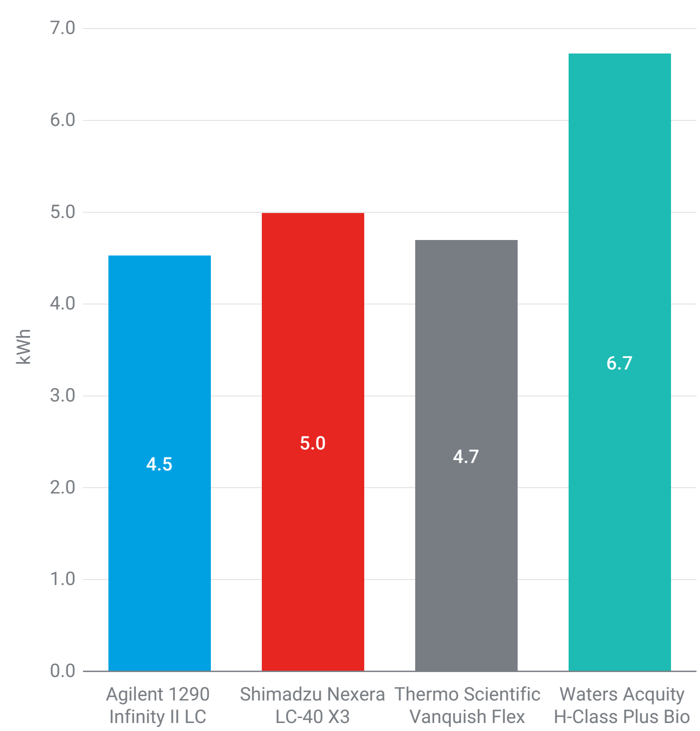


Figure 3. Extrapolated energy consumption in kWh per day.

High energy consumption per working day does not necessarily mean that operation of an LC is uneconomical. Measuring the number of samples that can be analyzed within a day is important to judge the true energy consumption of a running LC. Within the two hours of measurement, the different LCs were able to analyze 25 (Thermo), 26 (Waters), 27 (Agilent), or 28 (Shimadzu) samples, respectively. To calculate the energy consumption per sample, the energy per working day was divided by the number of samples that could be analyzed within eight hours. Of the four different systems, the Shimadzu LC was able to analyze most samples, which made up for the slightly higher energy consumption per working day. Both the Agilent and Thermo LCs were around the same range (see Figure 4). The Waters LC, again, stood out with the highest energy consumption per sample.

To use an LC system most efficiently and economically, laboratories with large sample loads might switch to working days that enable a 16-hour run time. This schedule would reduce the idle time to 6 hours, if a ready state of 2 hours is assumed to be constant. The number of analyzed samples would double, which would in turn reduce the energy consumption per sample. The calculation for this scenario is displayed in Figure 5. A comparison with Figure 4 shows that the Shimadzu and Thermo LCs have swapped places, with the Thermo having a slight edge given its lower energy consumption per sample. This example underlines that it is not just the energy consumption per day or during a run that counts. To judge the true energy consumption of an LC, it is important to consider the number of samples that will be analyzed with the instrument.

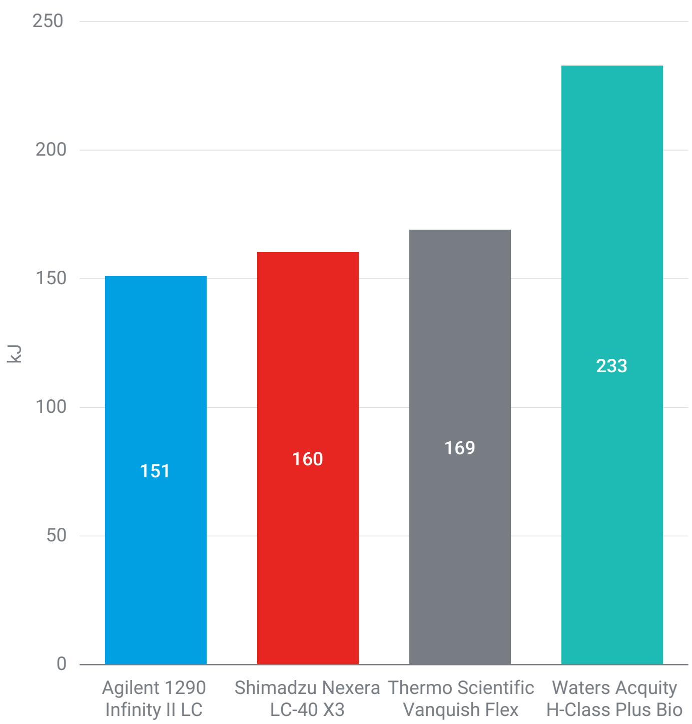


Figure 4. Calculated energy consumption per sample in kJ during an 8-hour working day.

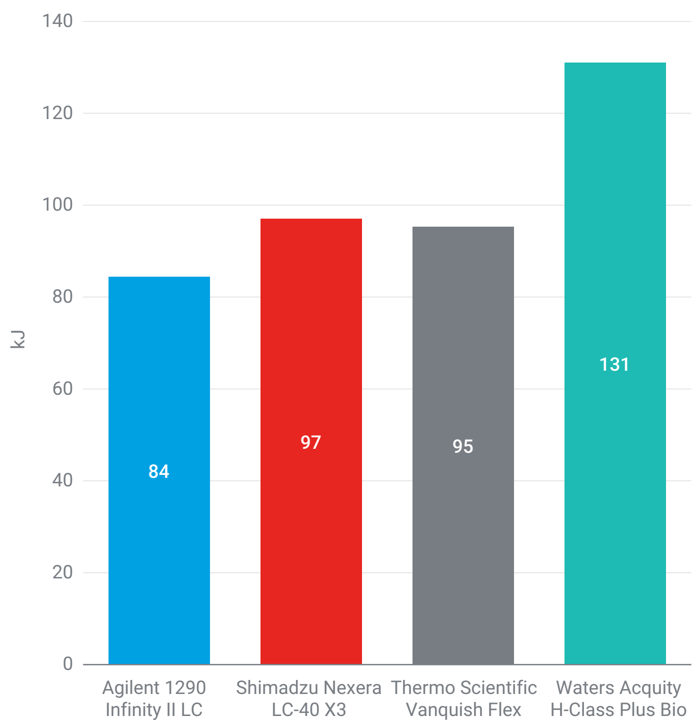


Figure 5. Calculated energy consumption per sample in kJ during a 16-hour working day.

Conclusion

The energy consumption of comparable UHPLC systems of four different vendors was examined in different states of operational activity. While in idle state, most systems had a similar consumption. Differences became visible during ready state and while analyses were running. Depending on the number of samples processed per day, a system that is economic in the idle state might consume more energy in total than a competing system that was less economic while idle. The actual energy consumption of a UHPLC system must therefore be judged based on daily use and the number of samples analyzed on a typical working day.

Reference

1. Rieck, F. Do You Know the Environmental Impact of Your HPLC? Energy consumption of four InfinityLab LC systems during routine operation. *Agilent Technologies technical overview*, publication number 5994-2335EN, **2022**.

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