Notebook Thermodynamics Part 1/2

Business-class notebook shakedown: Intel Alder Lake

We are back again for another business-class notebook thermal shakedown session! At this point in the series, it should be obvious to readers that thermal engineering is, in fact, the single most important discipline of product design on the entire planet; influencing the most significant traits on the devices we spend the most hours per day using. It should also be obvious to our readers that, while you show-up for the purely objective, data-driven comparisons of these products, you stay for the banter.

Getting right down to business, in this segment we are performing a thermal design comparison of the **Dell Latitude 7430**, **HP EliteBook 840 G9**, and the **Lenovo T14s Gen 3**, all of which are business-class notebooks based upon the latest Intel Alder Lake CPU architecture. In order to perform this comparison, we look at four Thermal Performance Indicators (TPIs):

- **Application Performance**: how “fast” the system feels
- **Skin Temperature**: how hot the surface is getting that you touch
- **Sound Output**: how loud is the system under various conditions (aka fan noise)
- **Battery Performance**: how much time can you remain productive while unplugged

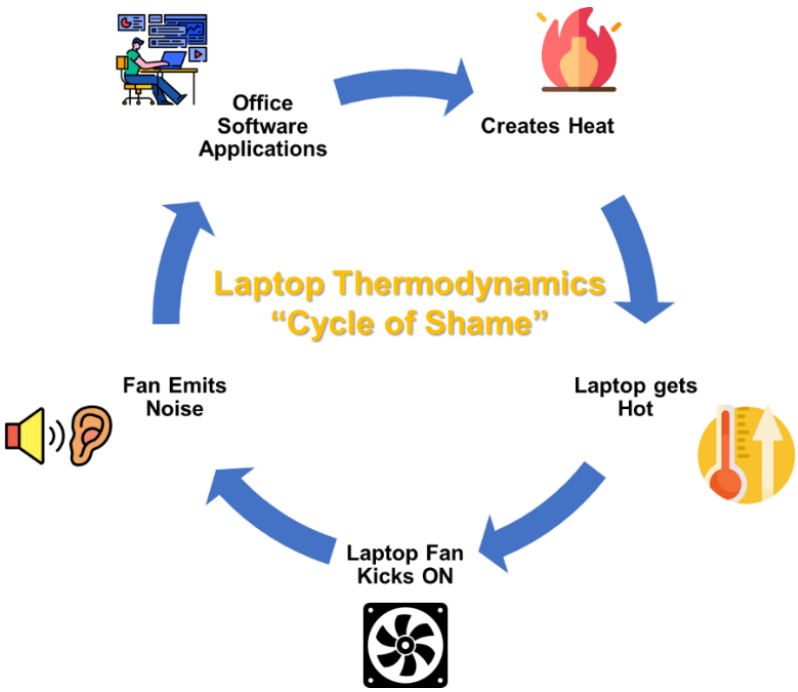
As a quick refresher or primer, these 4 TPIs are all amongst the most influential characteristics of a notebook upon the end user experience while at the same time being fully entangled with one another and dependent upon the product’s thermal design.

TLDR: The Dell Latitude 7430 and Lenovo T14s Gen 3 trade blows in application performance with each taking home some key victories. The T14s is the quietest of the 3 notebooks but at the expense of having extremely, possibly alarmingly high skin temperatures while stressed. Dell continues its historical battery life dominance in this segment and, unfortunately, the HP EliteBook 840 G9 effectively falls on its face in every category except skin temperature where it is consistently cooler to the touch than the other two competitors, which as we will see, is probably not entirely by design.

Introduction

Remind me again: What is thermal engineering and how does it affect my life?

No problem! Thermal engineering, in this context, is how an electronic device is designed to eliminate the heat that it dissipates during operation. Not everyone immediately realizes that **a computer's closest relative in the natural world is the small electric space heater you place beneath your desk** when the corporate energy czar sets the thermostats to 65°F in the middle of the winter. The components within computers that are responsible for actually "doing computer work" such as the Central Processing Unit (CPU) all create heat as your PC crunches through giant Excel worksheets, photo renders, or updating the web browser pointed at your favorite social media network. That heat eventually has to go *somewhere* and, in most cases, the most effective cooling solution is a small fan located within your laptop that dissipates your system's component heat into the air resulting in some form of fan noise emission. We call this process the Laptop Thermodynamic Cycle of Shame.



To be clear, this shame does not belong to the modern thermal engineer (OK, sometimes it actually does). No, this shame belongs to Sir Isaac Newton, Lord Kelvin, and all of their co-conspirators who invented thermodynamics. Alright, maybe blaming them is like shooting the messenger and we just need to blame physics. I'm good with that.

So then, in the spirit of not shooting the messenger, let me attempt to present the following Laws of Notebook Thermodynamics:

1. **Increasing laptop performance, for a given CPU, always increases the amount of heat generated.**

2. **Increases in heat generation require an increase in cooling capacity.**

3. **To increase a system's cooling capacity, the cooling solution must get louder, larger, or more expensive; sometimes all three.**

Wait: I bought a new laptop last week and I'm telling you it's smaller, quieter, AND faster than the 5-year-old model it replaced. It might have even been cheaper.

The reason that notebooks have steadily become faster over time without getting much louder or larger (in fact sizes are trending down) is that the CPU architectures themselves have been improving over time offering more application throughput per Watt of heat produced. You might have casually read through some random LinkedIn articles talking about "The End of Moore's Law" as though it were some cataclysmic doomsday prophecy wherein the world ceases to exist or, at a minimum, we have cats and dogs living together. If you want to really impress your friends with knowledge of things you may or may not really care about, the practical meaning of "The End of Moore's Law", for most people, is that we are approaching a physics limitation for the manufacturing of new CPUs that will soon stall or prevent further increases in the amount of compute power achievable per unit of heat. In other words, compute efficiency improvements are nearing a limit and that means getting more performance is going to come at the cost of extra heat production, something that really hasn't been true for 40 years, speaking in generational terms.

I'm not saying I didn't read your previous articles, and I'm not saying I'd rather not be reading your current article, but, let's just pretend like I didn't, what was all the talk about tradeoffs in 3 sentences or less.

The 3 laws of Notebook Thermodynamics are telling us that laptop size, battery life, noise emissions, skin temperatures, and application performance are all working against one another in a giant 1 vs All deathmatch. If we increase the performance of a given laptop we have to grow the heatsink size which makes the laptop get bigger and heavier or we have to steal space away from the battery. If we want to decrease fan noise, we might have to cap the CPU performance or allow the skin temperature to get uncomfortably hot.

Quick count…. 3 periods = 3 sentences; nailed it!

As before, the question continues to be: knowing that these parameters are working against one another what should the thermal engineer prioritize in their notebook design? To answer that question, Strategic Thermal Labs invested into one of the most trusted and indisputably accurate methods of statistical analysis in existence. We conducted a low-participation survey from our embarrassingly small number of followers on social media and concluded it was 100% accurate for the whole country, probably the whole world. Of course, with the obligatory caveat that there might be something like a 100% margin of error; we aren't barbarians.

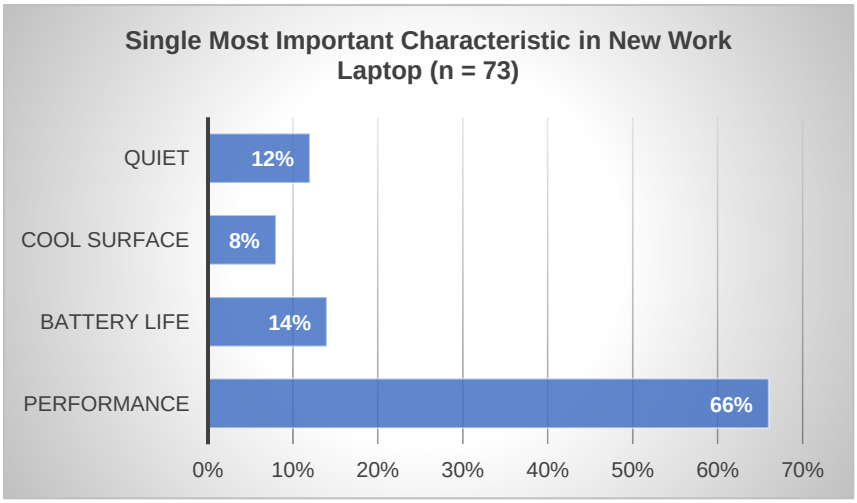


Figure 1. LinkedIn survey most desirable laptop trait.

The results on this humorously small but still interesting survey are that the polled user group (consisting of whatever friends, family, and coworkers I could coerce into clicking a button) overwhelmingly wants their next work laptop to be fast above all else. We spend far too much time sitting in front of these machines day in and day out and every second spent waiting on an application to load or a file to copy is seconds off our lives.

But this survey, statistically significant as it may be, doesn't tell the whole story, as survey's rarely do. Customers want their laptop to be faster, but what if that meant that it sounded like a jet engine? Or that the battery lasted for less than 30 minutes when unplugged? What if the surface of that "lap" top felt like a holding a frying pan?

You see where this is going. We need to fix the survey. With another survey.

For the second survey, we asked the question in reverse to try and understand what laptop trait was most likely to annoy users about their work laptop. It was surprising to find that while only 14% of respondents stated that battery life was the most important characteristic of a new laptop, 38% of respondents claimed that an underperforming battery was the single most annoying part of a laptop experience. It was also very surprising to the writer of this article that a laptop being too loud was the least annoying trait about a laptop because that's what I personally voted for. These survey's might be small, but they are, admittedly, a more accurate illustration of the greater market sentiment than my own gut, apparently. Who knew.

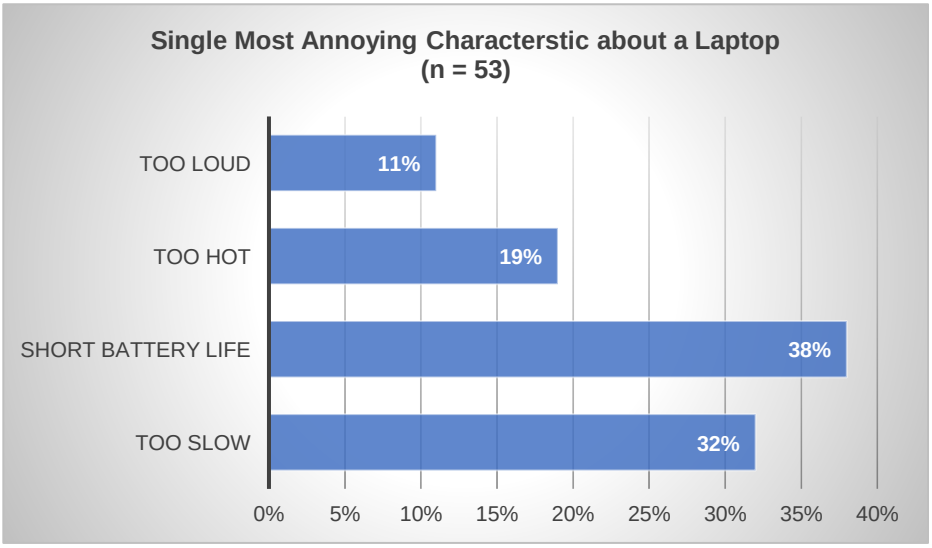


Figure 2. LinkedIn survey most annoying laptop trait.

So, what do these super scientific surveys tell us about laptops?

If we wanted to force these surveys to provide us with a laptop character trait hierarchy by which we could objectively grade competing laptops against one another, it would look like this:

1. Performance
2. Battery Life
3. Skin Temperature
4. Sound Output

BUT, these surveys also tell us something else: the opinions for what is most desirable and most annoying about a new laptop are still pretty diverse and there likely isn't a single answer that will make everyone happy with the product.

Given the latter point regarding the diversity of needs and wants from business-class laptop customers, we at Strategic Thermal Labs are very excited that Dell continues to invest into their User Selectable Thermal Tables (USTT) technology which allows for the end user to have some degree of control over how their system balances the tradeoffs between being fast, quiet, and cool. Characterizing a notebook for these extra operational preferences and tuning the CPU power state control and fan tables to provide unique system responses requires a nontrivial amount of additional engineering cycles during the development window (i.e. time and money). The infographic below helps provide some context about how the different USTT modes work on the Dell Latitude 7430 notebooks. For a more detailed explanation of this technology, check out our previous article on the Latitude 7420 here.

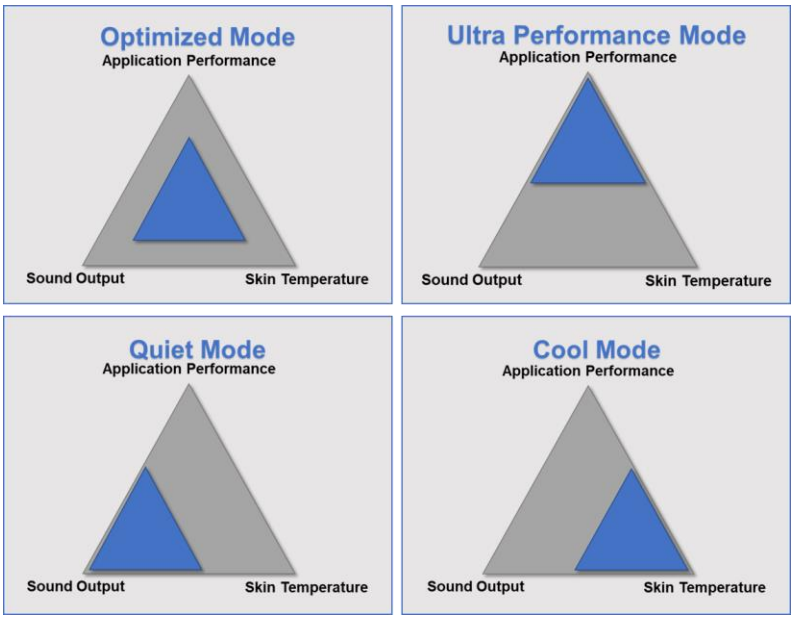


Figure 3. Infographic illustration of the various thermal feature priorities offered by the Dell Latitude's USTT.

I didn't think it was possible to beat a dead horse back into life, but you've actually done it. I'm hooked, tell me about these engineered laptops!

Today's article features a technical breakdown of the thermal performance on the three business class notebooks, each configured as similarly as their respective manufacturer's website will allow using Intel's latest 12th generation Core i7 P-series CPUs.

"P-Series" CPUs?

Intel's latest family of CPUs codenamed "Alder Lake" are available in a few different product categories each geared towards unique applications. The business notebooks included in this study can be purchased with both "P-series" and "U-series" CPUs where the "P-series" CPUs are oriented towards higher performance (and as we now know, higher heat) and the "U-series" CPUs are geared towards ultralight mobility (less heat). Customers might elect to choose P-series CPUs in their work laptop if they were occasionally using their notebook for tasks like photo rendering or video compilation where the extra performance cores in the P-series can noticeably improve performance.

Bonus: While not originally intended to be part of this business-class roundup, we were able to snag an identically configured Dell Latitude 7430 with the "U-series" CPU to provide a quick comparison of how the two CPUs perform the CPU-intensive task of photo rendering in Cinebench!

Table 1. System configuration details for the three business-class notebooks included in this study

	Dell Latitude 7430	Lenovo T14s Gen3	HP EliteBook 840 G9
Chassis Material	Aluminum	Magnesium	Aluminum
Processor	Intel i7-1270P	Intel i7-1270P	Intel i7-1260P
Memory	16GB DDR5 4800MHZ	16GB DDR5 4800MHZ	16GB DDR5 4800MHZ
Storage	512GB M.2 NVMe	512GB M.2 NVMe	512GB M.2 NVMe
Battery Capacity (Whr)	58	57	51.3
Display Type	14" Iris Xe 1920x1080	14" Iris Xe 1920x1200	14" UHD 1920x1200
BIOS Version	Dell 1.5.1	Lenovo N3CET30W (1.11)	HP U70 Ver. 01.02.04
Windows Power Mode	Balanced	Balanced	Balanced
Windows Version	Win 11 Pro v10.0.22000	Win 11 Pro v10.0.22000	Win 11 Pro v10.0.22000

Application Performance

Starting things off with the highest-ranking laptop characteristic in our infallible customer survey is application performance. In fact, there is a good chance that if you found this paper via search on Google, you were hoping that these charts were literally the only thing in the entire article. It takes one to know one.

As in previous studies, we are focusing on the following 3 productivity-oriented application benchmarks:

- PCMark 10:
  - Mixed-use office productivity including video conferencing, web browsing, app start-up, word processing, spreadsheets, photo editing, video editing, and professional graphics.
- SYSMark 25
  - Library of pre-recorded usage scenario scripts on actual copies of the most commonly used office software suites including Microsoft Office, Adobe Creative Suite, Google Chrome, and more.
- Cinebench R20
  - Timed photo rendering using the popular Cinema 4D image rendering engine.

Each of these benchmark suites is attempting to associate a numerical score with how fast your laptop performs the jobs that you ask of the system dozens, if not hundreds, of times per day. Find a more thorough explanation of how these benchmarks work here.

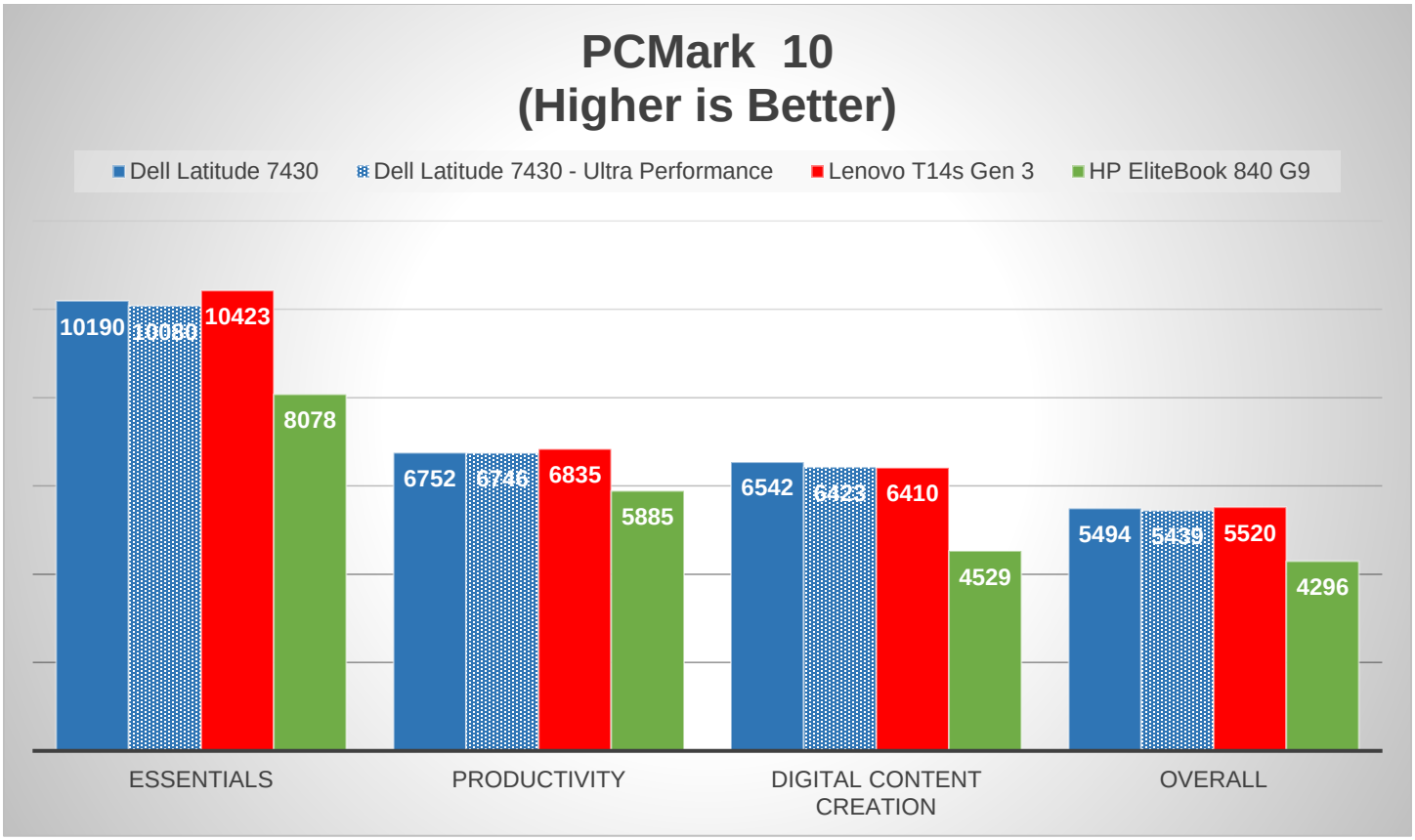


Figure 4. PCMark 10 Office application performance benchmark.

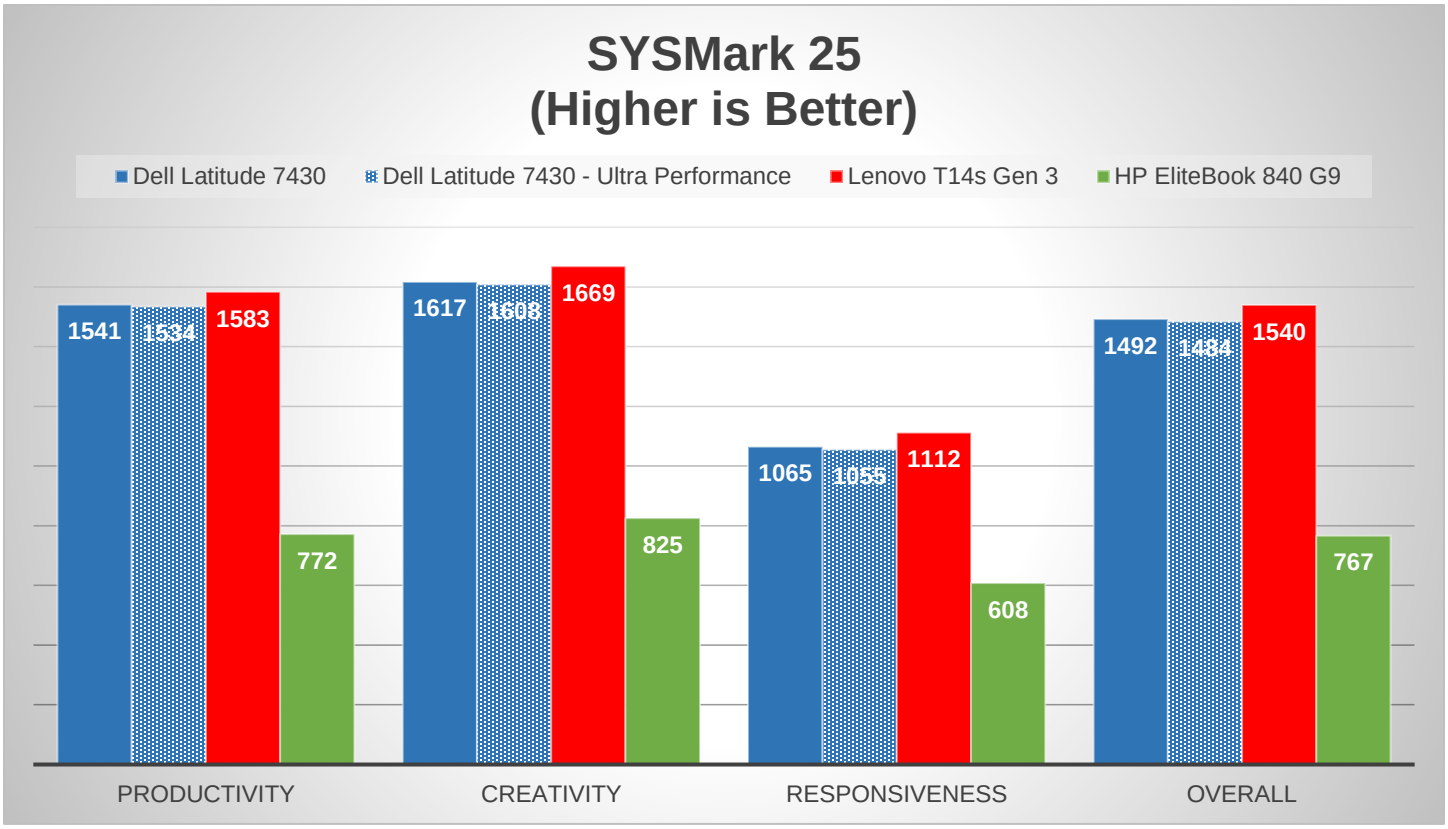


Figure 5. SYSMark 25 Office application performance benchmark.

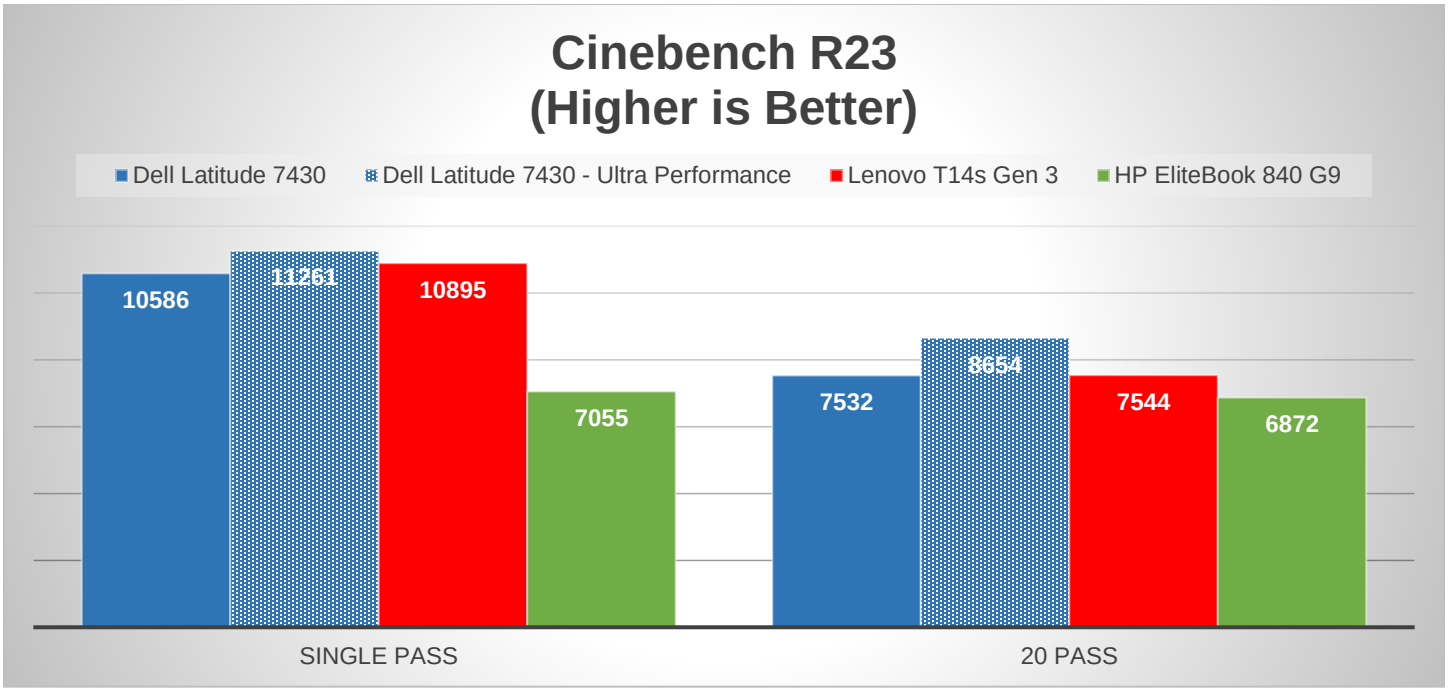


Figure 6. Cinebench R23 photo rendering performance benchmark.

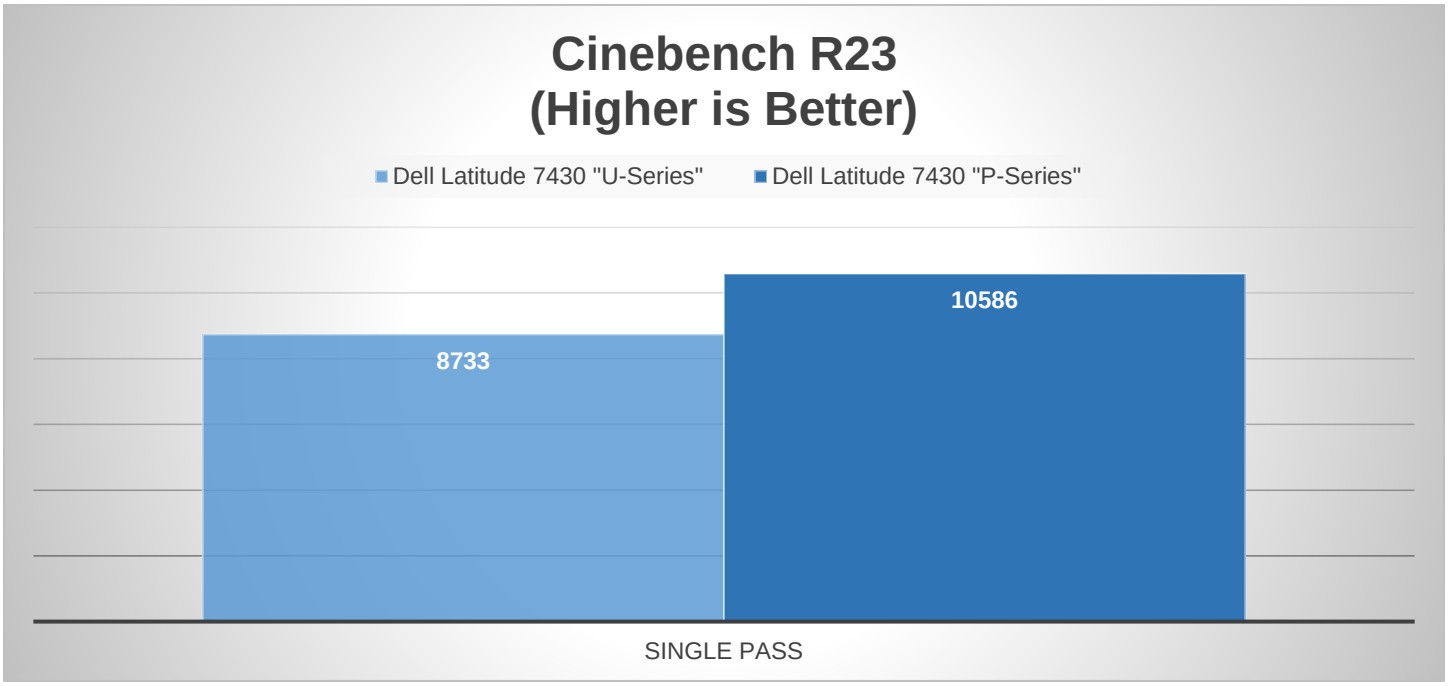


Figure 7. Single Pass comparison of the U-series vs P-series CPUs on the Latitude 7430

The application performance results provide us with a few quick takeaway messages:

- The Lenovo T14s edges out the Dell Latitude 7430 in both PCMark and SYSMark benchmarks but Dell's Ultra Performance mode allows for them to claim victory in Cinebench.
- HP's EliteBook 840 G9 performed abysmally in every benchmark tested.
- P-series CPUs can provide as much as 20% performance improvement over U-Series on CPU-intensive tasks like photo or video rendering.

The first bullet point is not altogether surprising because the business-class notebook sector competition is fierce and seeing Tier 1 brands neck and neck in application performance is nothing new. The abnormally low performance of the HP EliteBook 840 G9, however, is quite surprising given observations from previous studies on this product series.

A closer look at the CPU performance logs helps solve the HP performance mystery quickly. The HP EliteBook appears to not utilize any of the opportunistic Turbo Mode power increases afforded by modern Intel Core CPUs. Figures 8 and 9 below show the CPU power consumption and frequency during a single rendering pass of Cinebench R23 benchmark. Both the Dell and the Lenovo systems support a large, temporary, power increase during extreme workloads that drastically improve performance in common software applications. The HP EliteBook is stuck at a maximum CPU power of 20 Watts, even during burst operations such as a single rendering pass or during Office application startup.

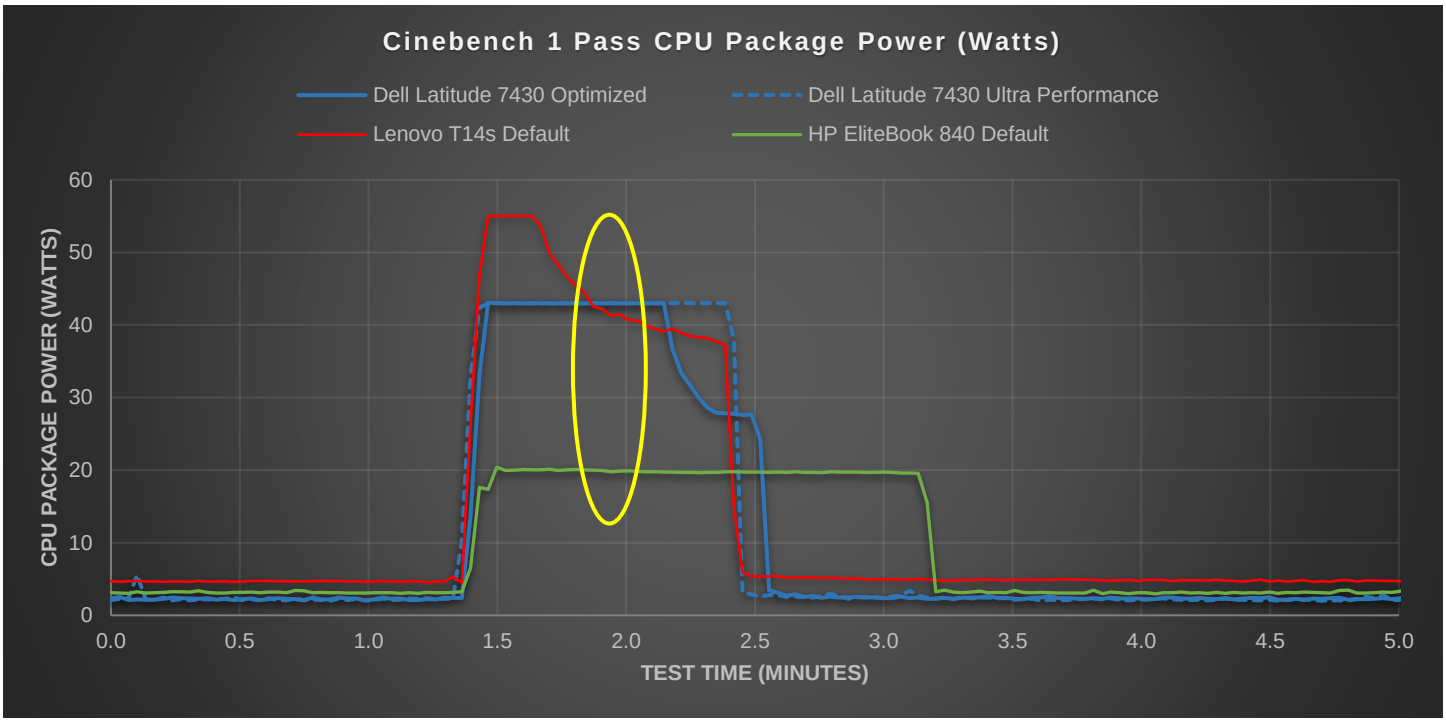


Figure 8. Comparison of CPU Package Power during a single run of Cinebench R23

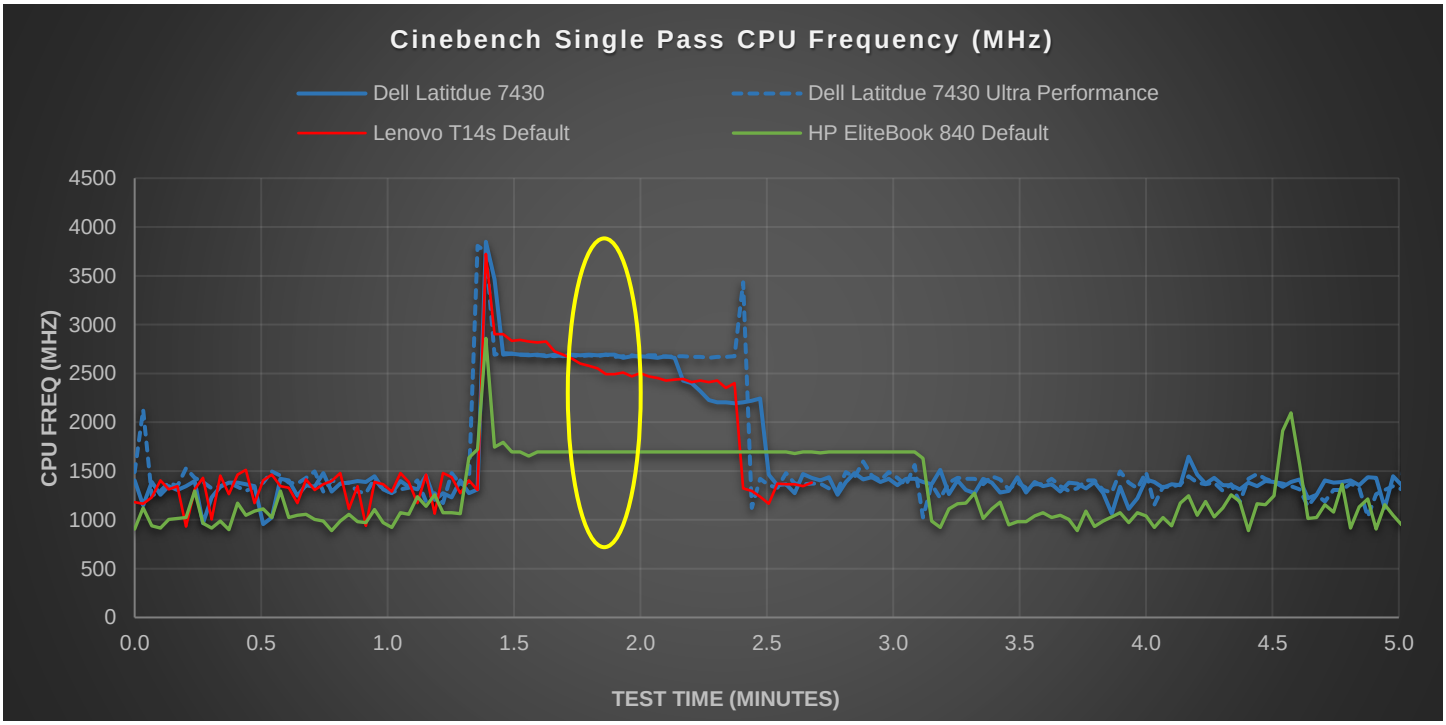


Figure 9. Comparison of CPU Frequency during a single run of Cinebench R23

Battery Performance

Battery life was the second highest-rated trait in our customer survey. Most end users and even some of the engineers who work on these platforms don't always understand the direct connections between battery life and system thermal performance. Of course, batteries are temperature-sensitive devices and if they get too hot during runtime they can suffer long-term health degradation which requires that engineers monitor and protect the battery temperature at all time. That said, battery temperature is rarely the limiting factor for notebook performance. The less obvious connection is that battery life is directly linked to the volume (size) of the battery itself and growing the size of the battery can often mean that the real estate allocated for the CPU fan and heatsink gets shrunk in a notebook that is always trying to be thinner and lighter than it was yesterday. Figure 10 below reveals exactly this relationship. The HP EliteBook has a substantially larger heatsink volume while also providing a substantially smaller battery.

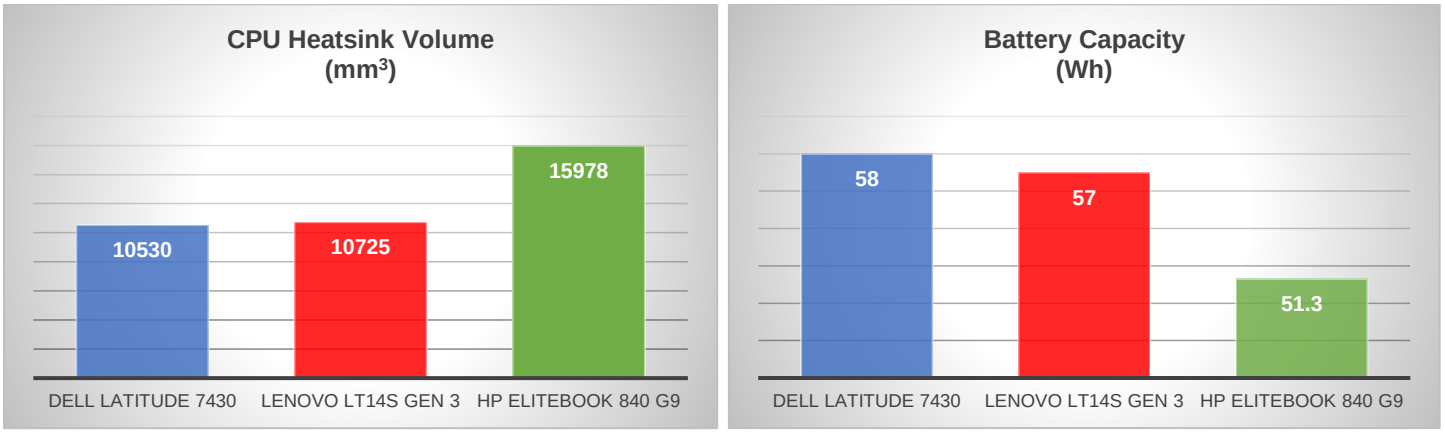


Figure 10a and 10b. CPU Heatsink Volume and Battery Capacity comparison between the three tested notebooks.

While battery *size* is one of the primary contributors to battery *life*, it is not the only relevant factor. Power consumption or conservation plays a significant role in determining how long your battery life will last as well. In the same way that laptop designers can control CPU power levels for performance, they can also tune them for extending battery life when your system is unplugged.

The PCMark 10 Modern Office battery test allows for the simultaneous capture of battery life and performance measurements when a laptop is unplugged. This test runs the same Office application scenarios as the standard performance benchmark in a continuous loop until the system's battery drops below 3% forcing a hibernation.

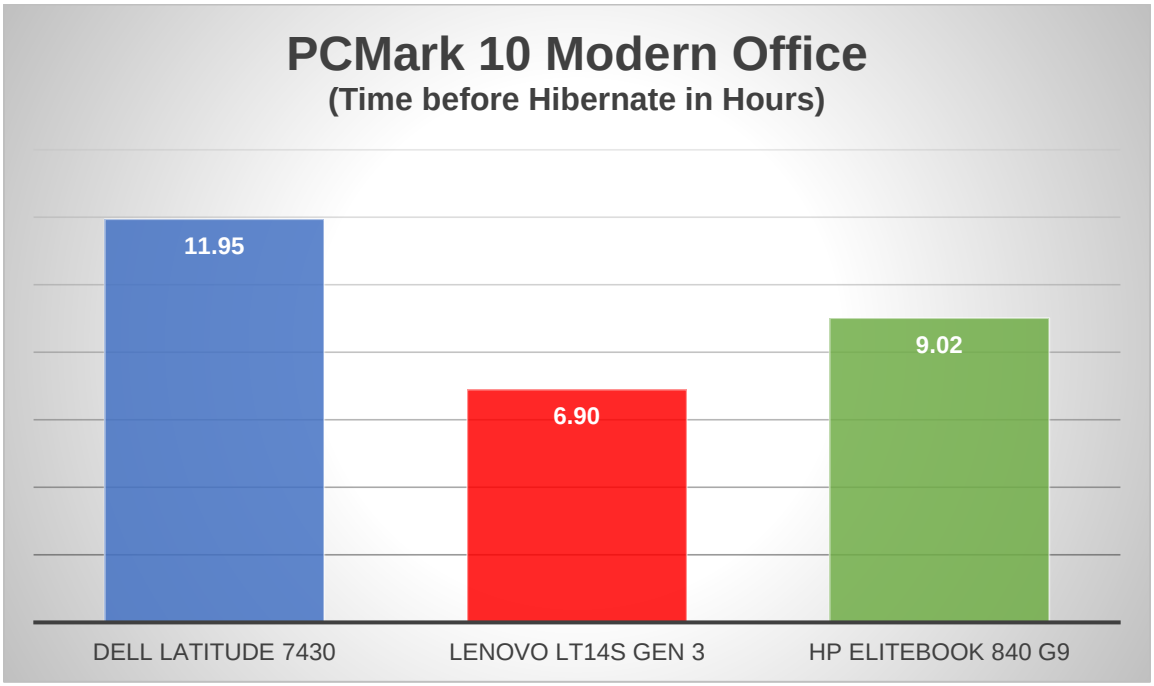


Figure 11. PCMark 10 Modern Office benchmark runtime – hours before hibernation from fully charged battery.

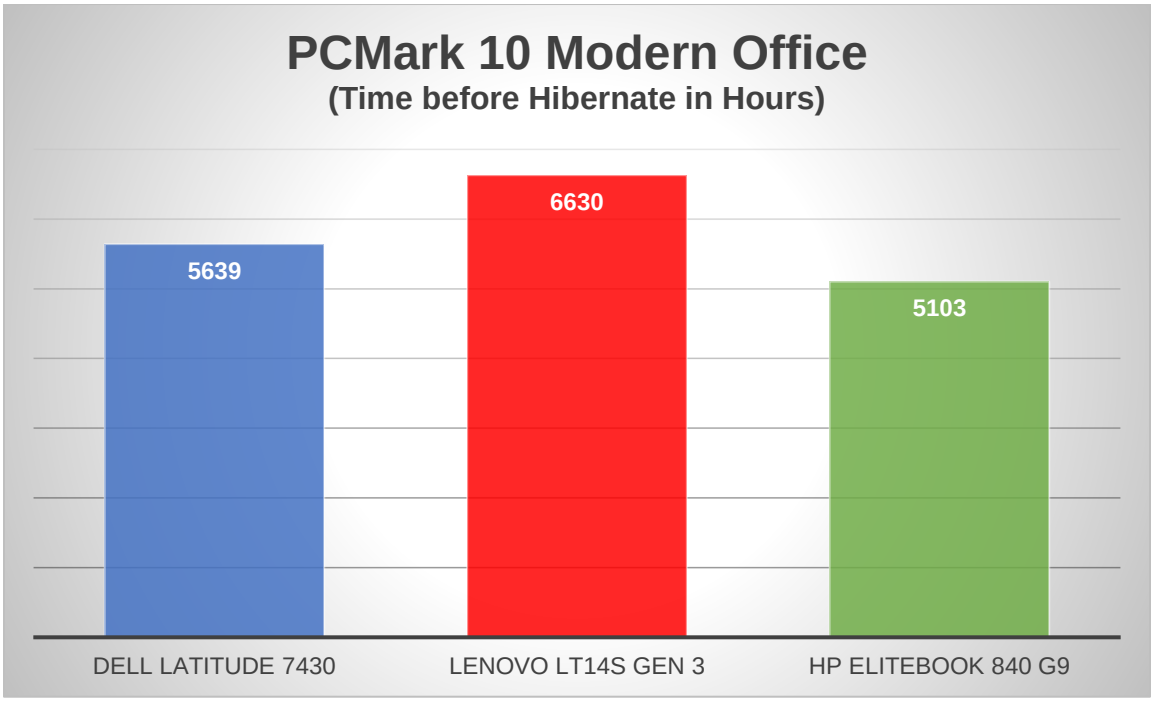


Figure 12. PCMark 10 Modern Office application performance while on battery power.

The Dell Latitude 7430 dominates the battery life test providing nearly 12 hours of runtime during the Modern Office battery stress. The Lenovo T14s, having nearly the same capacity battery, dies 5 hours sooner but does so while providing substantially higher performance. The HP EliteBook 840 manages to provide middle of the pack battery life even with the smallest battery by throttling back system performance to save power.

Skin Temperature

Next on the list of customer annoyance traits is skin temperature. It's one thing to mentally accept that your notebook is, in fact, a heater; it's another to be reminded of that fact every time you set it on your lap or rest your fingers on the keys during an invigorating game of online Scrabble. In order to test how hot the skin or surface of a notebook is getting, we first use a FLIR IR camera to identify the hottest locations on each face of the notebook. Then we attach thermocouples directly to those locations to monitor those temperatures in real time during each of our application benchmarks.

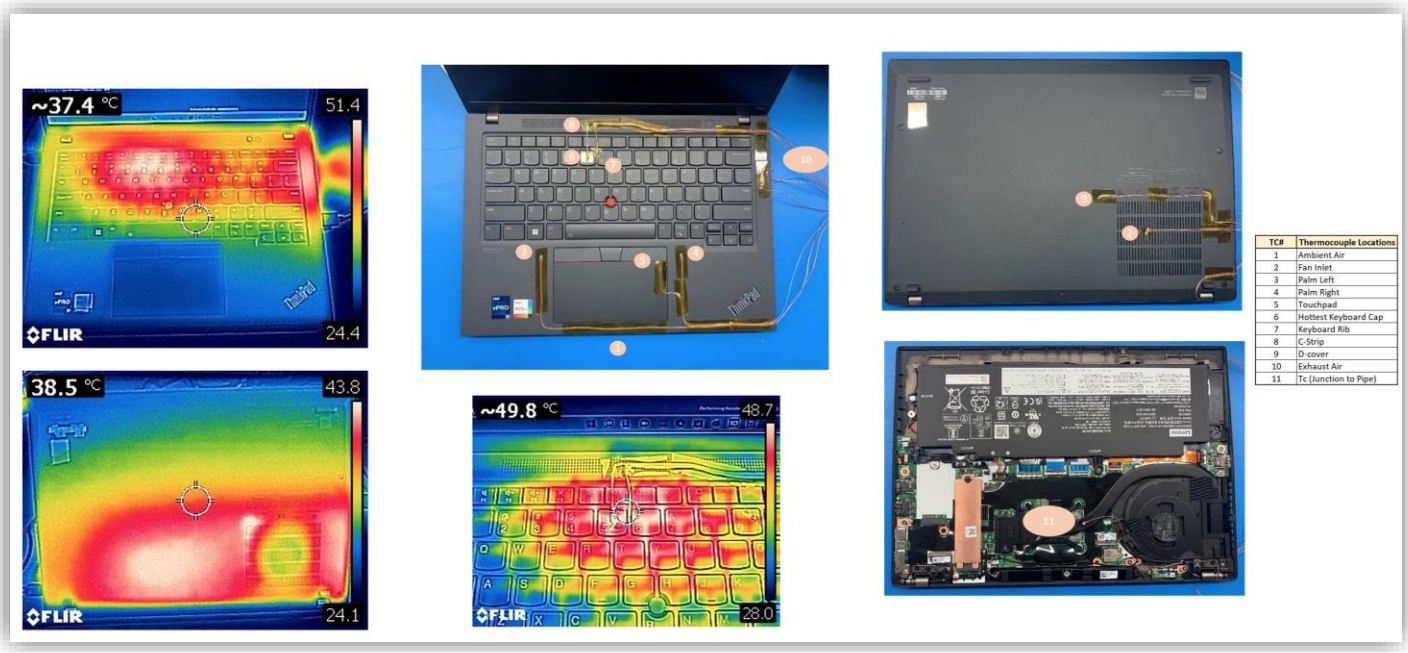


Figure 13. Skin temperature instrumentation shown for Lenovo T14s Gen 3.

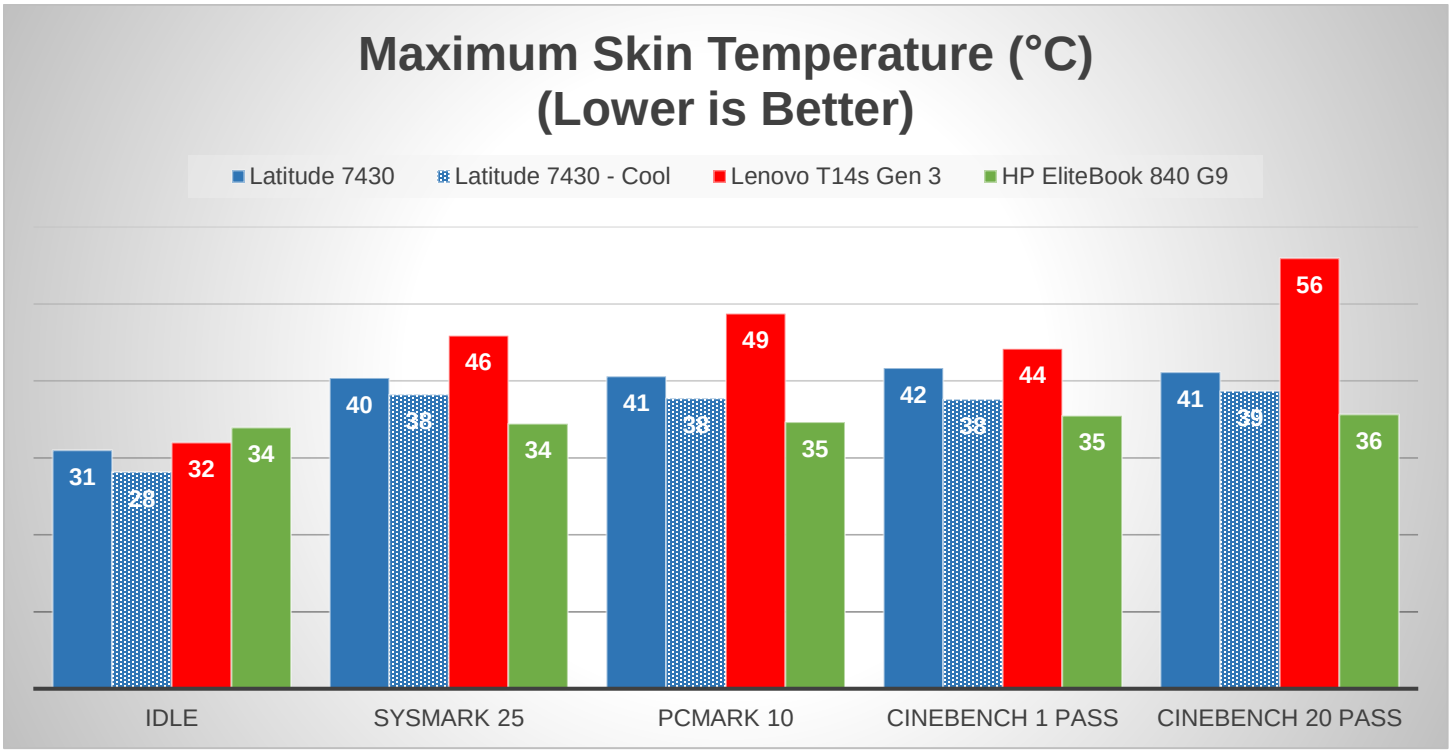


Figure 14. Maximum skin temperature on each of the tested notebooks while running all of the application benchmarks.

Sound Output

Though scoring lowest on our combined importance survey, acoustic testing is a critical function of laptop development. I am personally of the opinion that most people don't care about fan noise until their fan kicks ON but our survey says otherwise. At Strategic Thermal Labs, we capture system noise emissions in our pseudo-anechoic chamber for each of the application performance benchmarks.

Figure 15. STL pseudo-anechoic chamber testing the HP EliteBook 840 G9

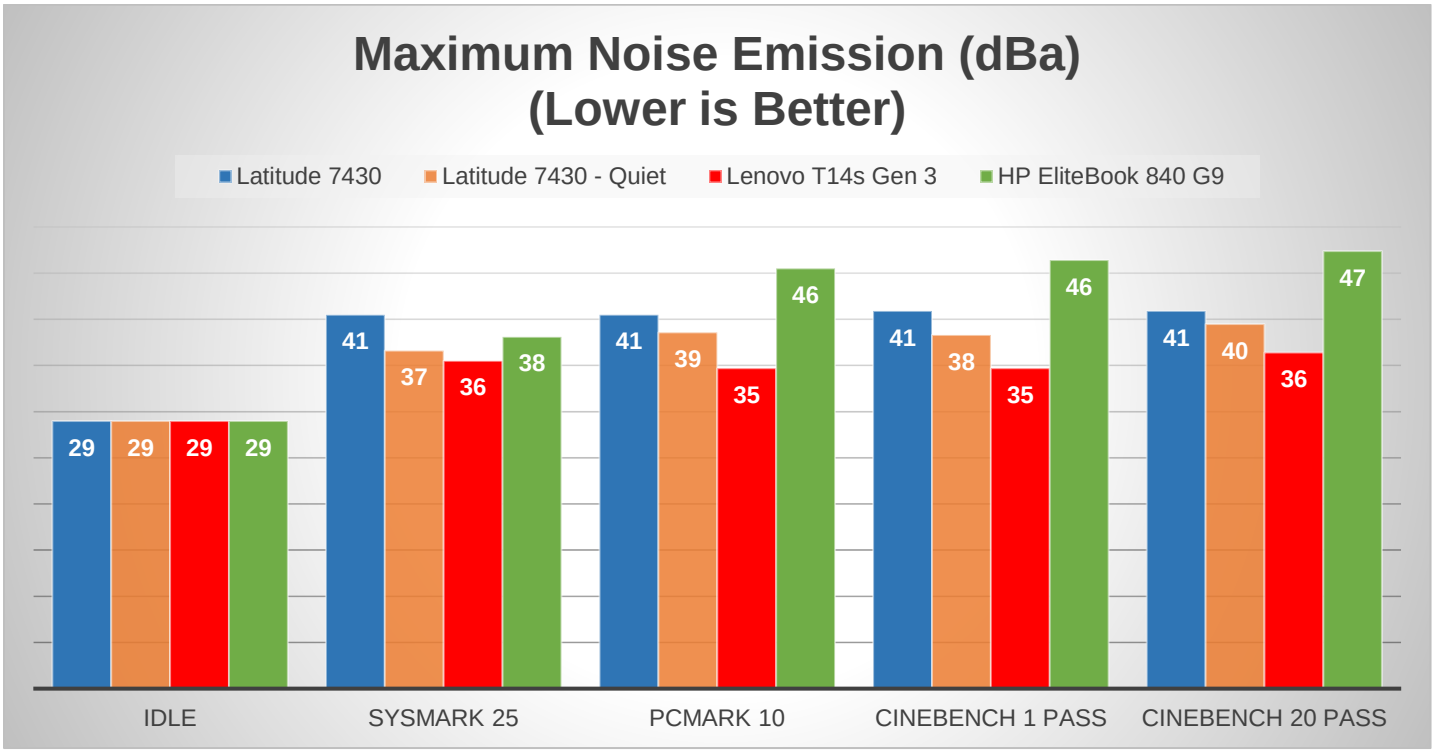


Figure 16. Maximum noise emission on each of the tested notebooks while running all of the application benchmarks.

Result Discussion

There you have it. All of the empirical data that anyone could possibly want to properly inform their next work laptop purchase along with what was hopefully enough humor to keep you reading until the end. In case you did not keep reading until the end and jumped straight to the end, here is what you need to know:

- The Dell Latitude 7430 and Lenovo T14s Gen 3 are both highly competitive in application performance with the Latitude winning photo rendering with Cinebench and the T14s winning general Office applications.
- The Lenovo notebook appears to have gone all-in on application performance at the expense of skin temperature with some tests showing a finger-throbbing, pant-warming, 56°C max surface temperature!
- The HP EliteBook G9 performed very poorly in all application benchmarks due to a restricted upper power limit on the CPU that prevented opportunistic Turbo Mode in most tests.
- Dell Latitude wins battery life by a considerable margin besting the HP EliteBook by 3 hours and the Lenovo T14s by 5 hours in sustained Office application support while unplugged.
- The HP EliteBook offers the coolest skin temperatures in the test group but at the expense of low application performance and the loudest fan noise in the group by a fairly large margin coming in at 47 dBa during the extended Cinebench test.
- Dell Latitude 7430 continues to build upon the previous generation's USTT allowing users to shift their preferences in any of the three directions. Cool mode makes the skins cooler to the touch; Quiet mode makes the system fans spin slower; and Ultra Performance opens up extra rendering performance for those who need to get the job done faster.

If you are looking for the best all-around system for work, the Dell Latitude 7430 is the most consistently high performer across all 4 Thermal Performance Indicators. If you are shopping for absolute maximum performance in Office applications and are not put off by excessive skin temperatures, the Lenovo T14s Gen 3 is the right choice. Unfortunately for HP, the EliteBook 840 G9, as tested, does not offer any quantifiable reasons to choose it over its competitors.

Thanks for reading and stay tuned for the second installment in this series where we bakeoff the Dell Latitude 9430, HP EliteBook 1040 G9, and the Lenovo X1 G10!

Information about this Paper and its Author

Author

Austin M. Shelnutt, P.E., President at Strategic Thermal Labs, LLC

Inquiries

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