Dynamic Adaptation of Runtime Systems Based on Energy Consumption

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Energy crisis

Greenhouse gas emissions of ICT projected to be 14% of total in 2040 [1]

We should take steps to decrease energy consumption of software!

However

- Measuring energy consumption is hard
  - Cannot isolate a single process
- Decreasing energy consumption is even harder!
  - No control over environment and background

[1] Lotfi Belkhir, Ahmed Elmeligi, Assessing ICT global emissions footprint: Trends to 2040 & recommendations

Adapt to runtime changes

Cannot isolate energy consumption of a single process

- Consider system's energy consumption as a whole

What users can measure

- CPU total energy consumption (RAPL)

What we can control

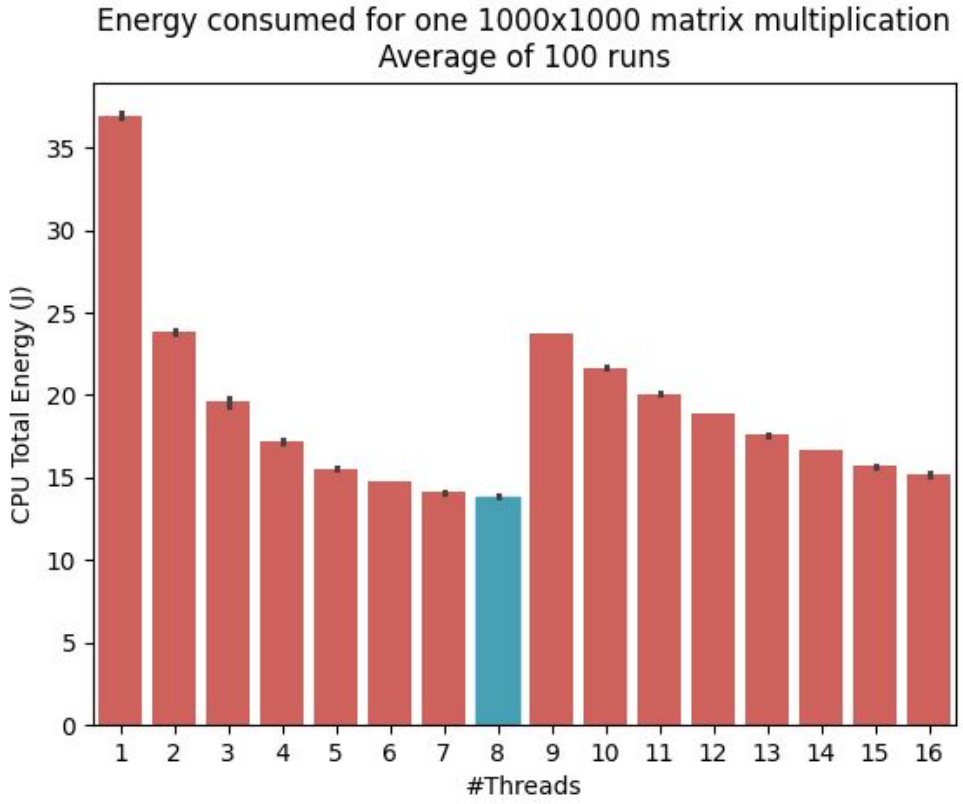
- Thread-count
- Perfect for HPC
- Interested in the variation between measurements

Why is a static choice not good enough?

Energy per thread-count

Intel Xeon E-2378
- 8 homogeneous cores
- 16 threads

What about
- Other running programs
- Different hardware
- Performance/efficiency cores
- Power profile
- Architecture
- Throttling
- Pinning
- etc.



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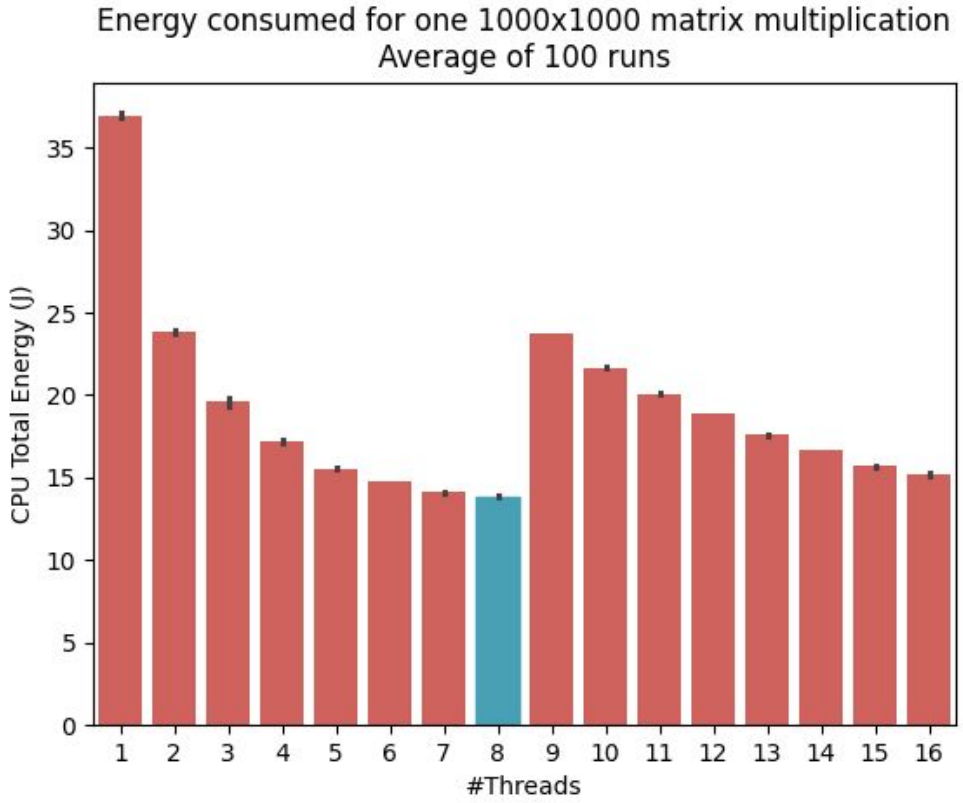

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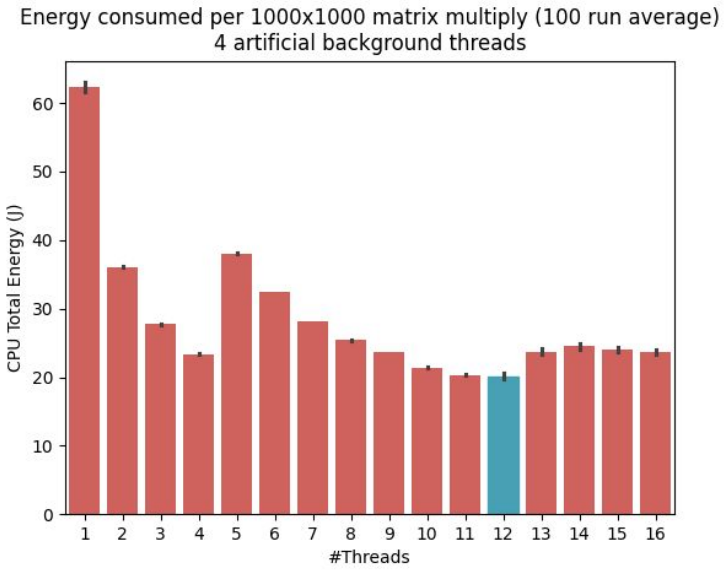
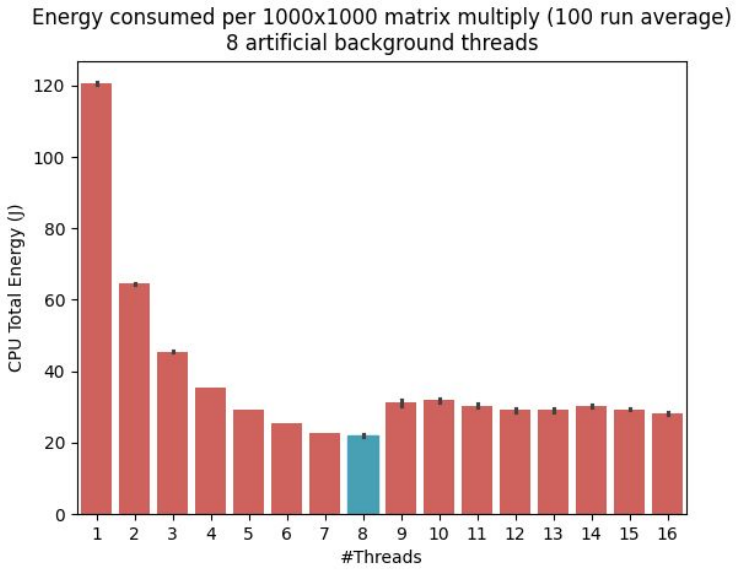
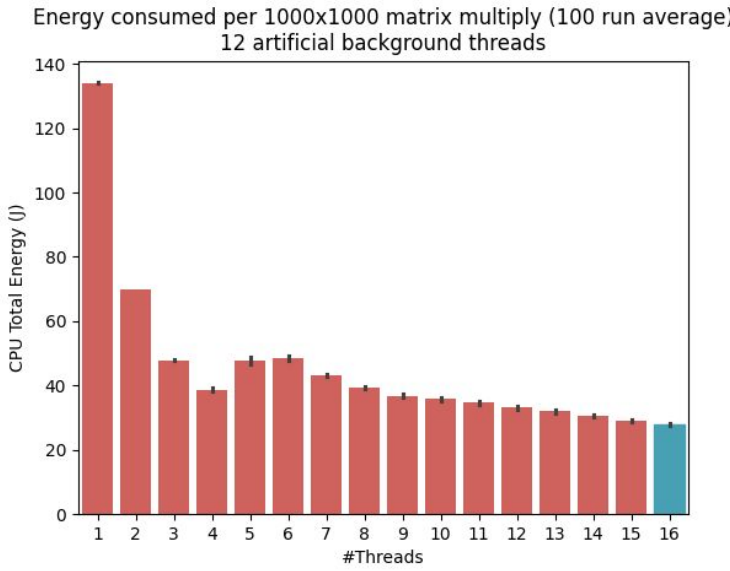
Energy per thread-count

How does optimum change if we add a background load?







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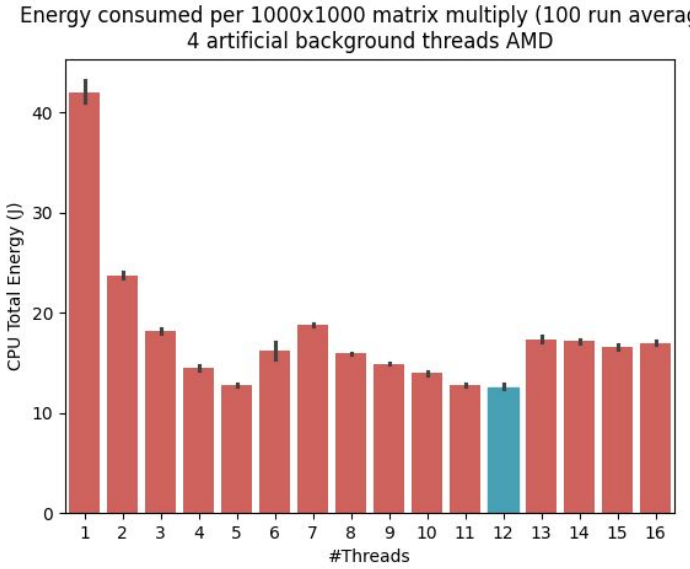
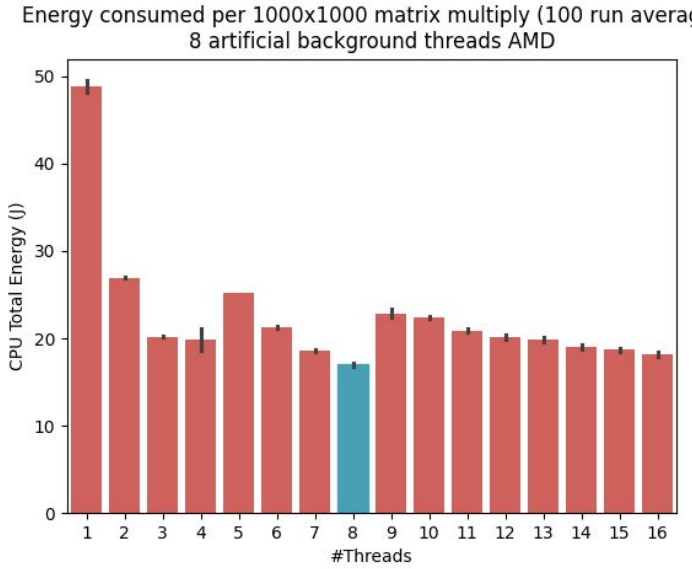
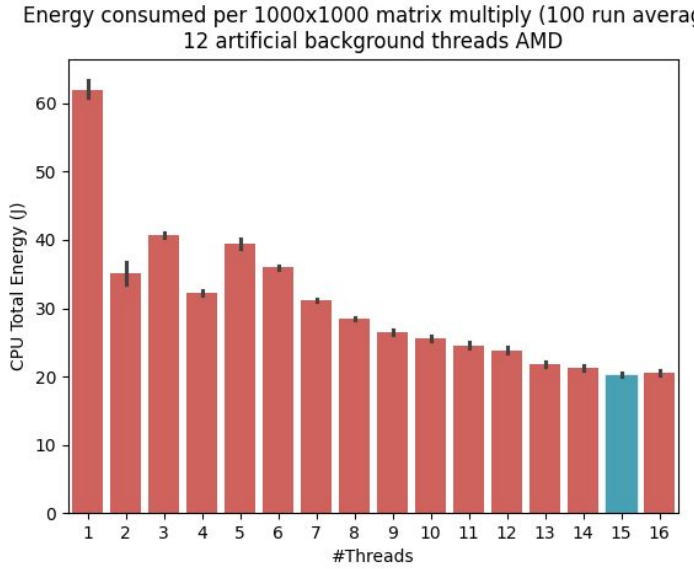
Energy per thread-count

AMD Ryzen 7 5800H

- 8 homogeneous cores
- 16 threads







Dynamic Adaptation

Shows why we need dynamic adaptation

Note that

- System changes relatively slow compared to measuring time
  - Other relatively long-running programs
  - Otherwise we consider it as noise
- Require a repeated parallel application
  - Matmul
  - Stencils
  - N-body
  - etc.

How?

Program provides energy statistics of the parallel iteration

- With-loop in the case of SaC
- Energy measured with RAPL

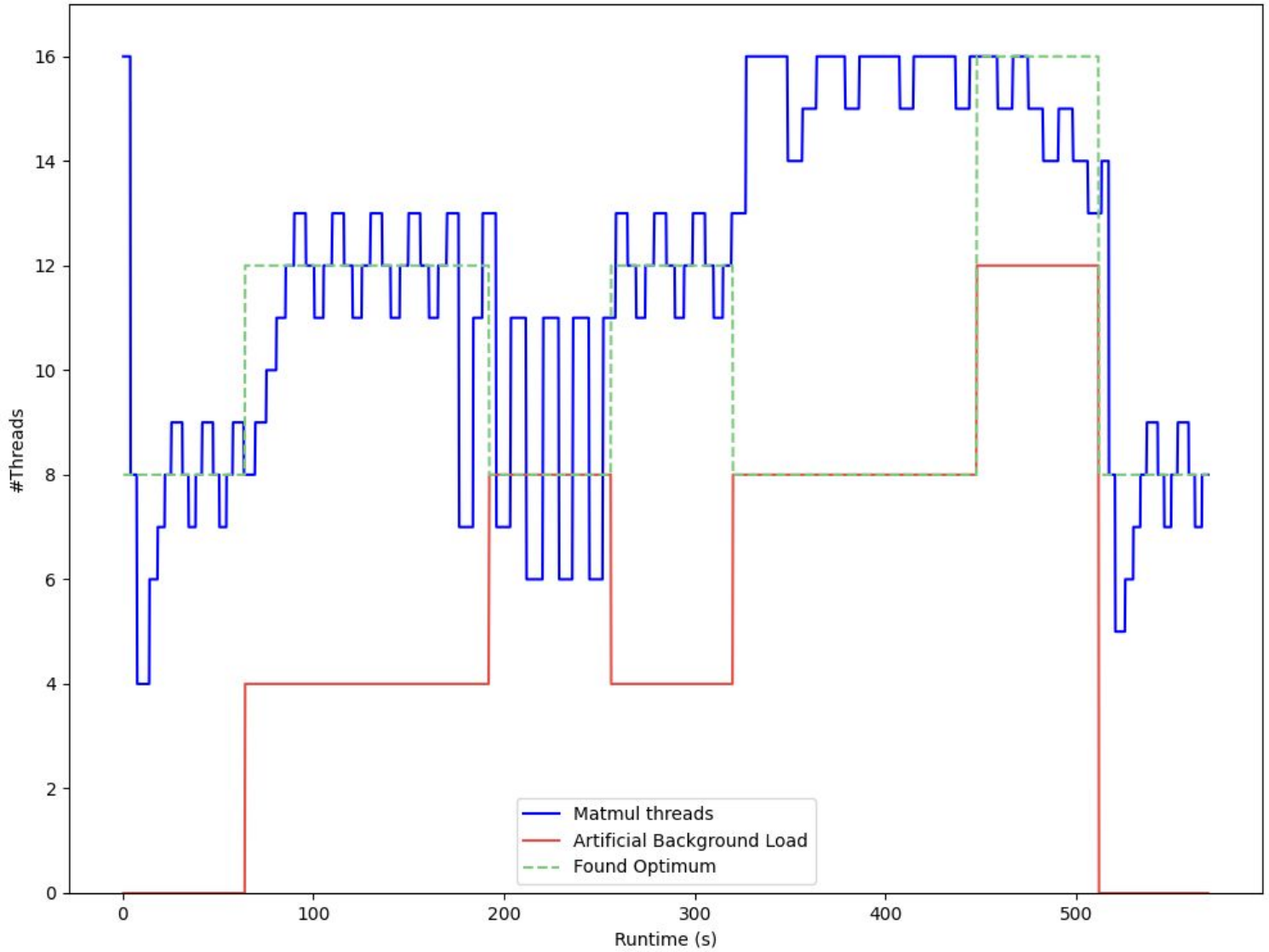
Framework updates optimal thread-count every 20 iterations

- Get lowest energy consumption those measurements
  - Frequency distribution
- Compare against
  - Previous energy consumption
  - Currently known best energy consumption
- Accordingly adjust step direction and step size

Changing background load

Results

Able to adapt to runtime changes



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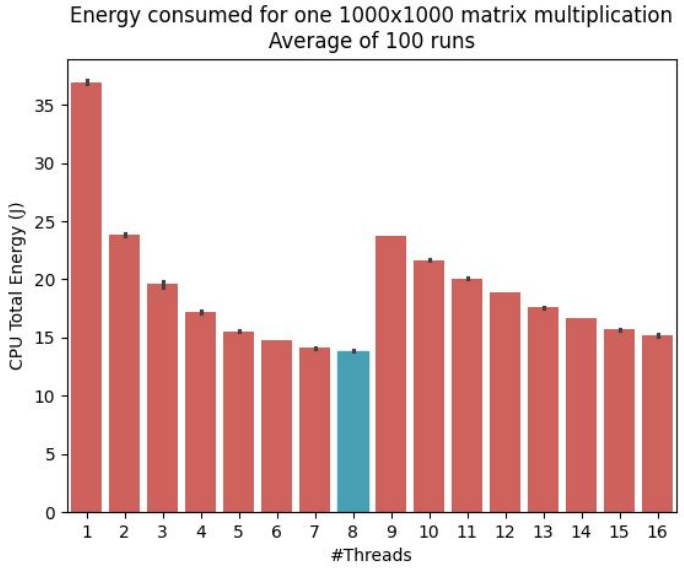

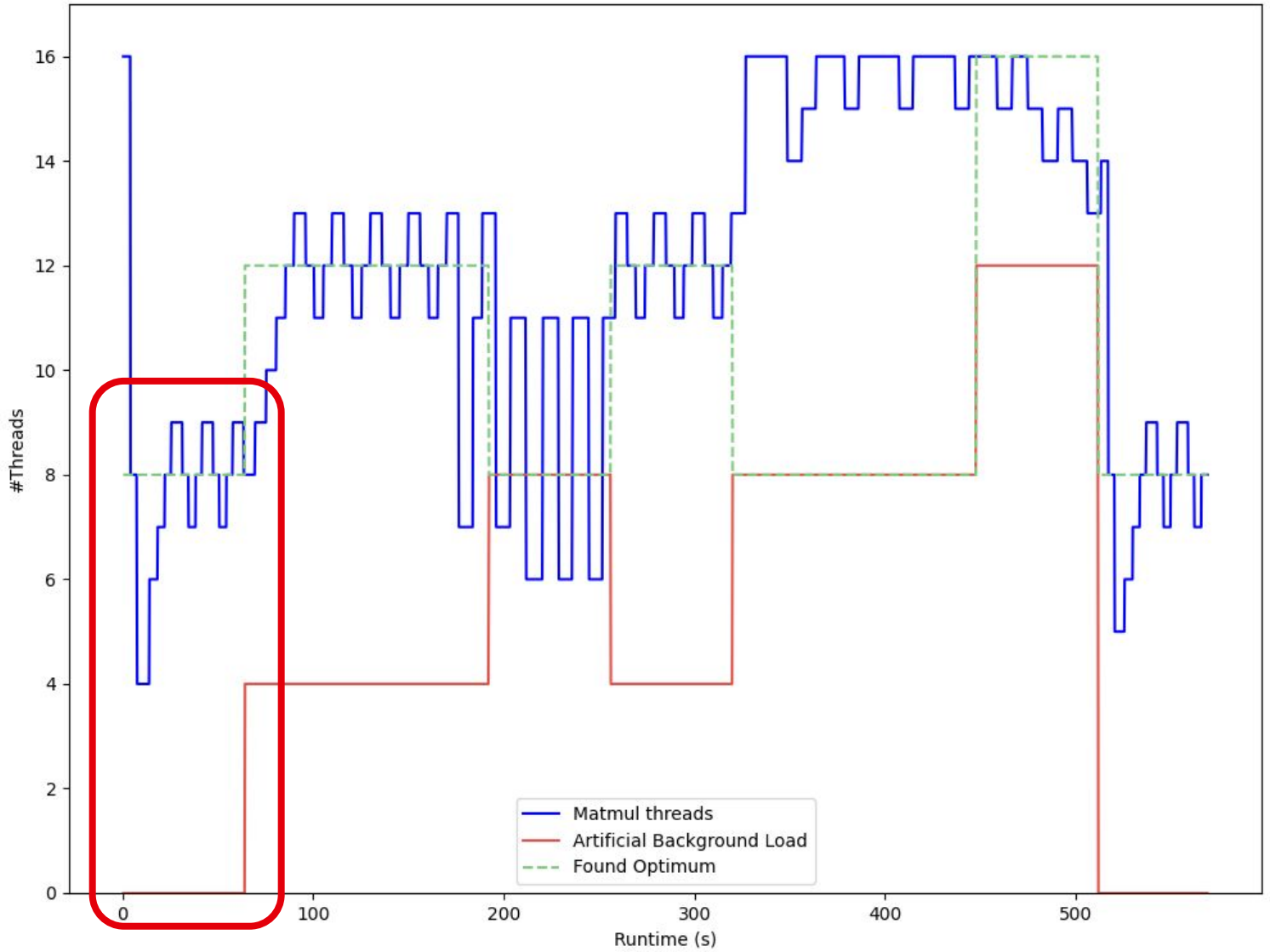

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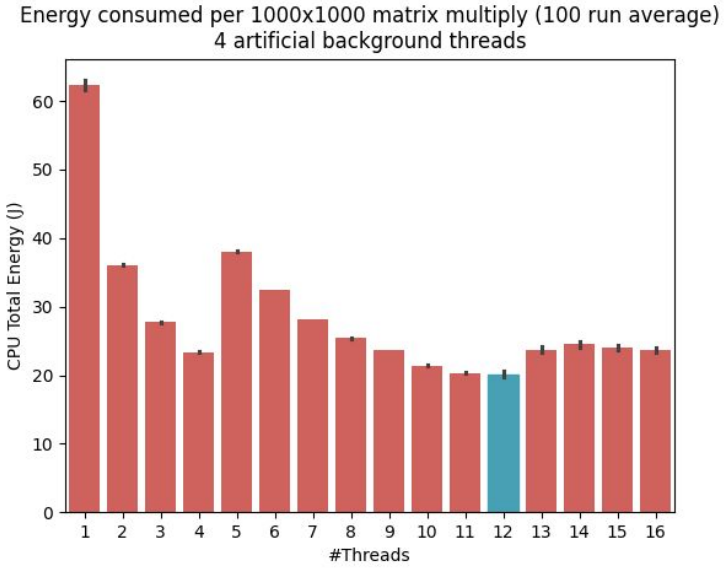
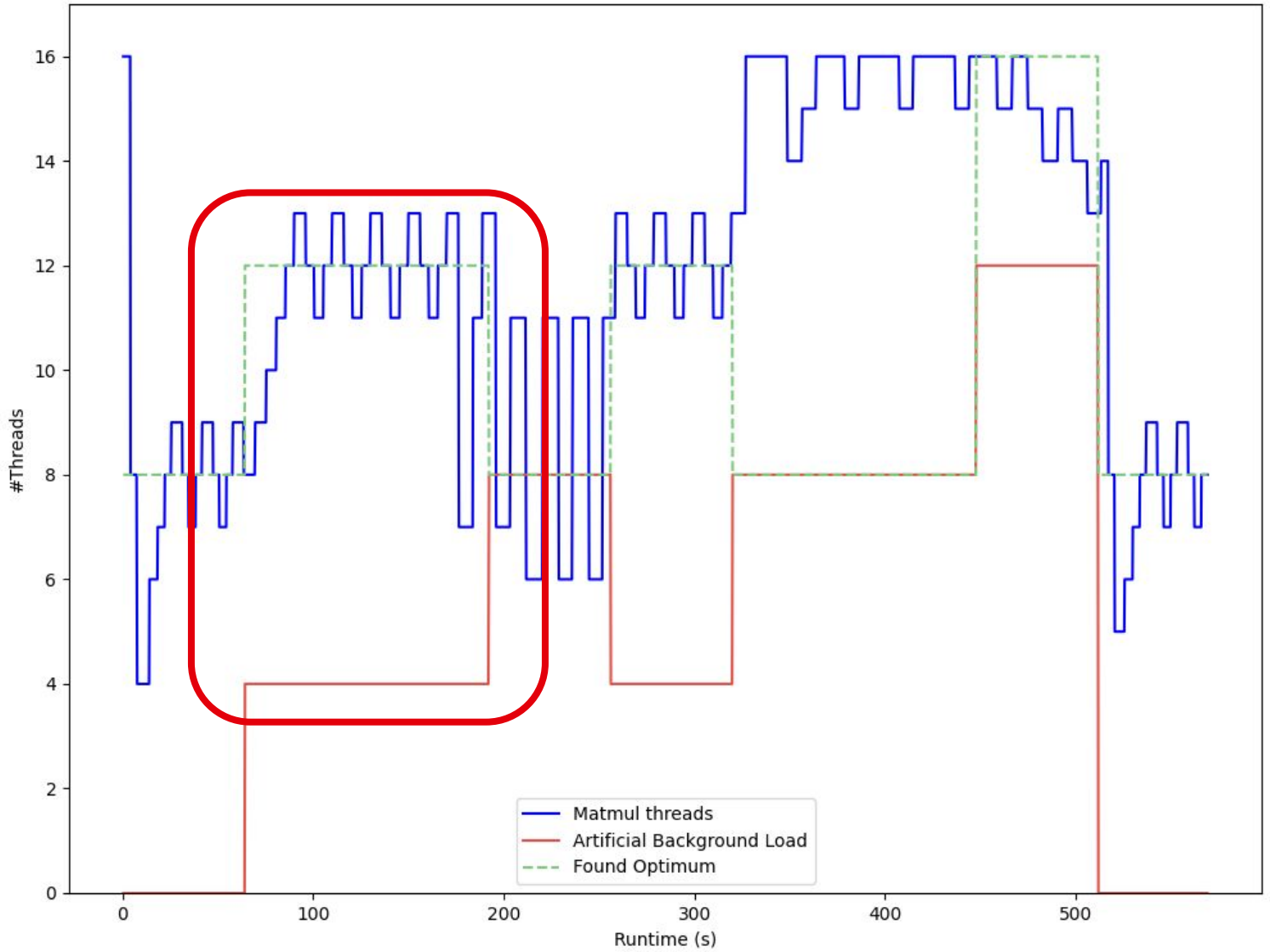
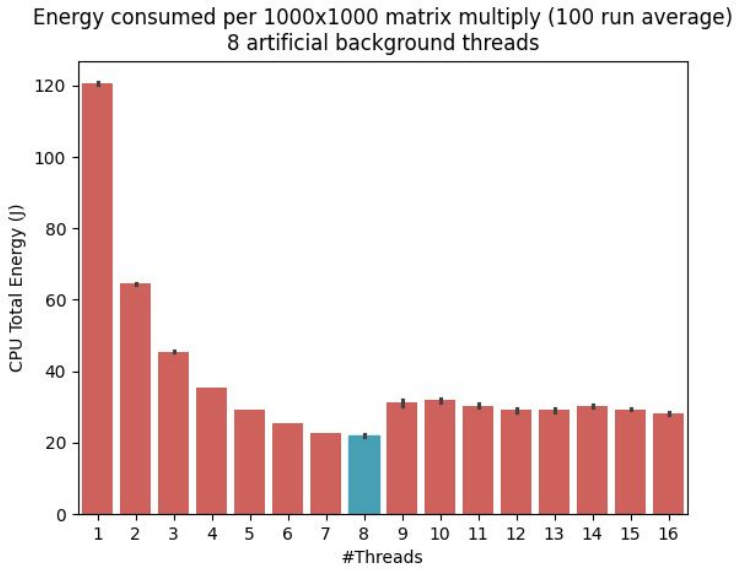


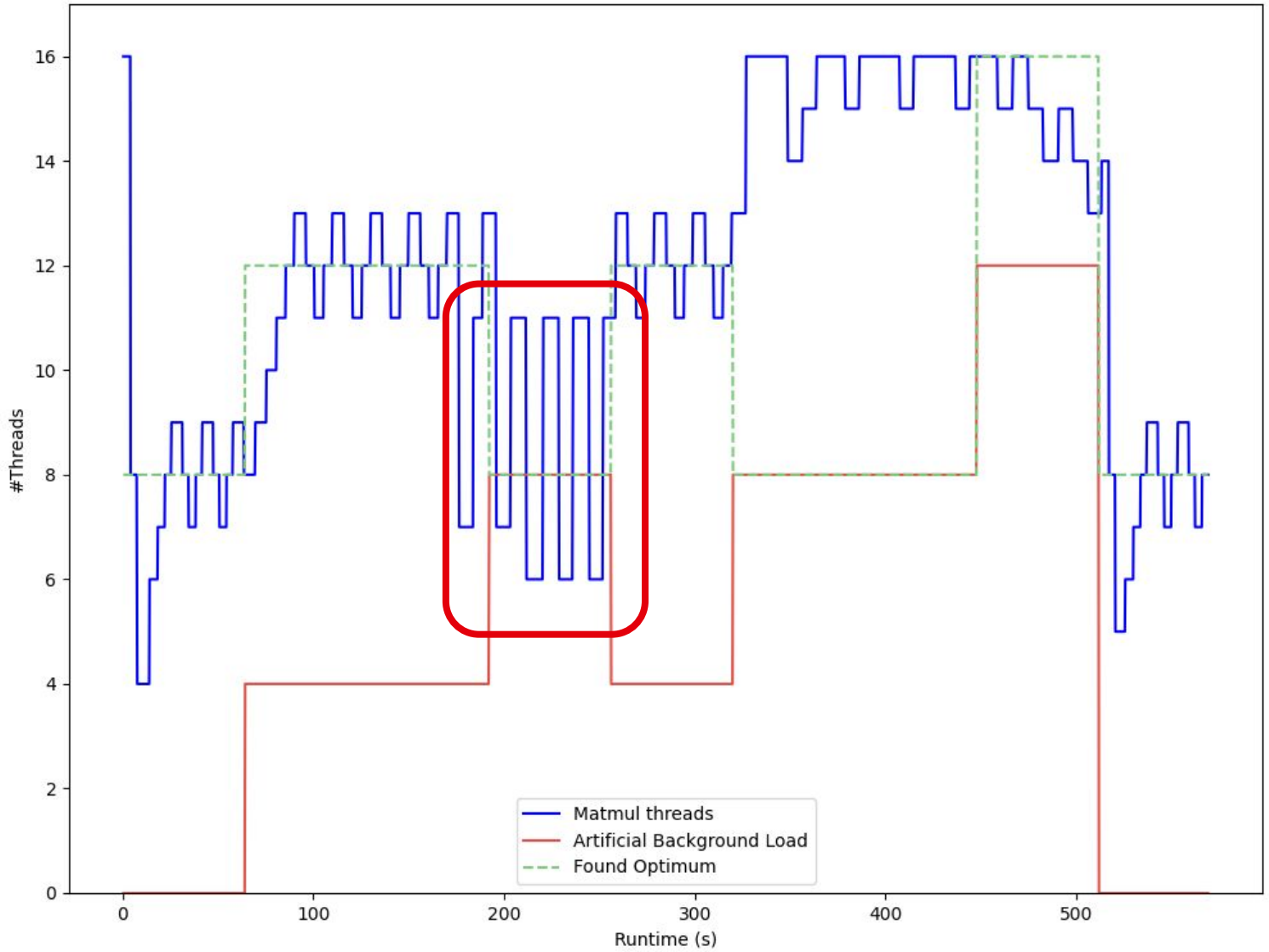


Changing background load

Results

We keep jumping too far past the optimum





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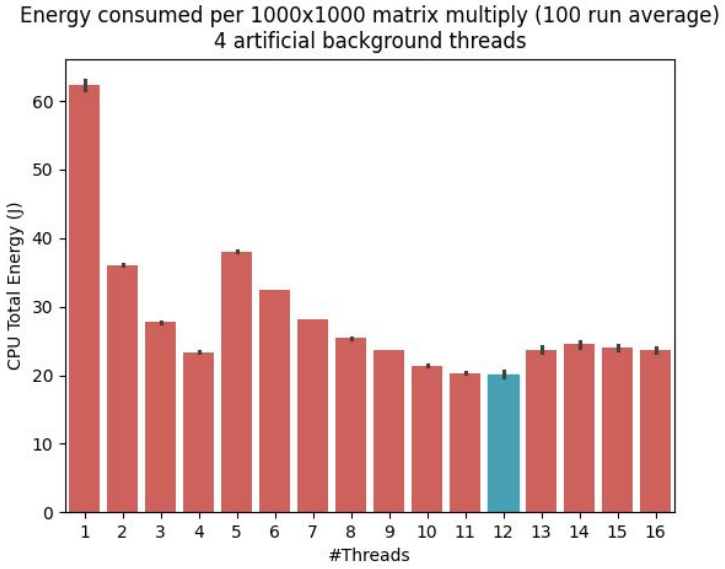

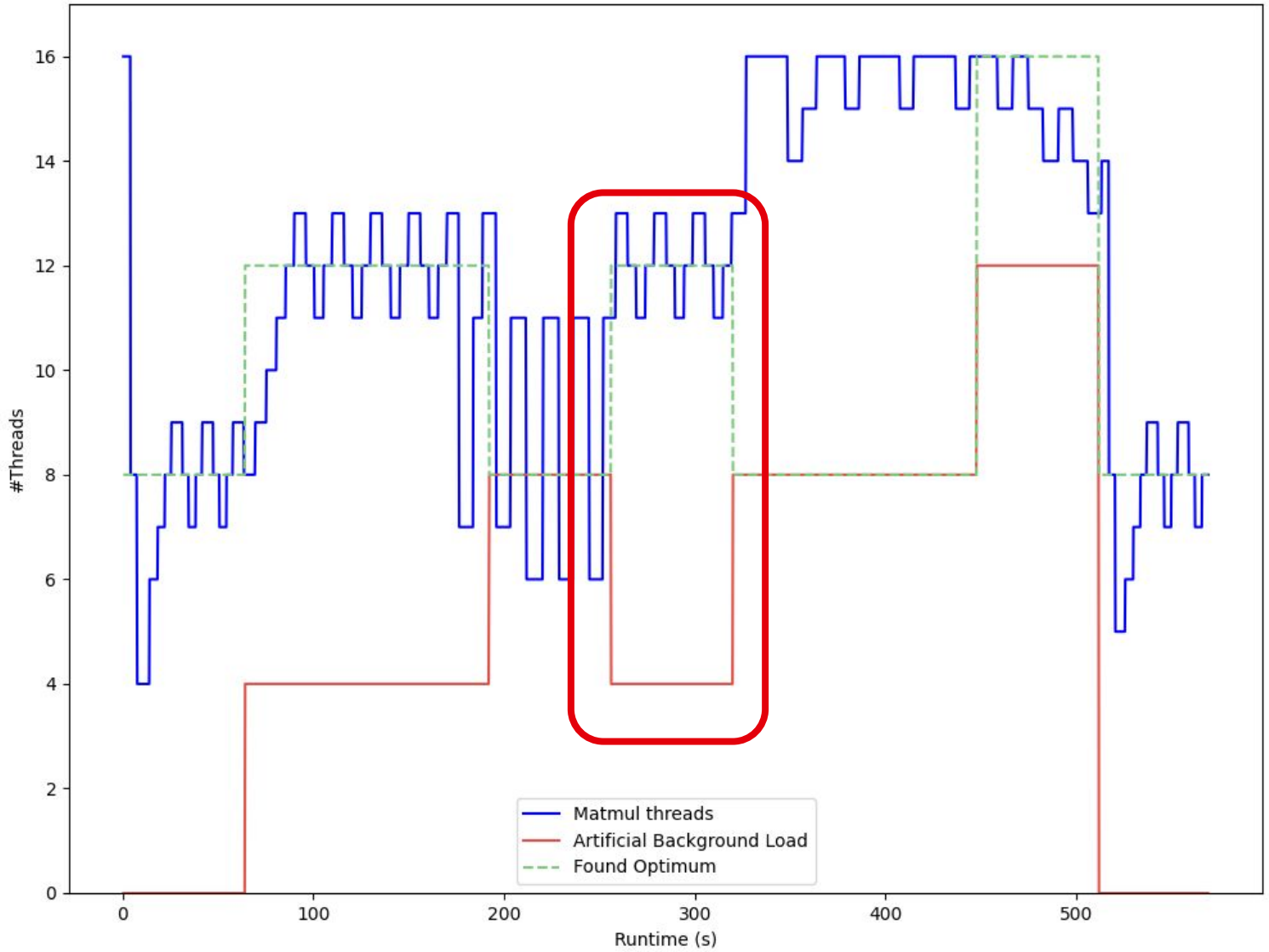

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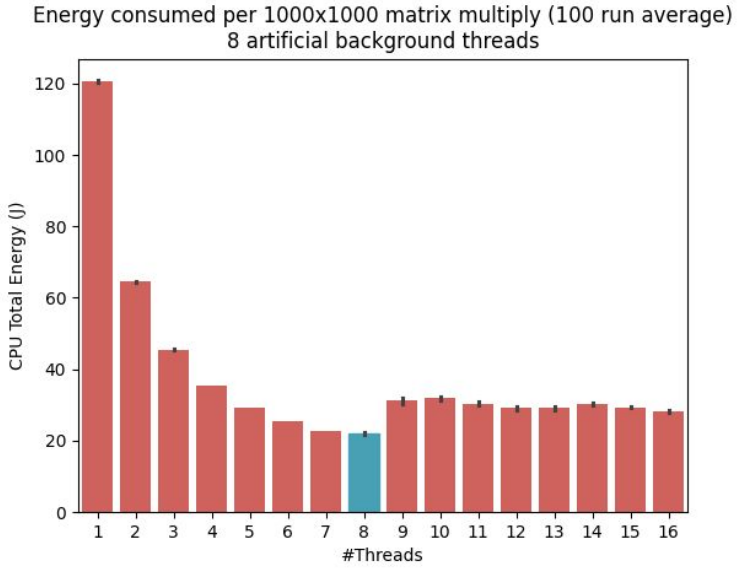
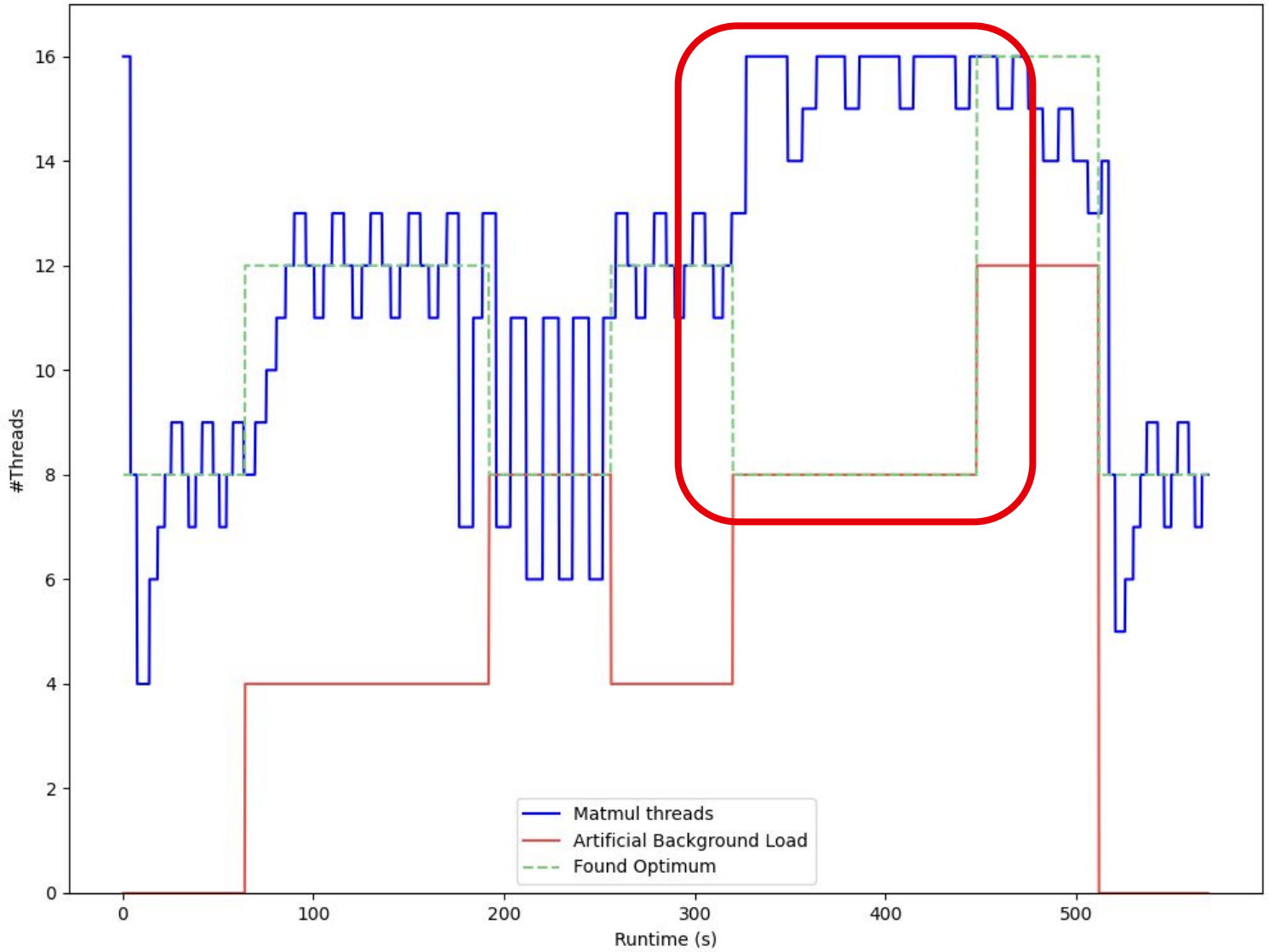
Results

Local optimum





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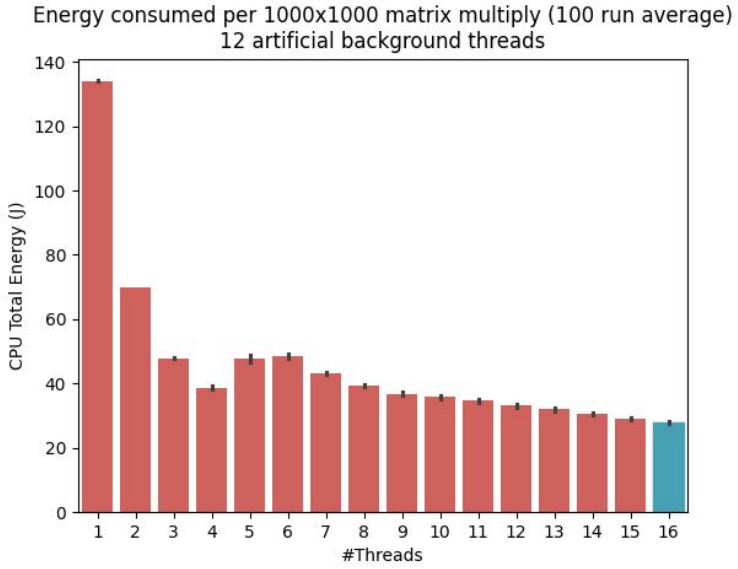

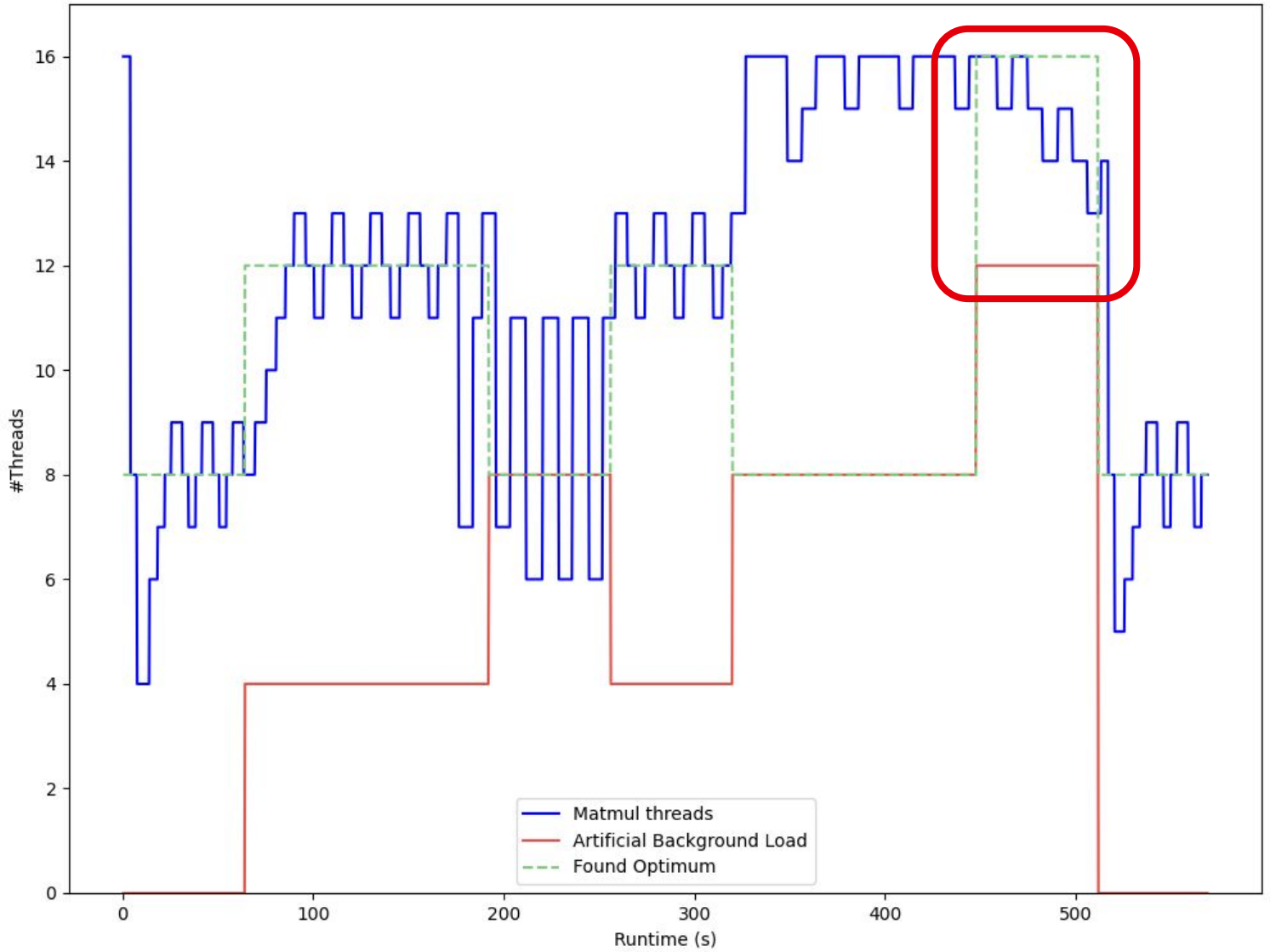

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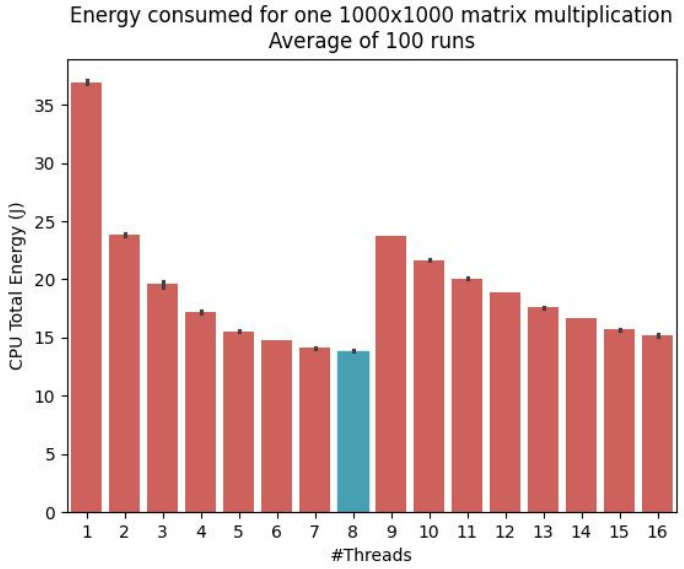
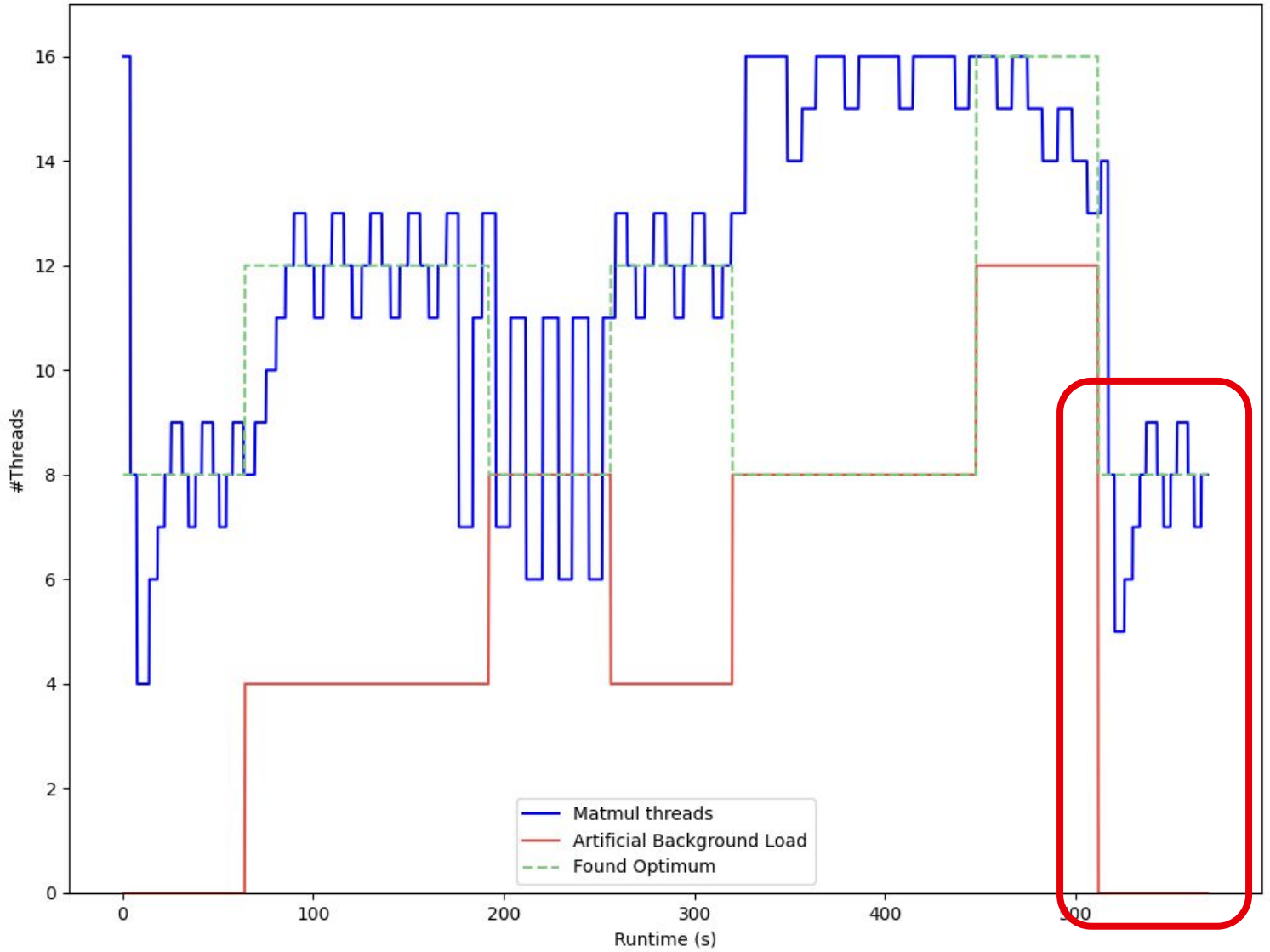
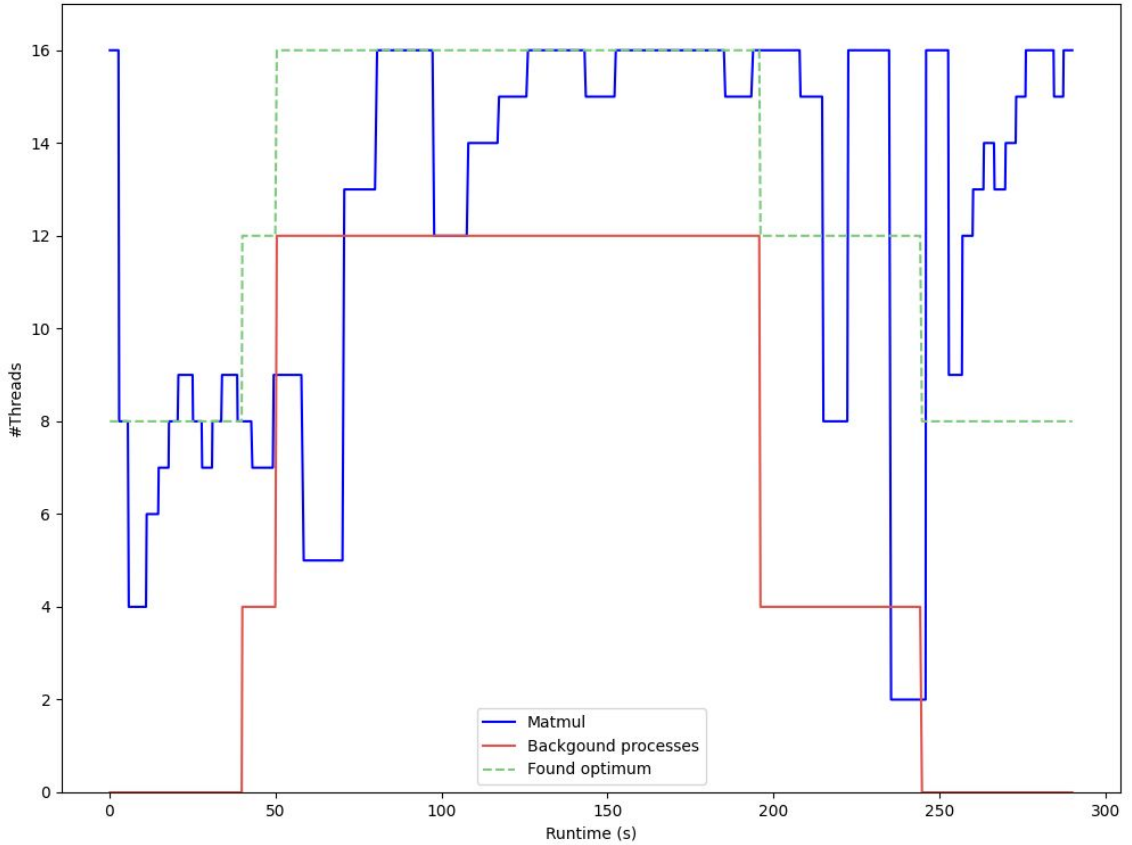




Results

Energy needed for 1300 matrix multiplications

- Changing background load
- Background load no longer artificial

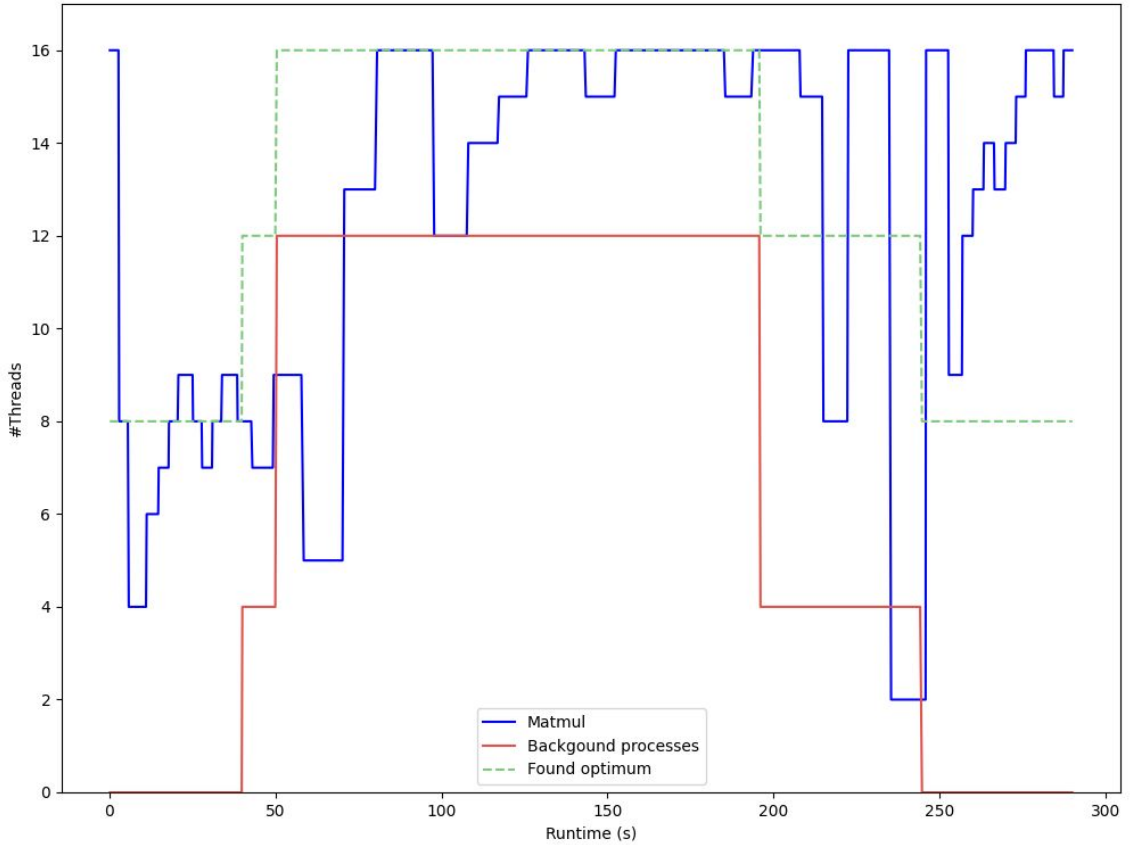


	Dynamic	Static 8 Threads	Static 12 Threads	Static 16 Threads
Energy	12.8kJ	13.6kJ	14.0kJ	14.8kJ
Runtime	290s	302s	303s	322s

Results

Energy needed for 1300 matrix multiplications

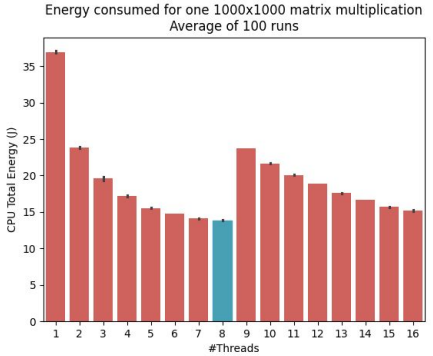
- Changing background load
- Background load no longer artificial

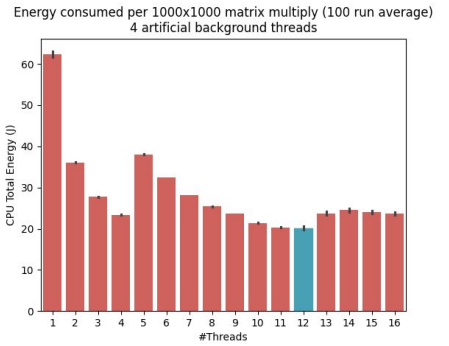


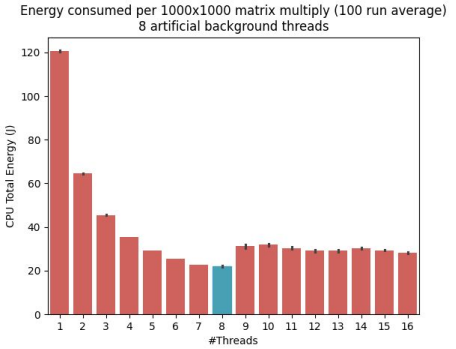
	Dynamic	Static 8 Threads	Static 12 Threads	Static 16 Threads
Energy		-6.3%	-9.4%	-15.6%
Runtime		-4.1%	-4.5%	-11.0%

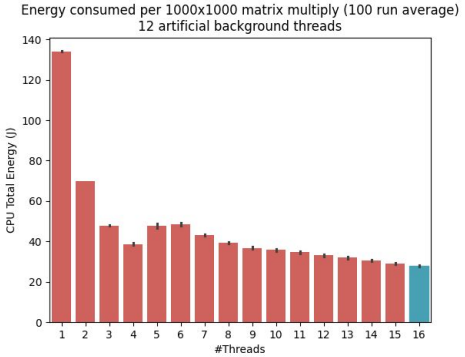
How much do we lose for being dynamic?

Overhead









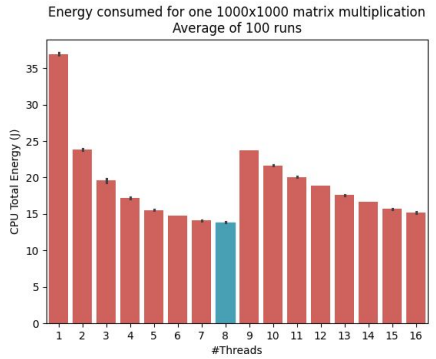
Magic oracle that knows the optimal thread count

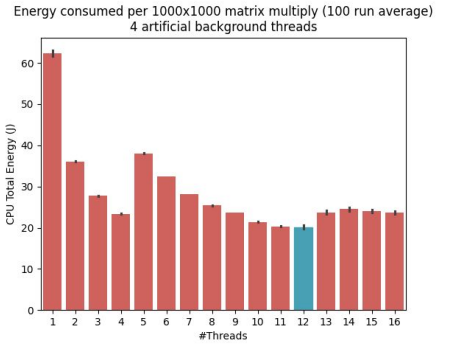
- For the task at hand
- For the given system
- For the given (artificial) background load

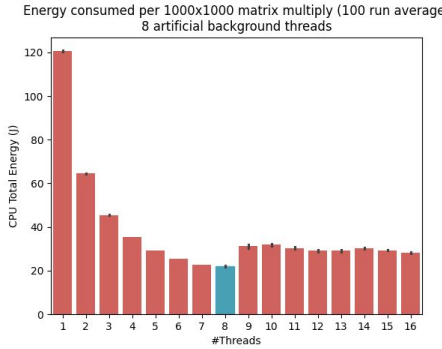
		No BG load	4 BG threads	8 BG threads	12 BG threads
Dynamic	**Energy**	7.11kJ	**11.17kJ**	**8.94kJ**	14.19kJ
	Runtime	165s	278s	197s	342s
Oracle	**Energy**	- *	**10.72kJ**	**7.51kJ**	13.88kJ
	Runtime	- *	236s	157s	331s

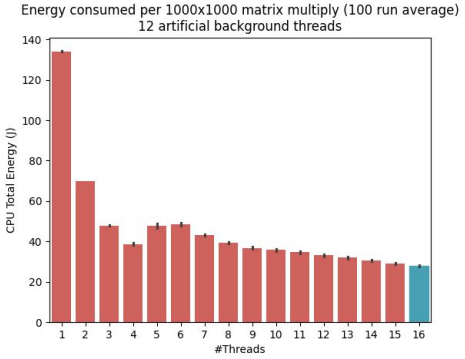
How much do we lose for being dynamic?

Overhead









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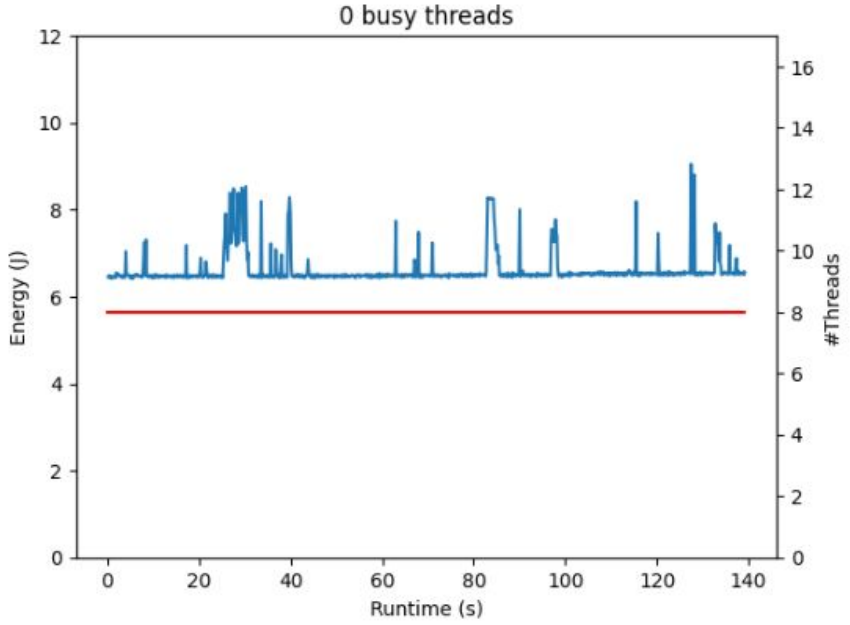
		No BG load	4 BG threads	8 BG threads	12 BG threads
Dynamic	**Energy**	- *	-4.2%	-19.0%	-2.2%
	Runtime	- *	-17.8%	-25.5%	-3.3%

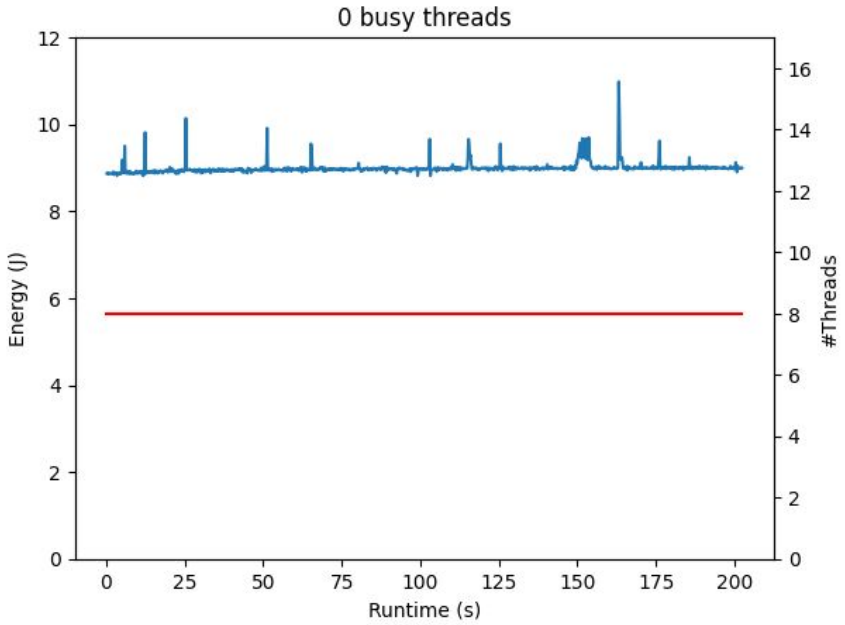
How much do we lose for being dynamic?

Overhead *

Even on a relatively well controlled device we have a lot of variation

- Why? Hard to tell!
- Future work: pinning threads might reduce variation
- Anecdotally: less variation with dynamic adaptation





Conclusion

Language-independent
- Functional languages especially suitable
- POC in SaC

Already shows potential to save energy
- Able to adapt to runtime changes
- Reasonable compared to magic oracle
- Other types of programs?
- Other ways to measure?

6 - 15% less energy consumed vs. static