Advanced energy analysis – moving from algebra to calculus

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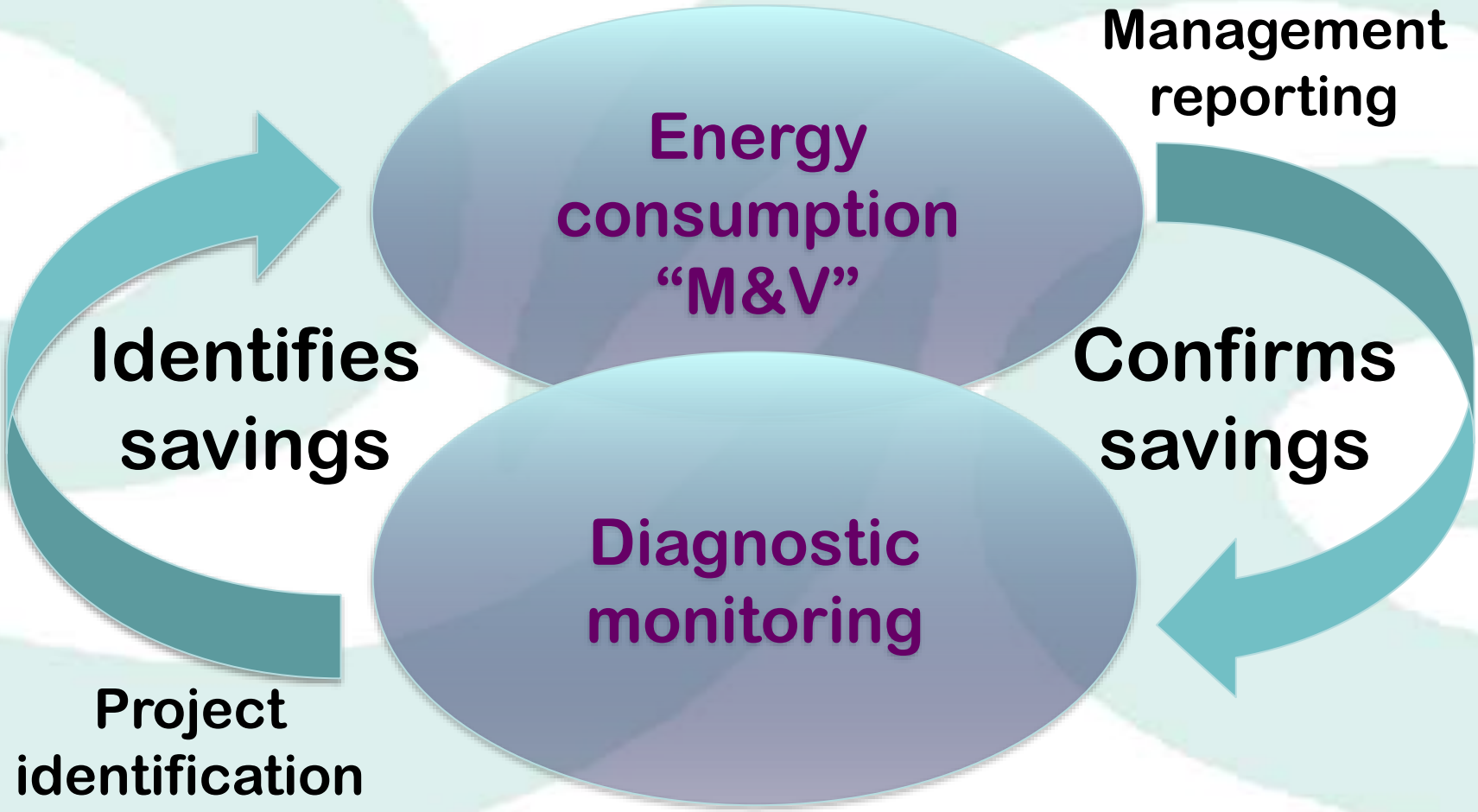
Overview

- Purpose: generating *actual, verifiable* energy savings.
- Concept: slope of the CUSUM line is the best performance indicator.
- Case studies illustrate this.

Two main components of energy analysis



ISO 50-001 requirement

"… to achieve continuous improvement of energy performance, and of EnMS."

How do you measure "continuous improvement of energy performance"?

How do you measure "improvement"?

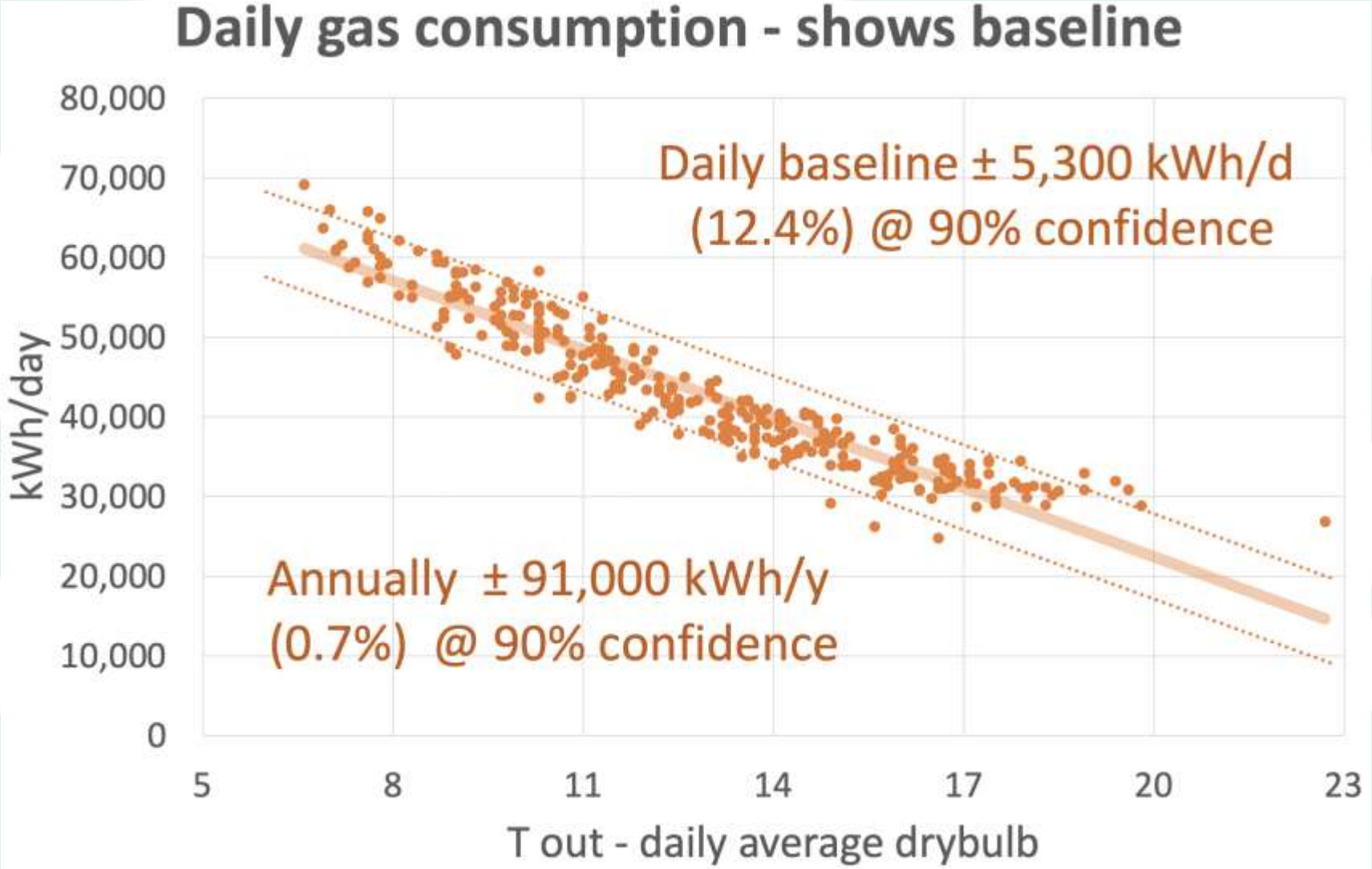
Improvement = change in performance with time

Mathematically equal to:

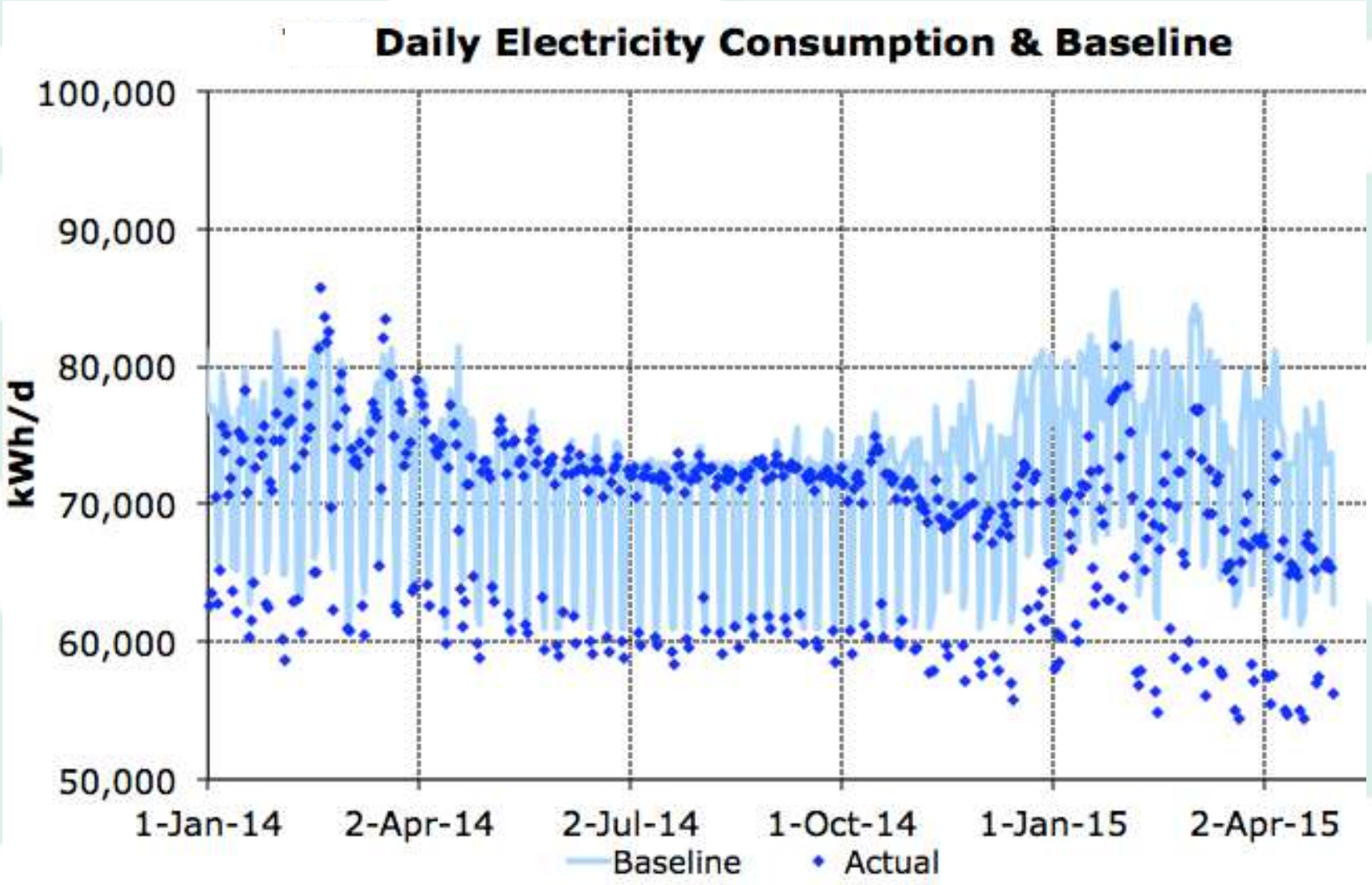
the first derivative of performance with respect to time.

= slope of the CUSUM line.

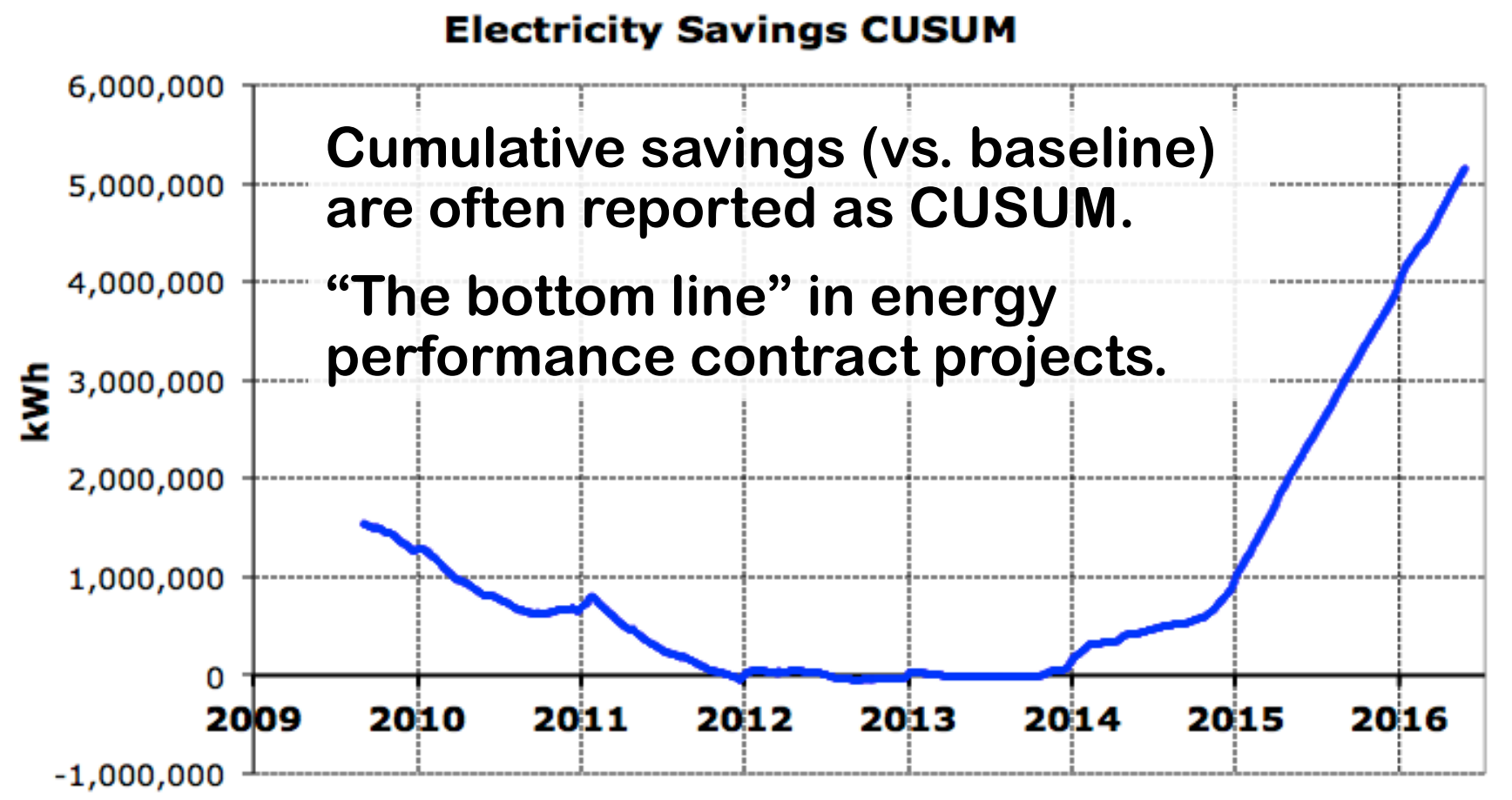
Traditional M&V – develop baseline



Use the baseline to compare to actual (= “savings”)



Accumulate daily savings into cumulative sum (CUSUM)



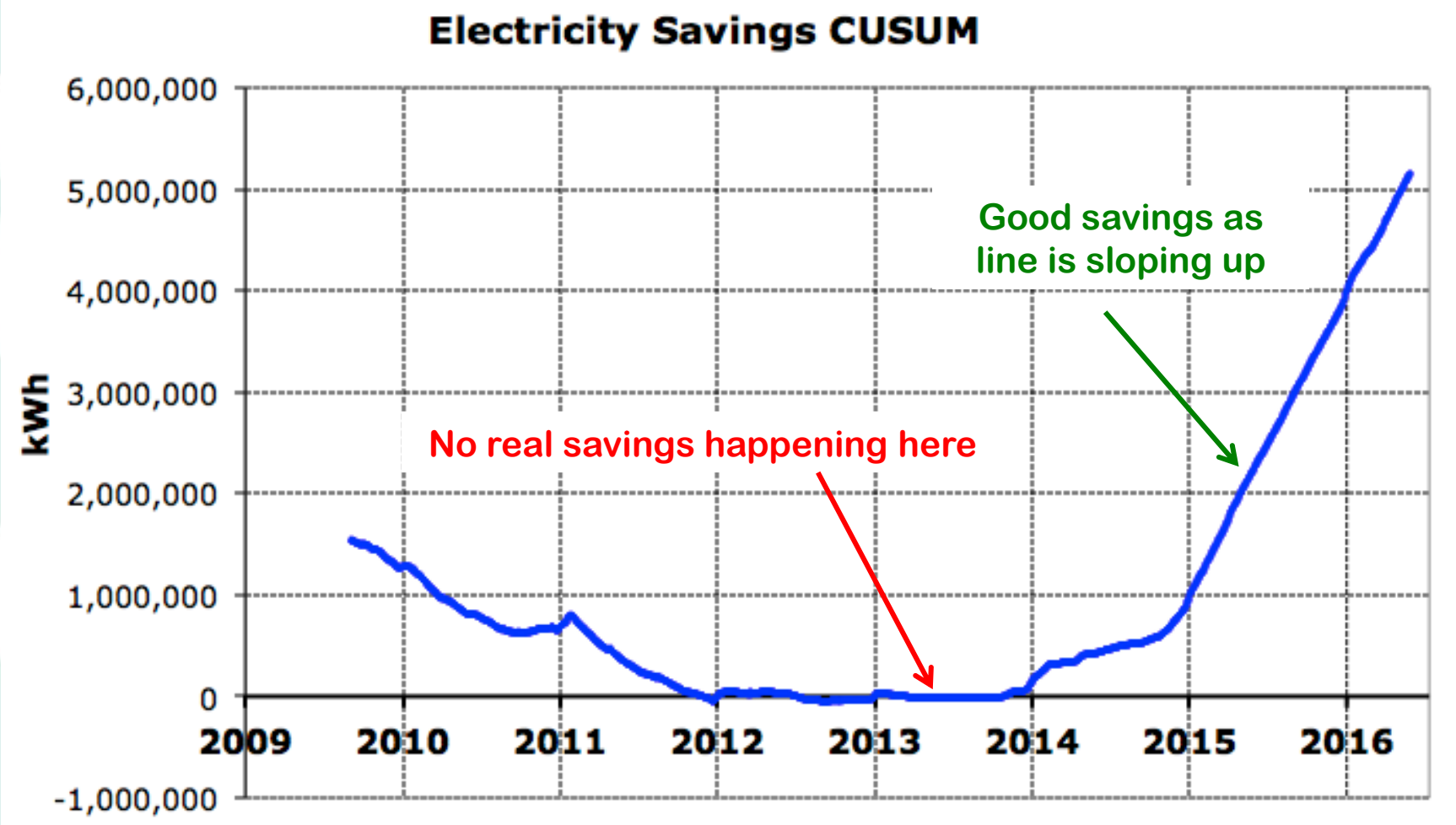
Cusum - the theory

- Energy performance is a complex process, affected by many random factors.
- So, there is some scatter of actual energy performance with respect to the baseline.
- Some days the usage will be less than the baseline (so the calculated savings are positive)
- Other days the usage will be more than the baseline (the calculated savings are negative).
- The important thing is to have more positive savings than negative, over time.

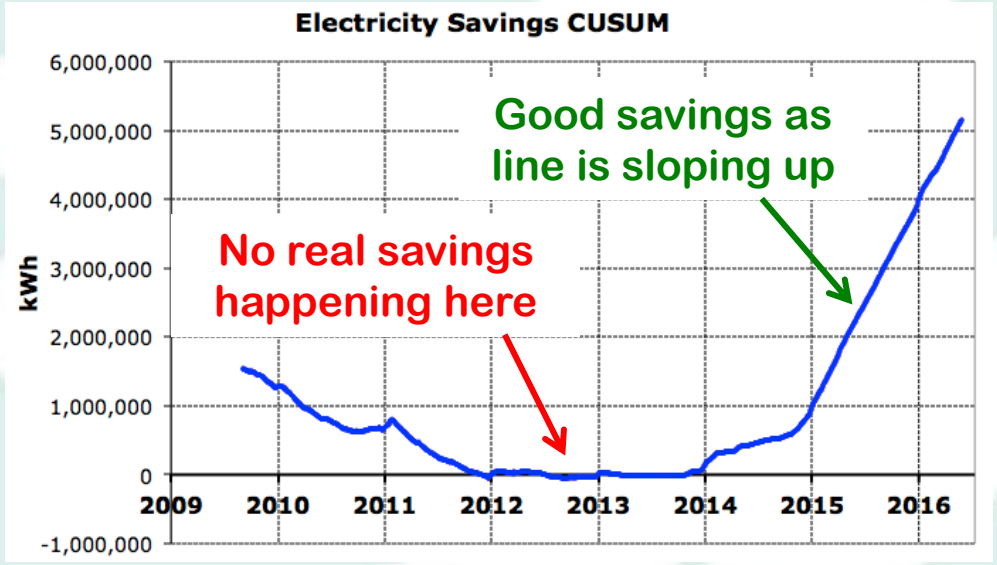
Cusum - how it works

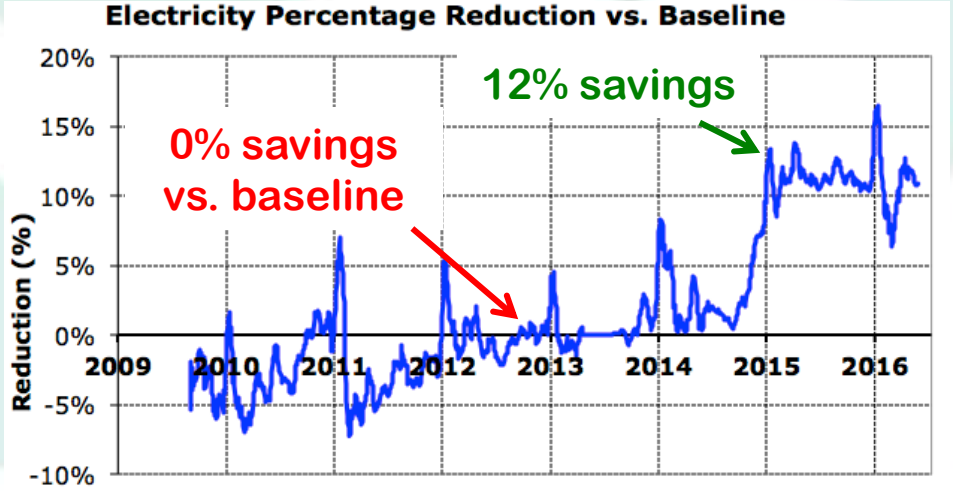
Condition	...means daily...	So...
Cusum line fluctuates around zero value.	Savings vs. baseline are being achieved as often as losses.	Energy performance is relatively stable, on baseline.
Cusum line slopes upward (trending positive).	Savings vs. baseline are being achieved more often than losses.	Energy performance is improving.
Cusum line slopes downward (trending negative).	Savings vs. baseline are being achieved less often than losses.	Energy performance is declining.

Increasing CUSUM is intention



Best performance indicator is % savings = *slope* of CUSUM line

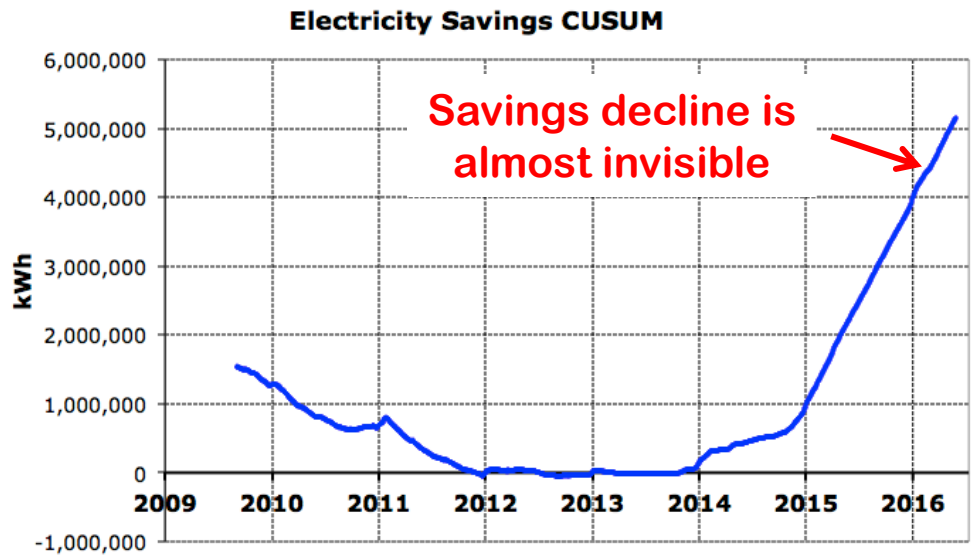


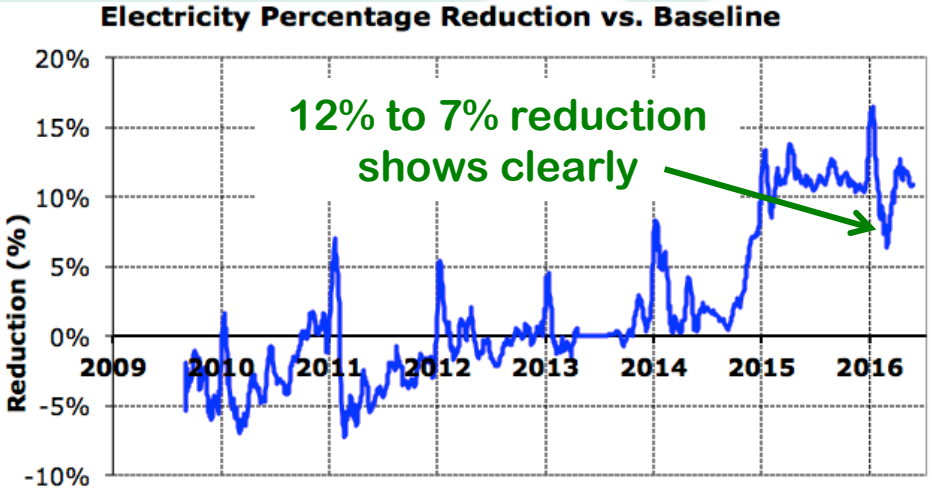


- CUSUM slope shows how fast savings are being achieved.
- % Savings =

  daily savings ÷ daily baseline
- Higher % savings means faster growing CUSUM.

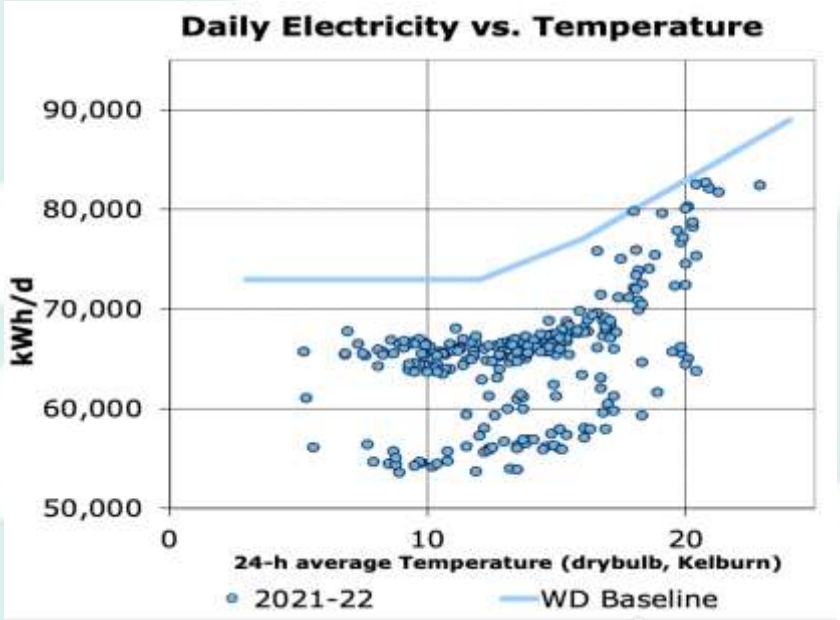
Advantages: visibility, diagnostics

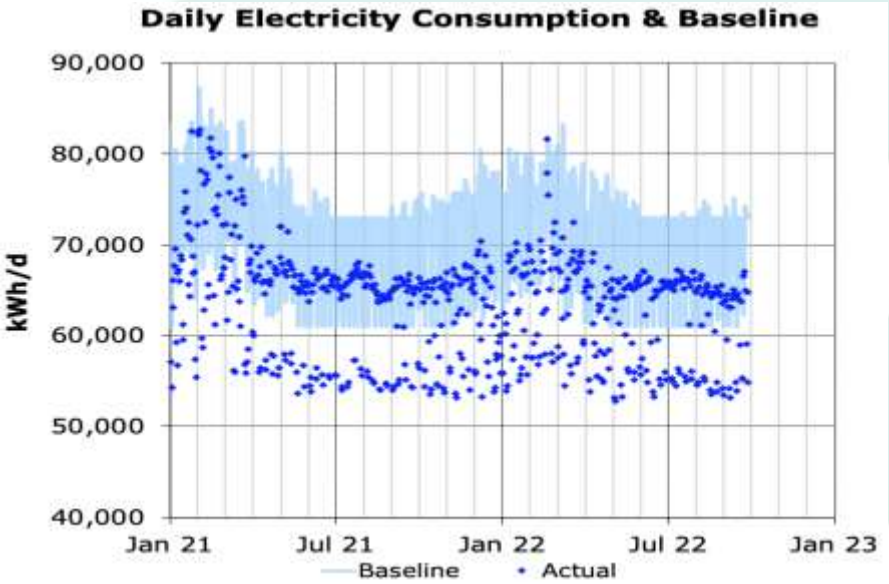


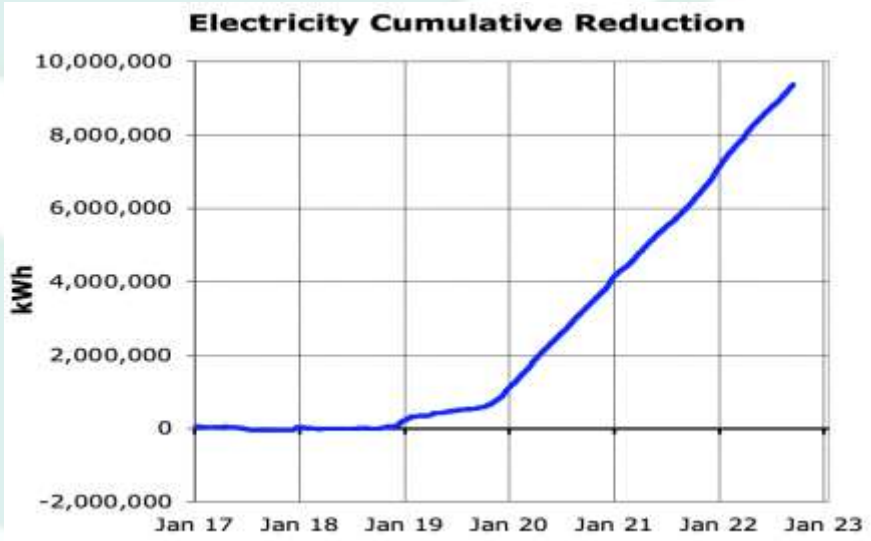


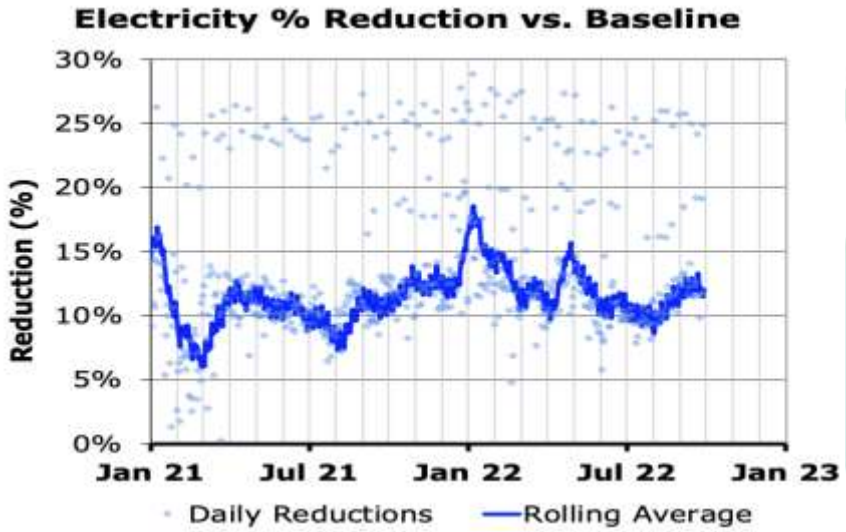
- Notice the problem in Feb. 2016. Almost invisible on CUSUM; clear in % reduction.
- % reduction allows higher resolution of performance changes
- Also means baselines don't need to be updated as often.

Summary – 4 graph types



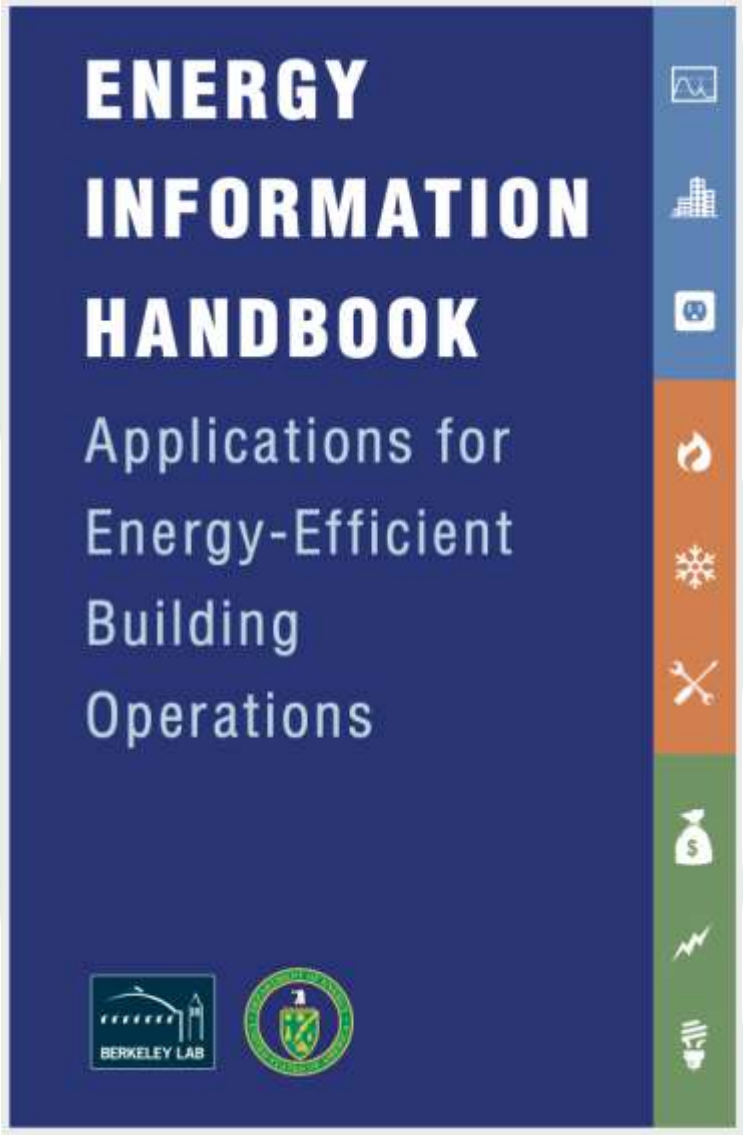






Recommended compendium of energy analysis techniques

Free download, 298 page pdf



https://buildings.lbl.gov/publications/energy-information-handbook

One mention to diagnostics using CUSUM in EIH references

CUSUM quality control chart for monitoring energy use performance

Publisher: IEEE | Cite This | PDF

Vinod. S. Puranik All Authors

6 Paper Citations | 455 Full Text Views

Abstract

Document Sections

I. INTRODUCTION

II. METHODOLOGY

III. CASE STUDY

IV. RESULTS AND DISCUSSION

Abstract:
This paper builds on measuring and evaluating energy use performance of a process using statistical process control charts. This paper discusses the application of the latest SPC tool named cumulative SUM of difference (CUSUM) to monitor energy use data so that abnormal changes can be detected in a timely manner. The application case study to highlight the benefits of CUSUM charts for monitoring energy use performance is presented and performance of these charts is compared to the traditional control chart.

Published in: 2007 IEEE International Conference on Industrial Engineering and Engineering Management

One mention in IPMVP documents

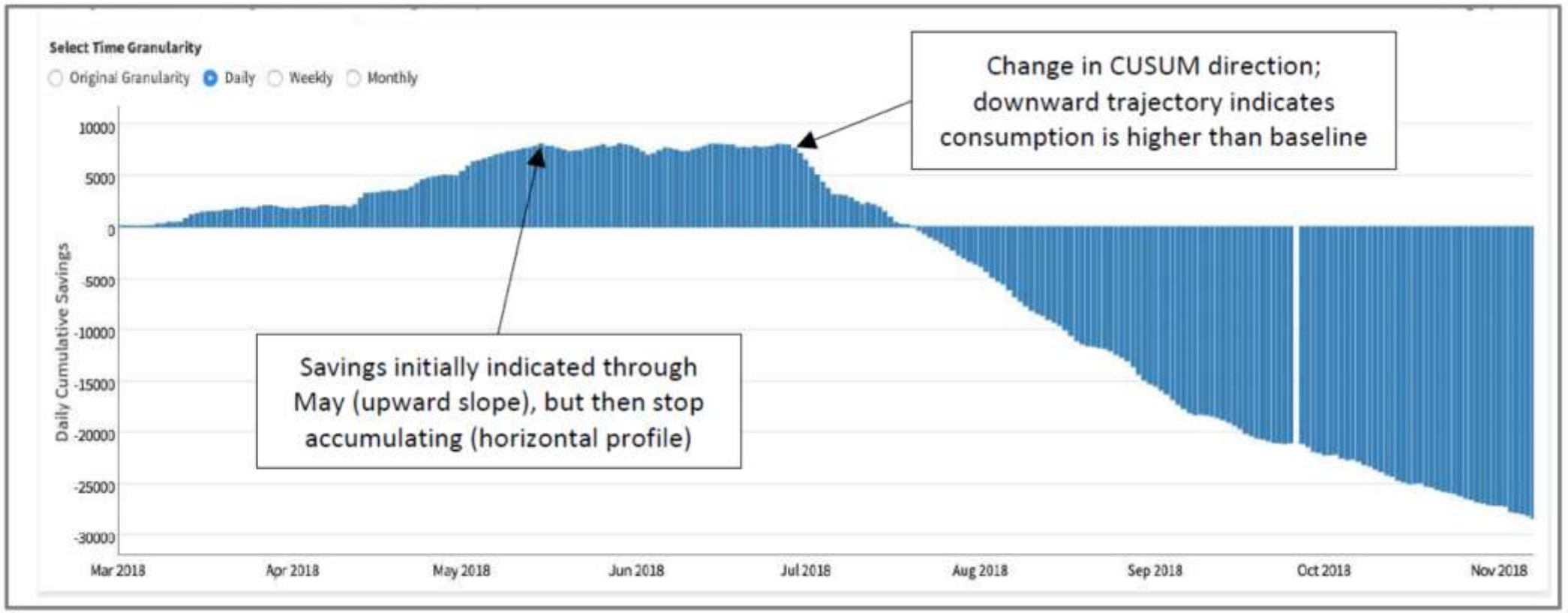
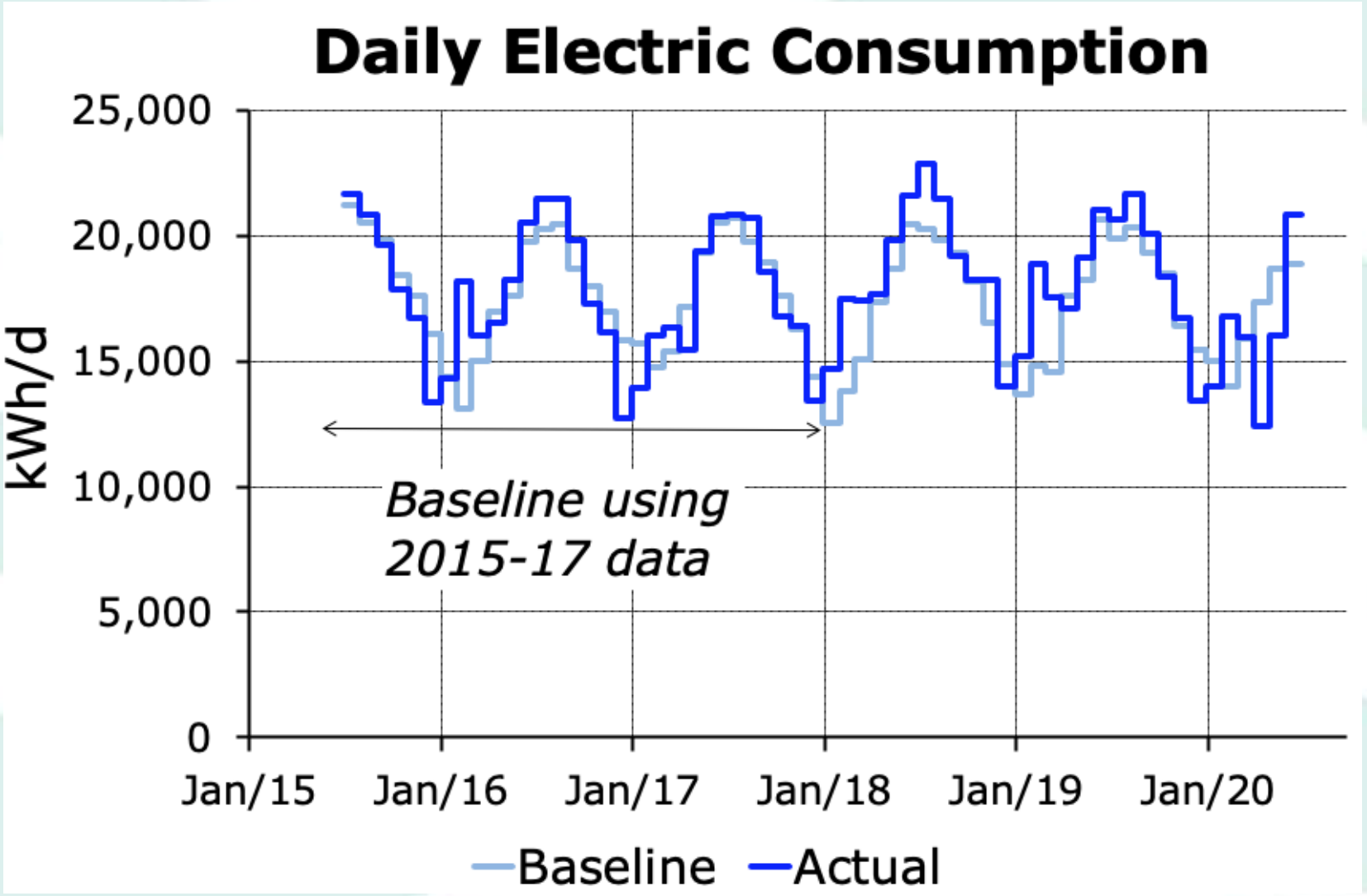
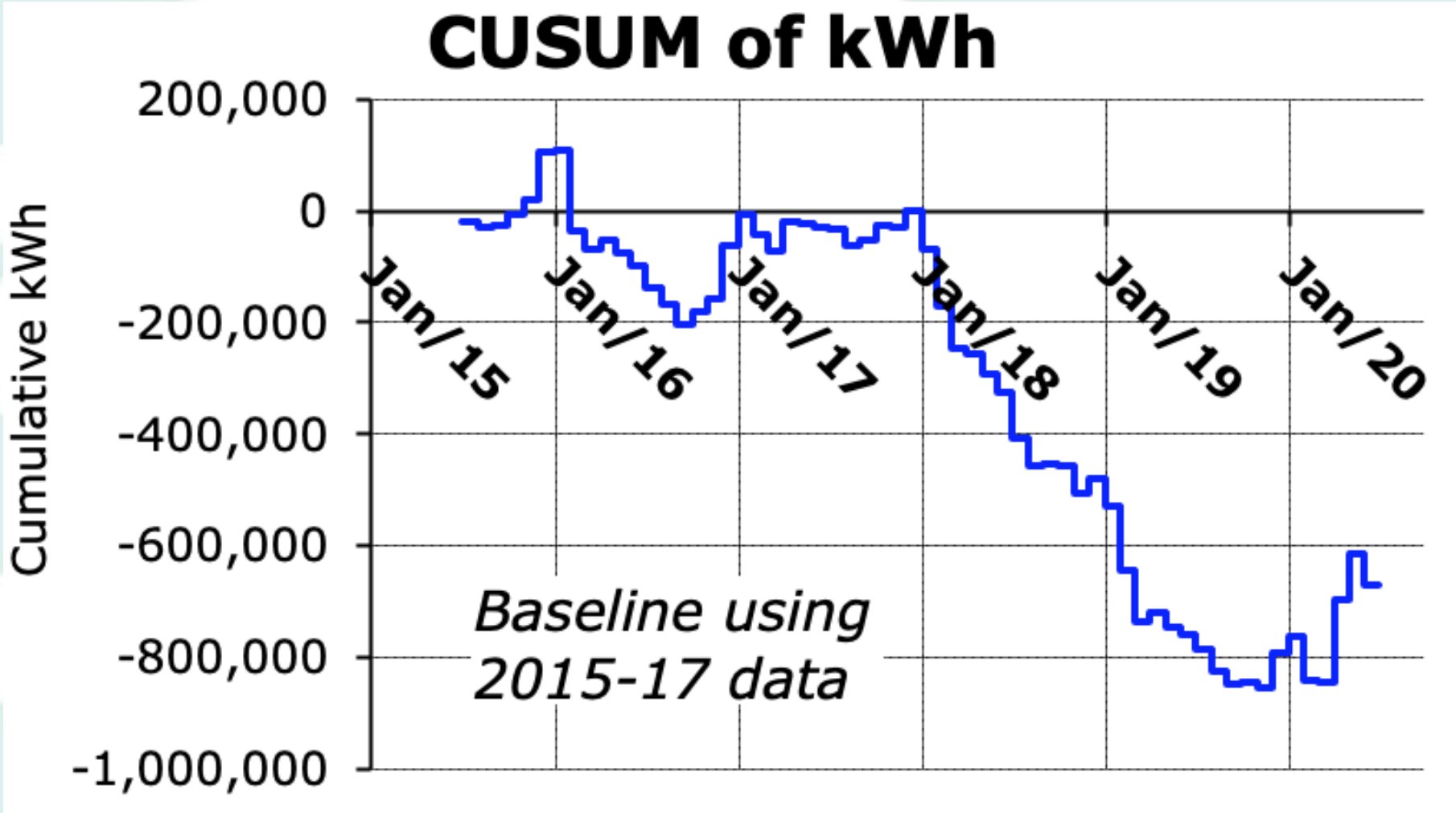


FIGURE 12: CUSUM SHOWING INCREASE IN ENERGY USE (NEGATIVE SAVINGS)

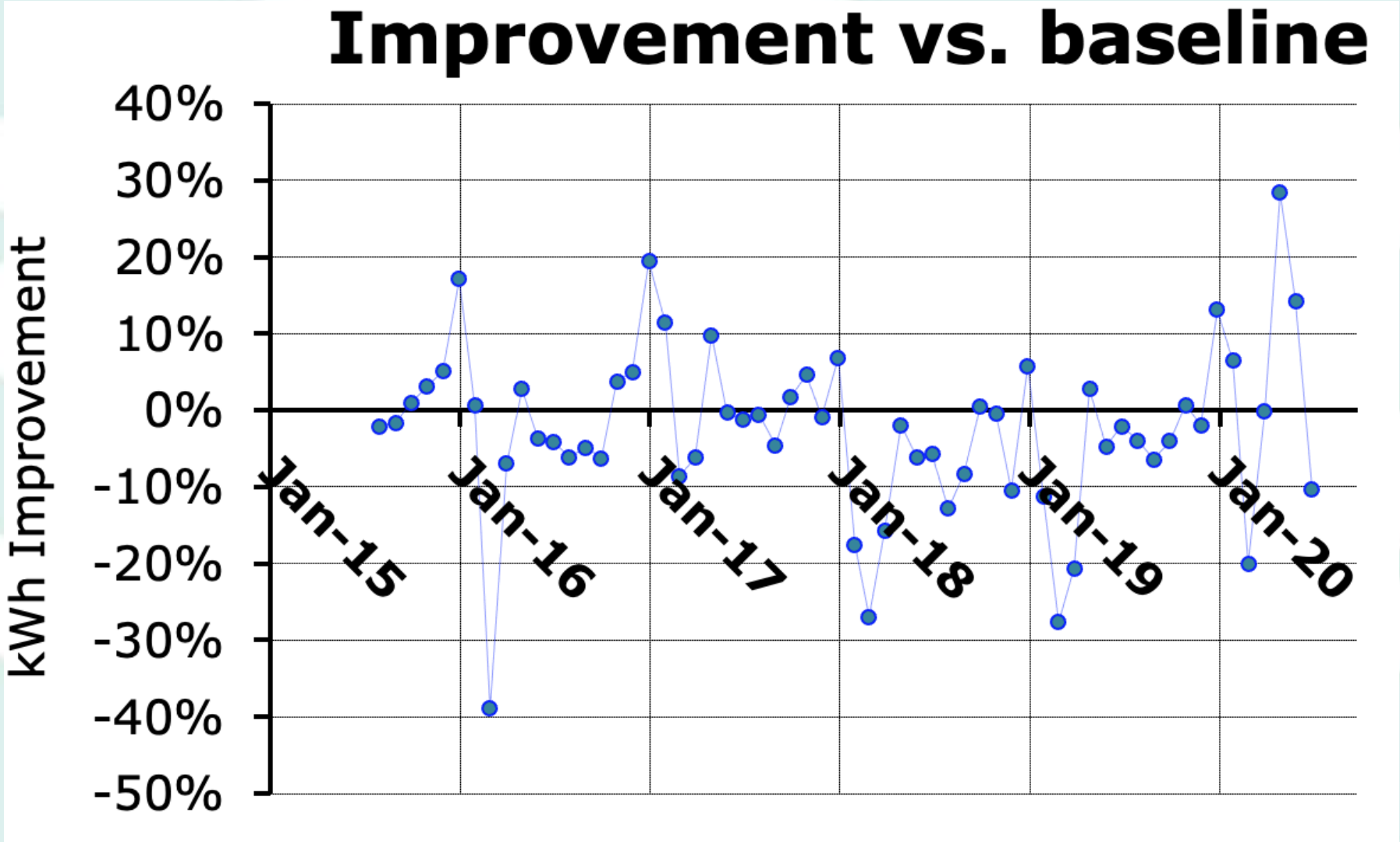
From *IPMVP APPLICATION GUIDE ON NON-ROUTINE EVENTS AND ADJUSTMENTS EVO 10400 -1:2020. OCTOBER 2020*

Example: 10% jump – visible?

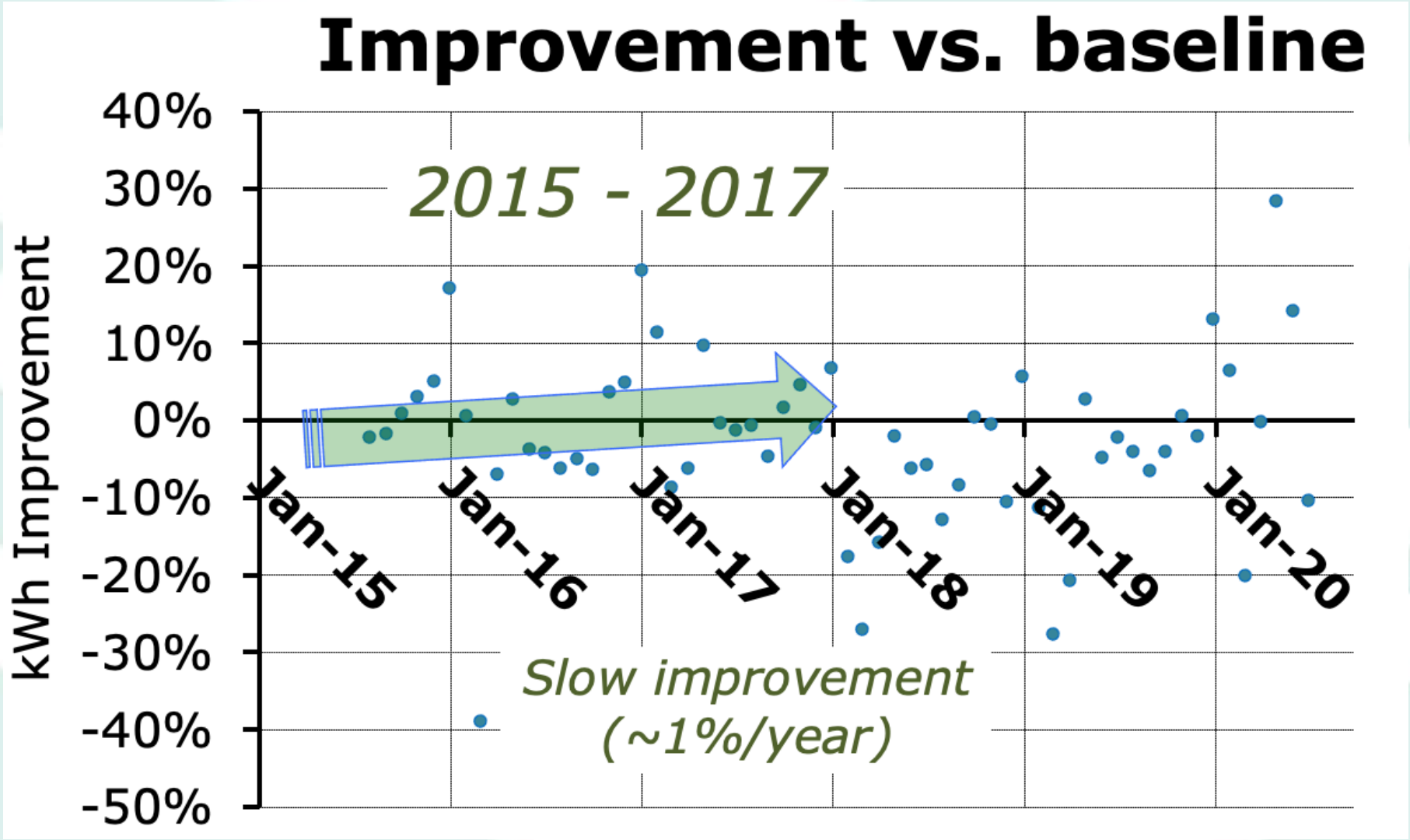



CUSUM of kWh
Cumulative kWh
200,000
0
-200,000
-400,000
-600,000
-800,000
-1,000,000
Jan/15
Jan/16
Jan/17
Jan/18
Jan/19
Jan/20
Baseline using
2015-17 data

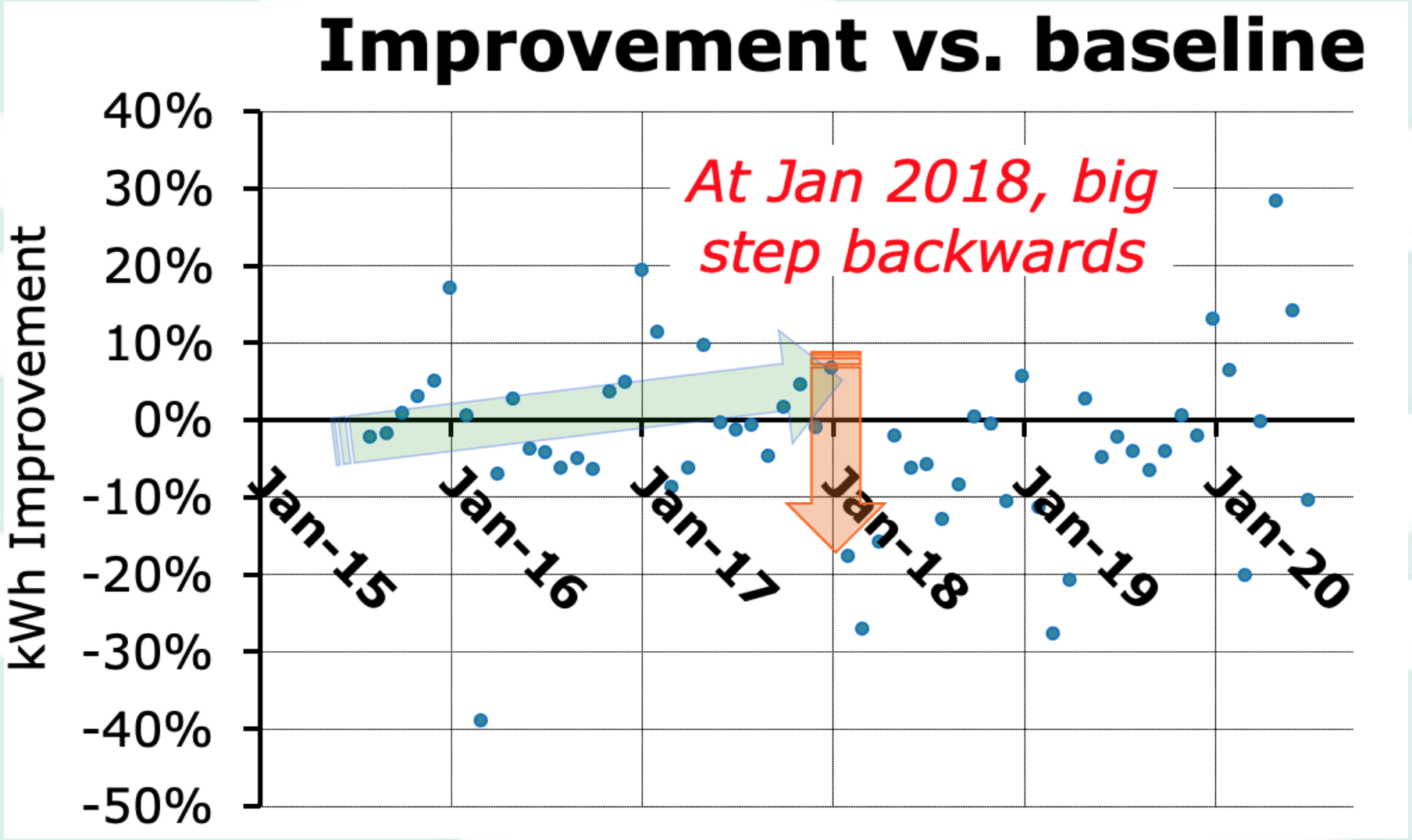
Slope of CUSUM line



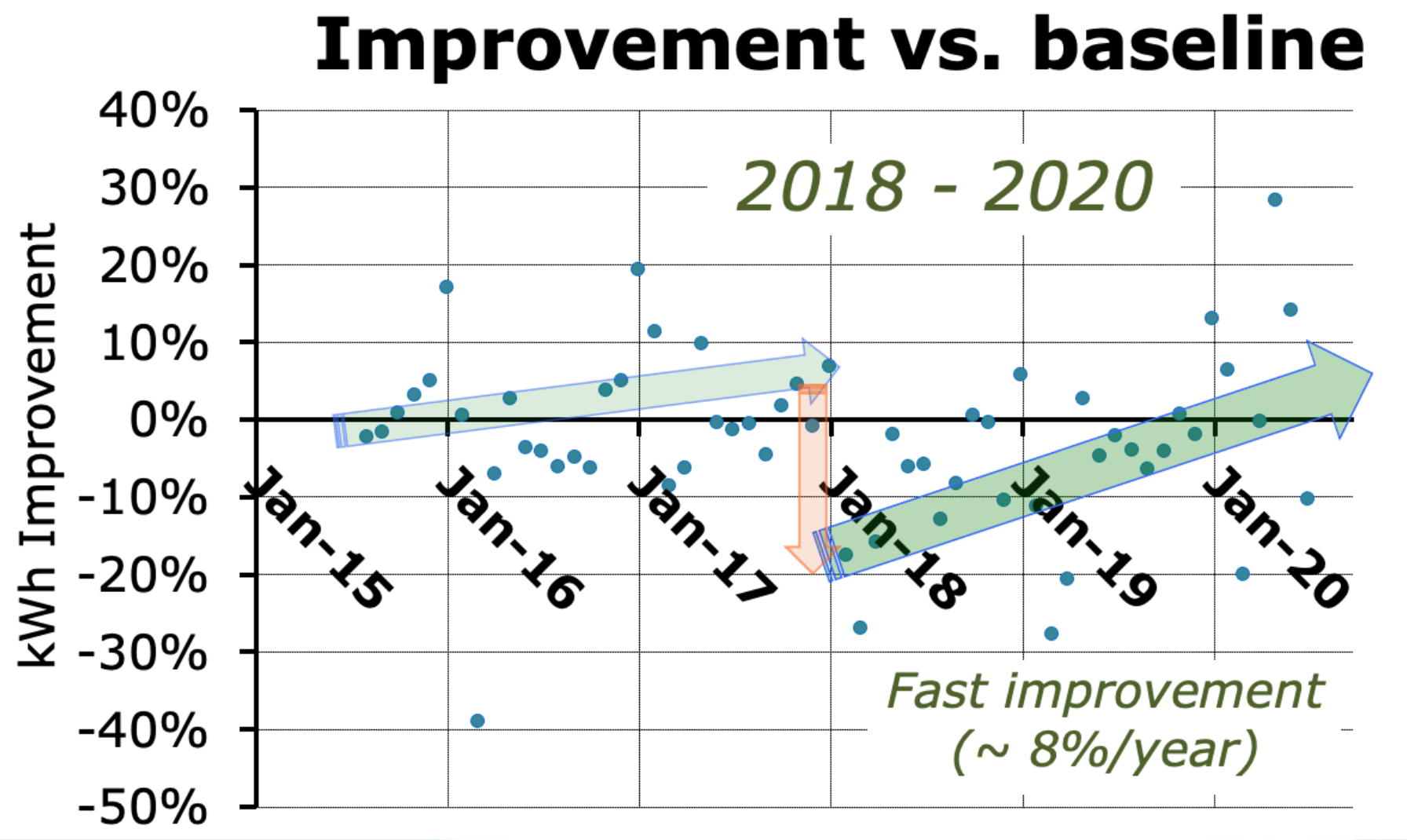
Interpretation



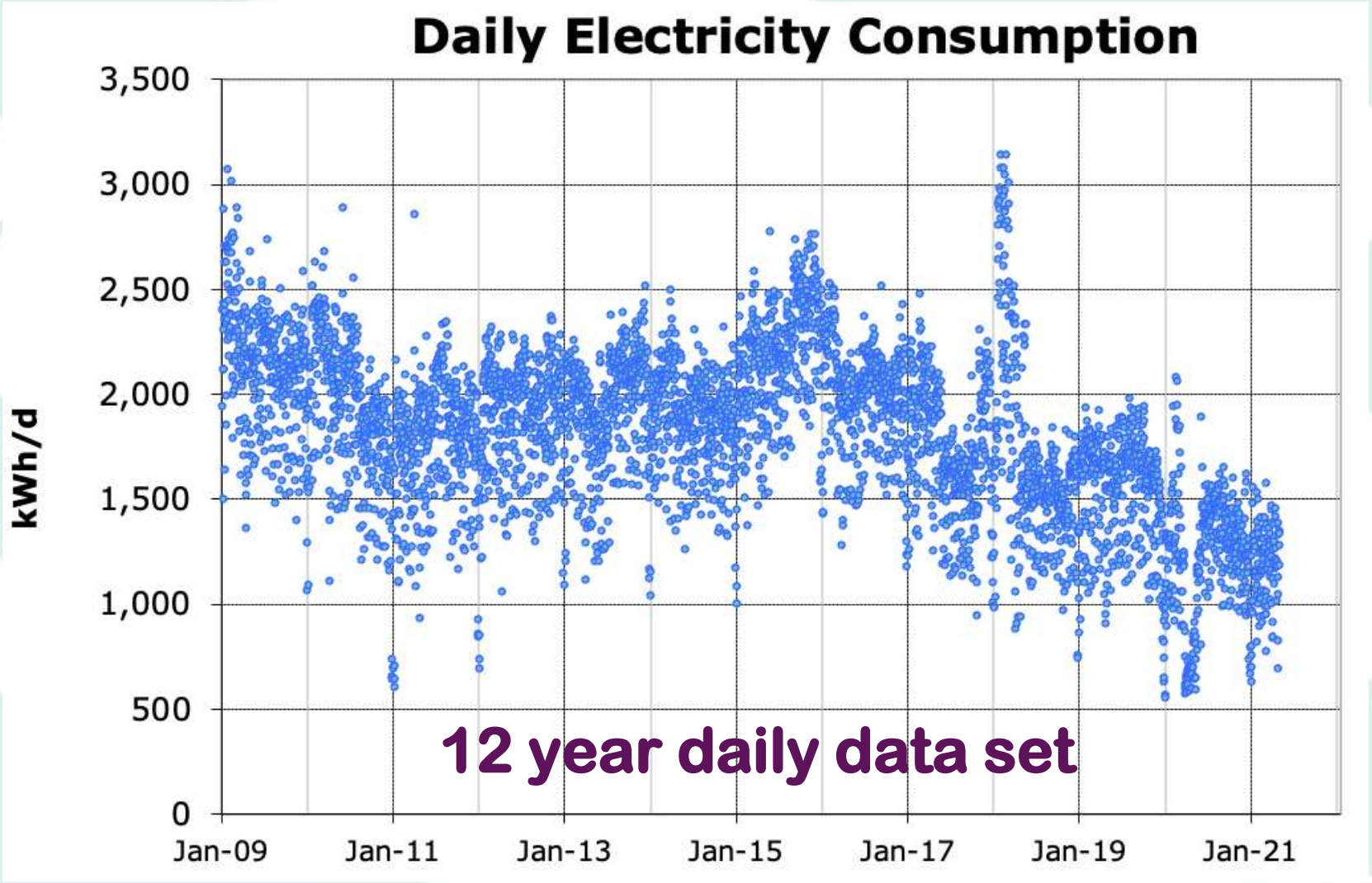
Interpretation



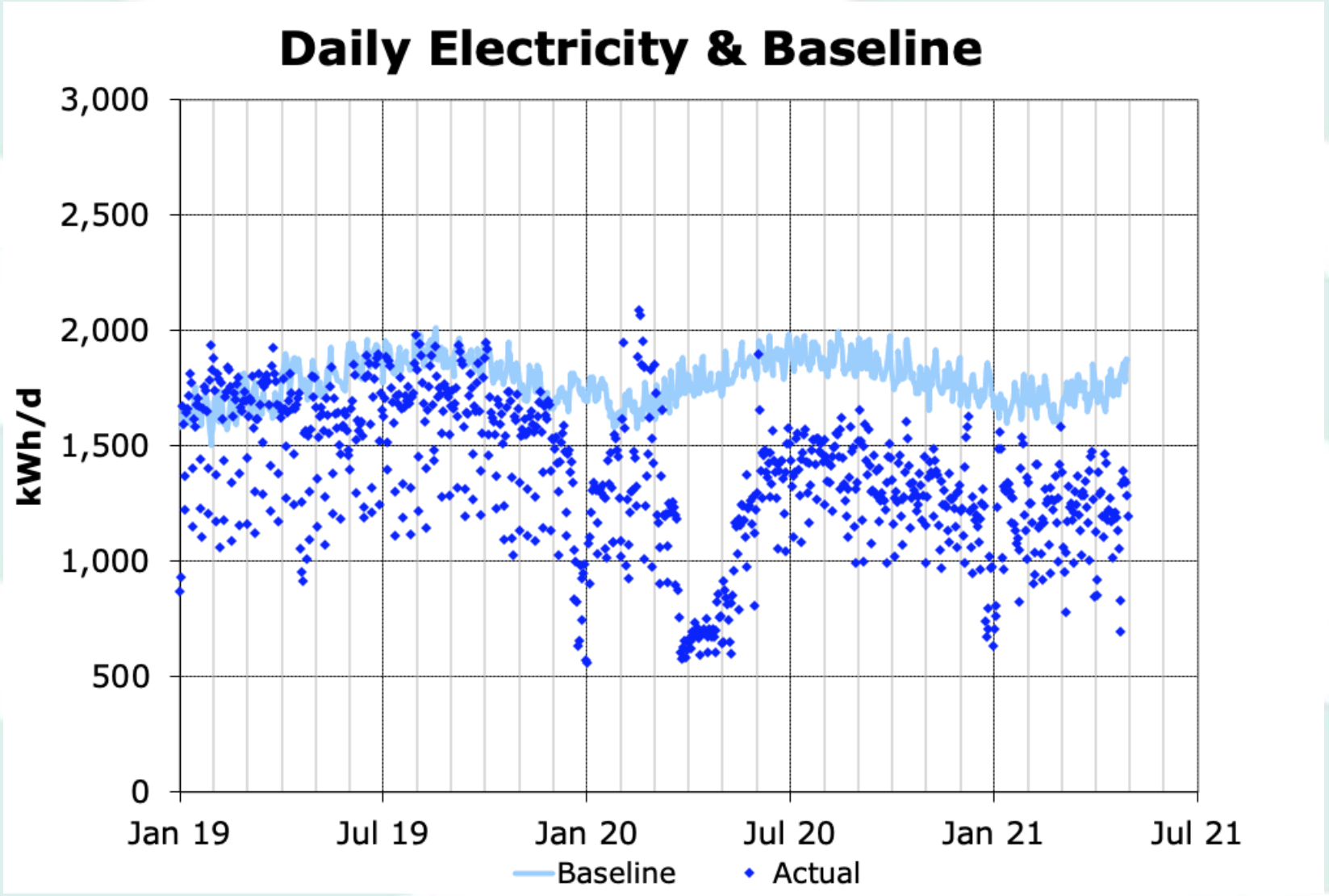
Interpretation



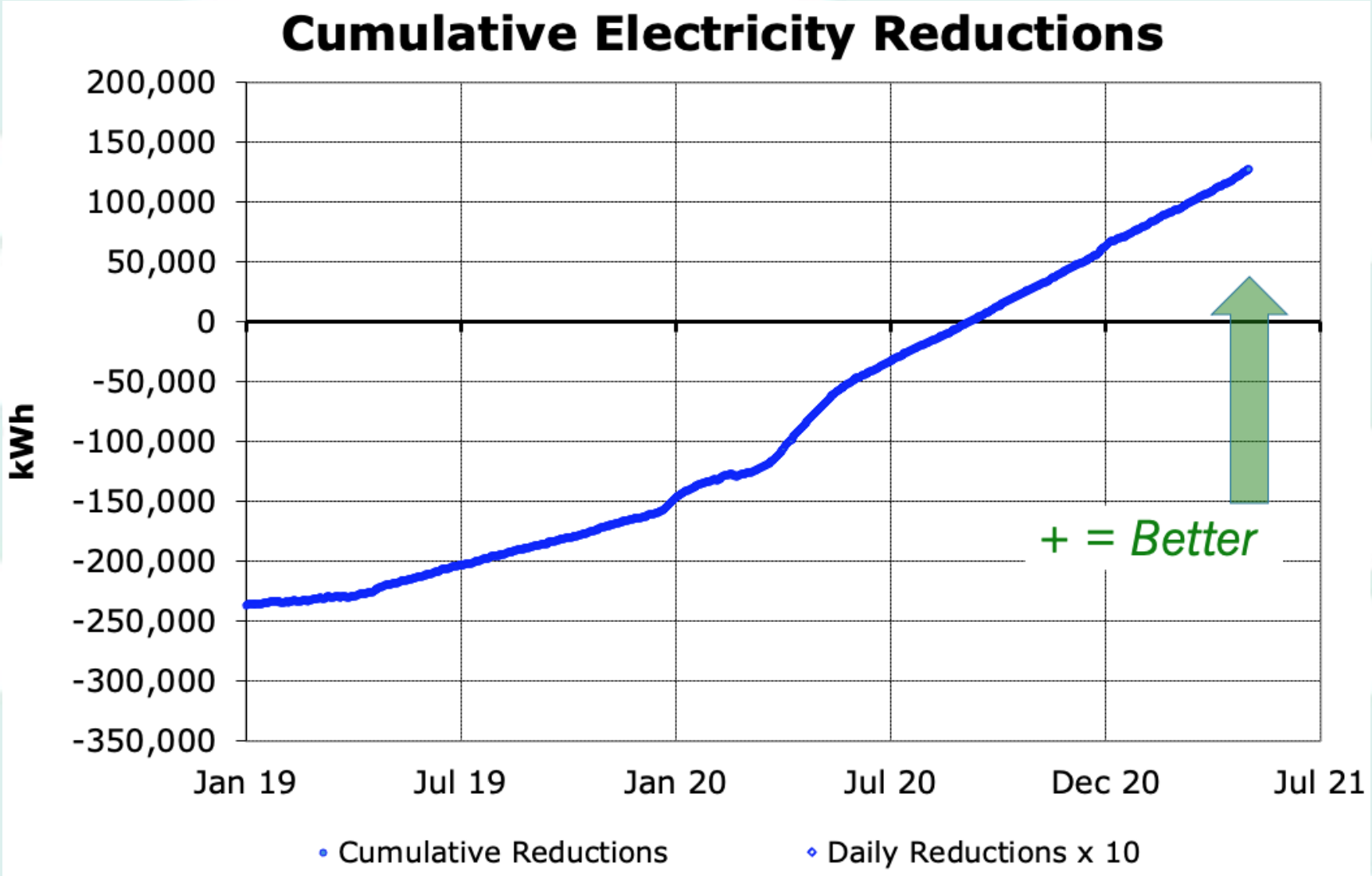
Example 2 – Municipal building



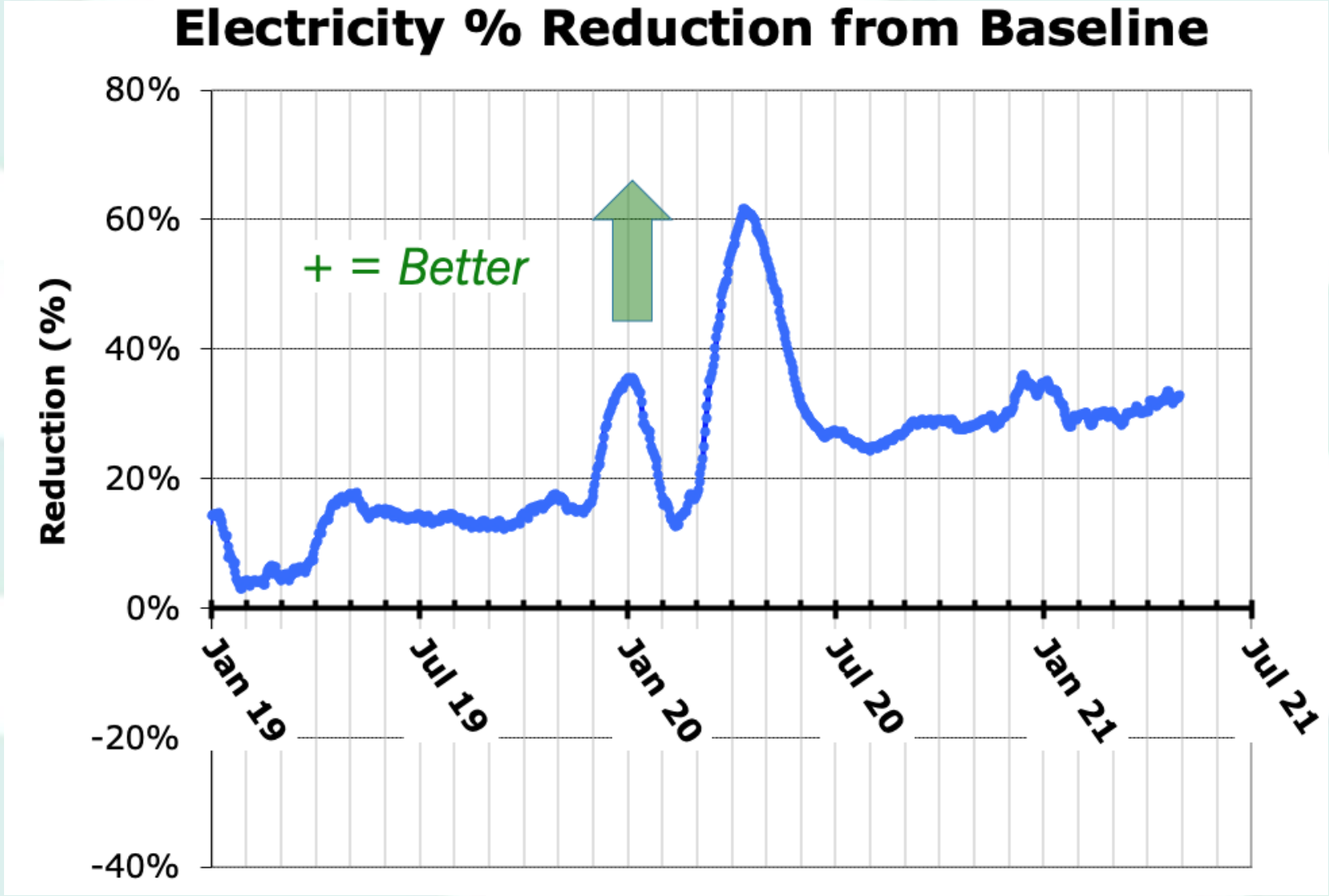
Example 2 – last 2 years



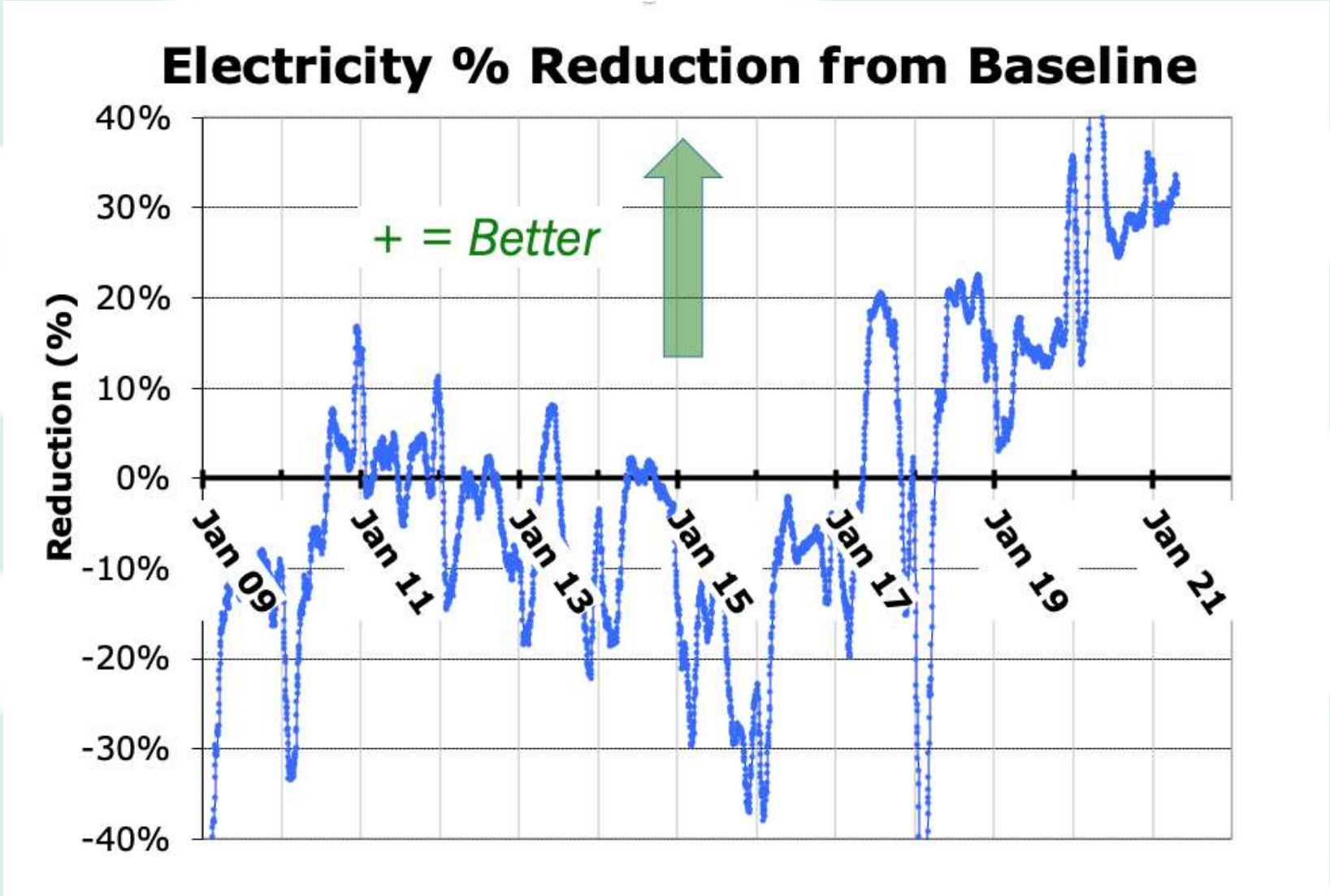
Example 2 – CUSUM last 2 years



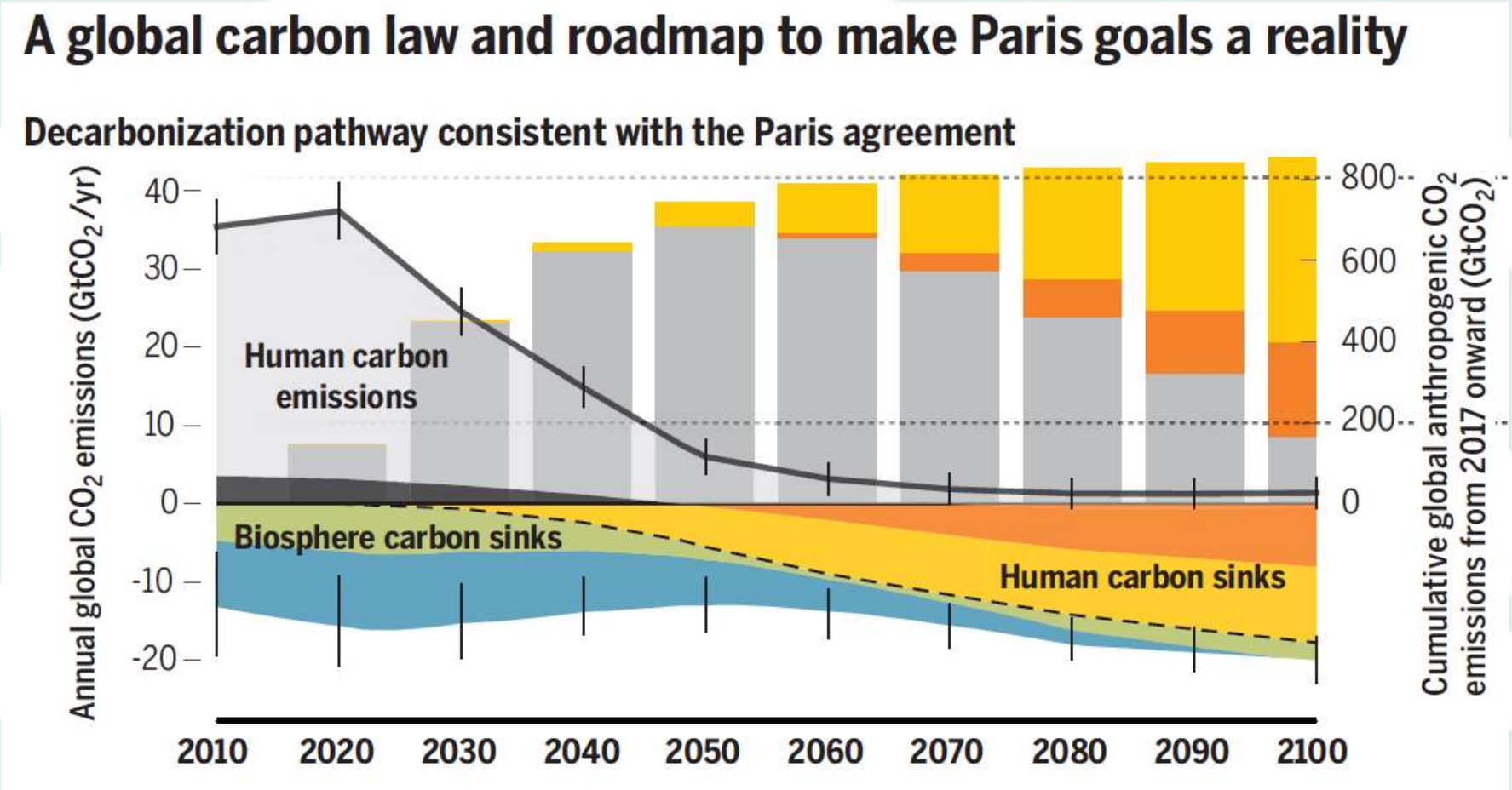
Example 2 – CUSUM slope



Example 2 – CUSUM slope 12 years

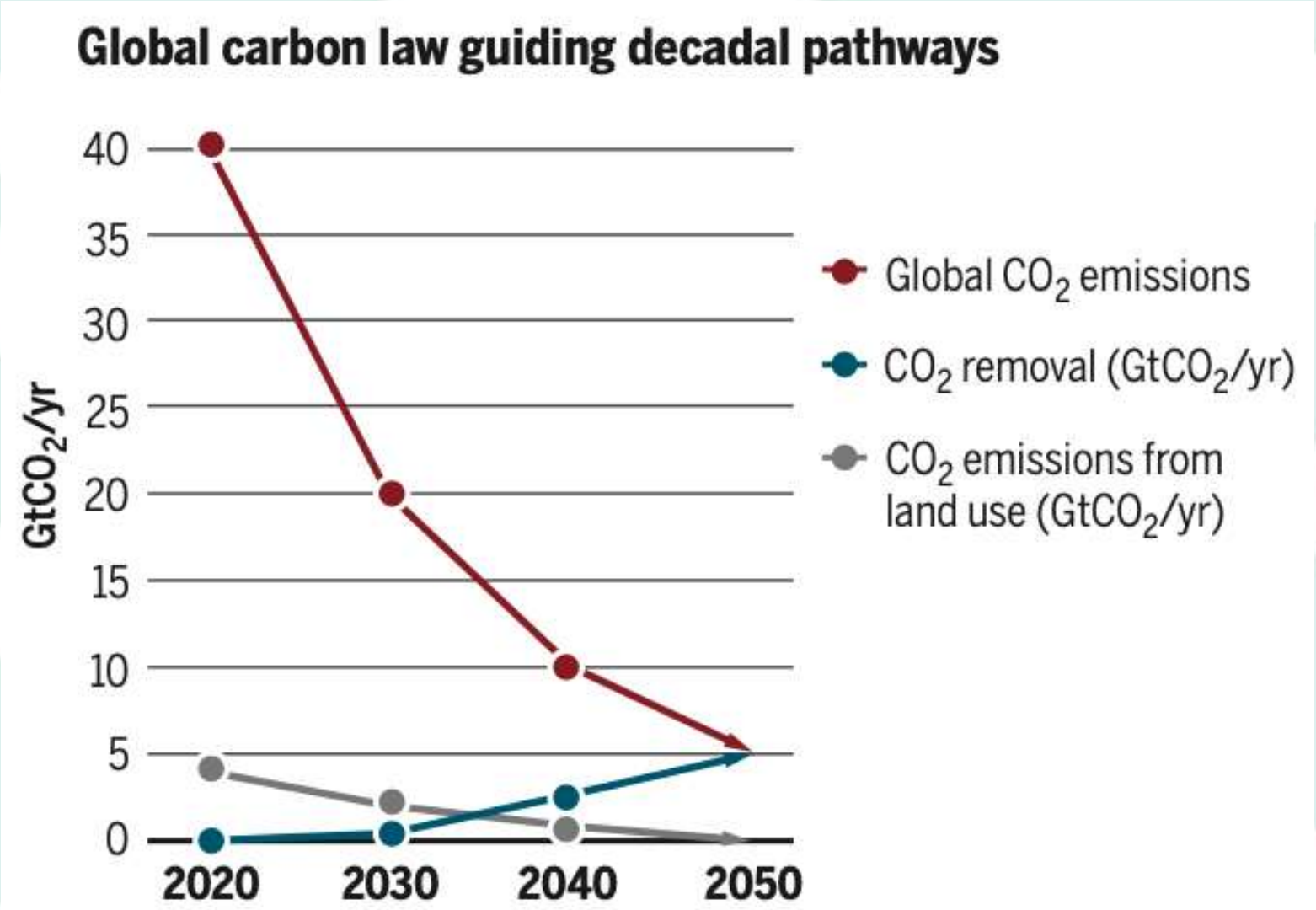


To net zero emissions by 2050

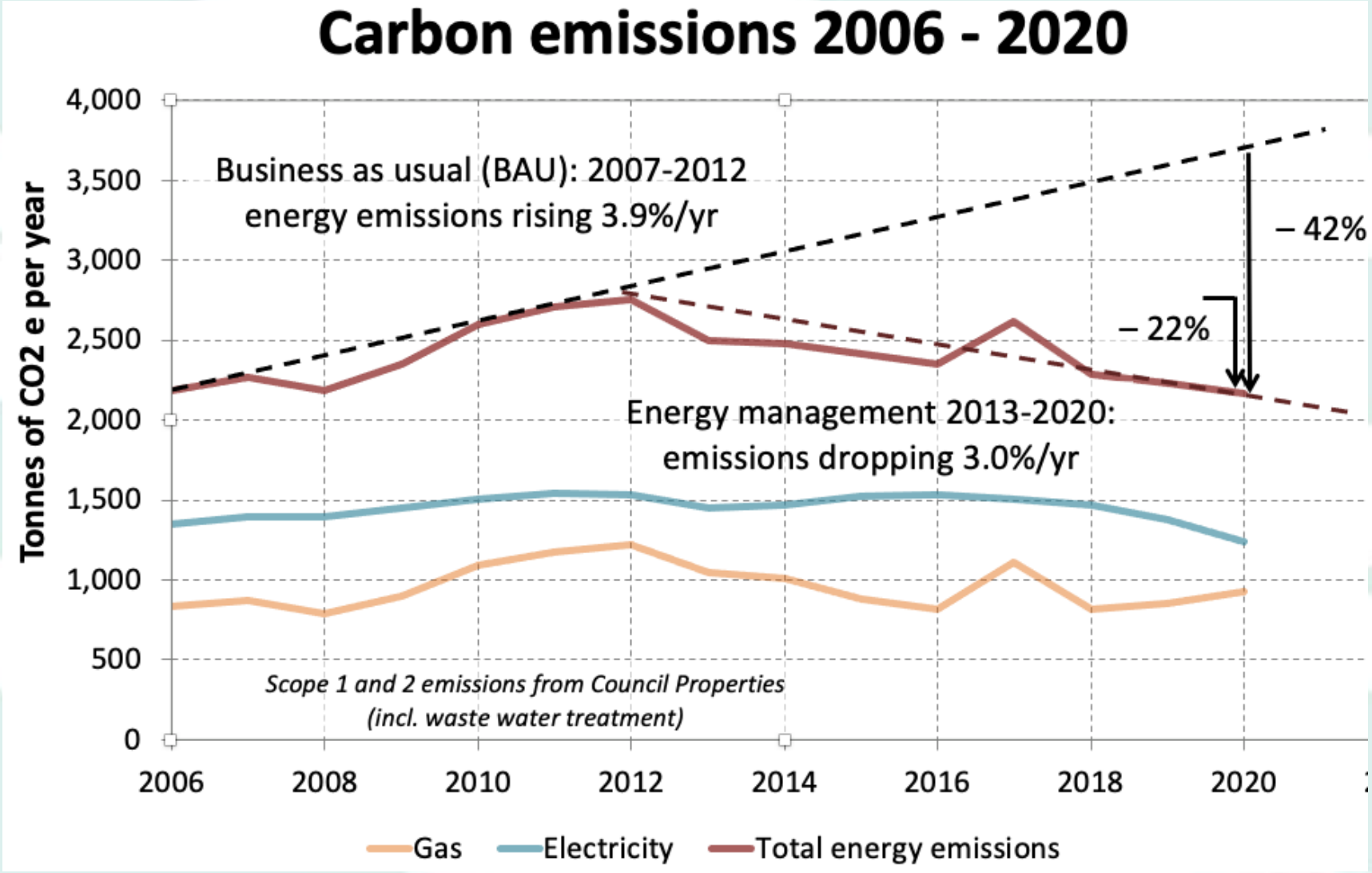


A roadmap for rapid decarbonization
Johan Rockström, Owen Gaffney, Joeri Rogelj, Malte Meinshausen, Nebojsa Nakicenovic and Hans Joachim Schellnhuber (March 23, 2017)
Science **355** (6331), 1269-1271. [doi: 10.1126/science.aah3443]

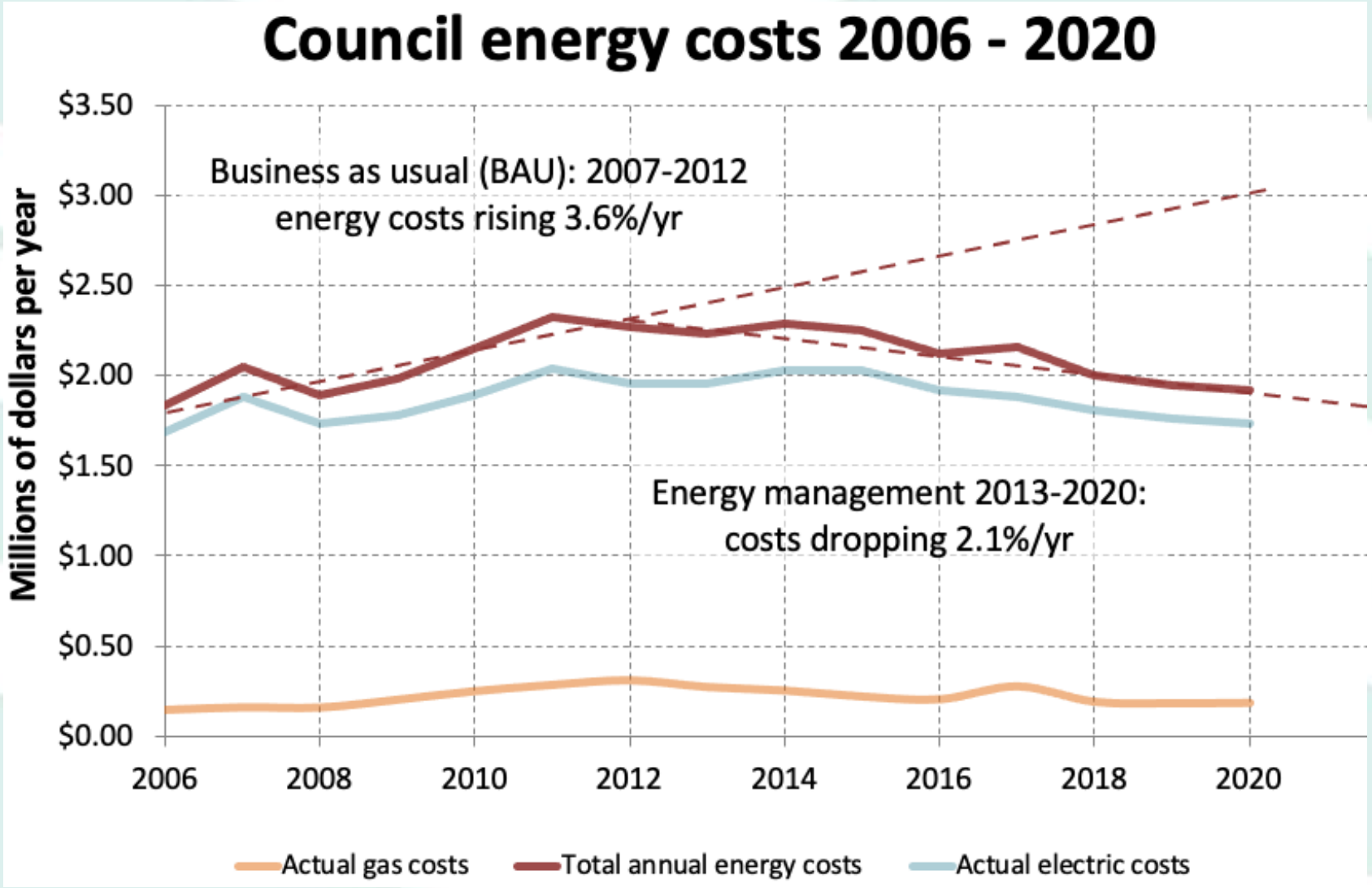
7%/year decline is required to achieve 50% emissions reduction every 10 years



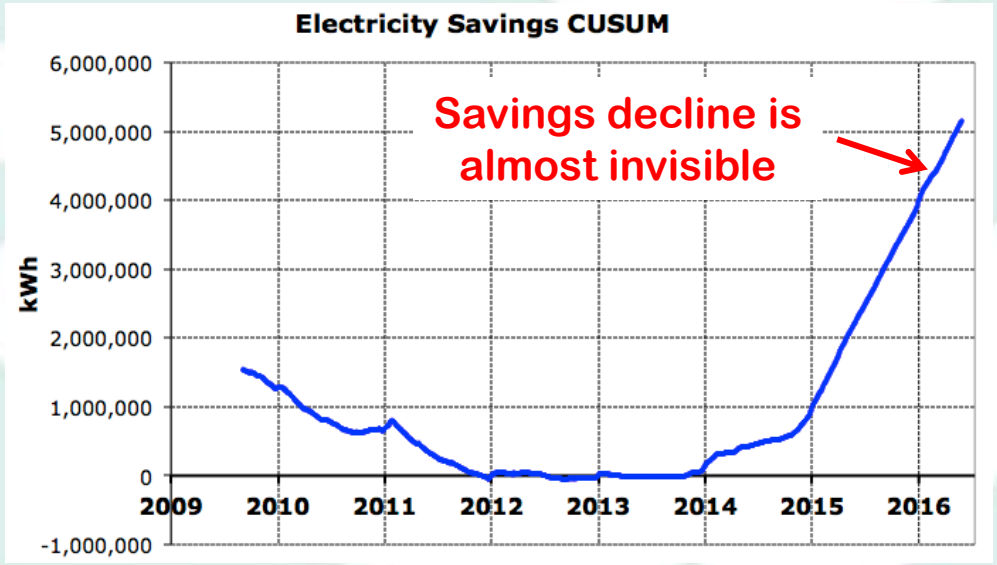
3%/year decline is possible…

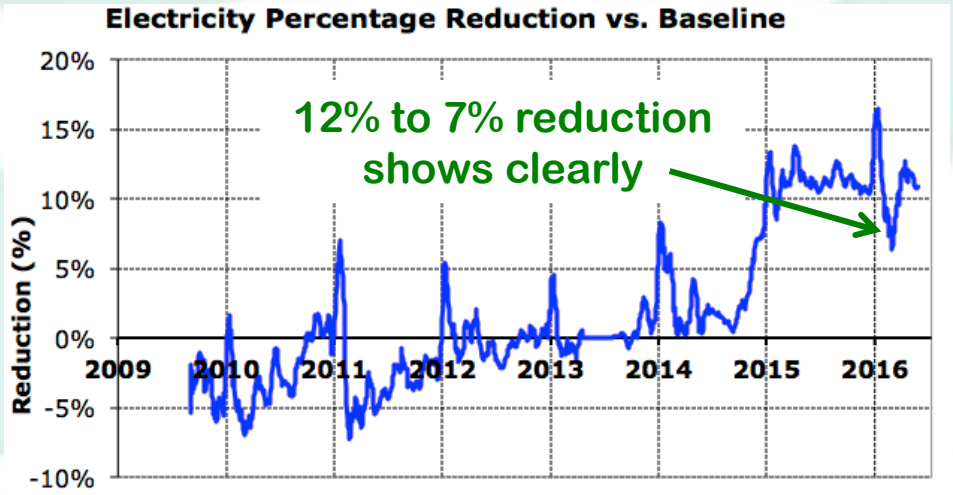


2%/year decline in costs



Summary: CUSUM slope is the best indicator for diagnostics





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