Skillful, Meter-free, Hourly Energy Consumption Forecasting for Building and Campus Managers

Is it worth installing meters at every facility?

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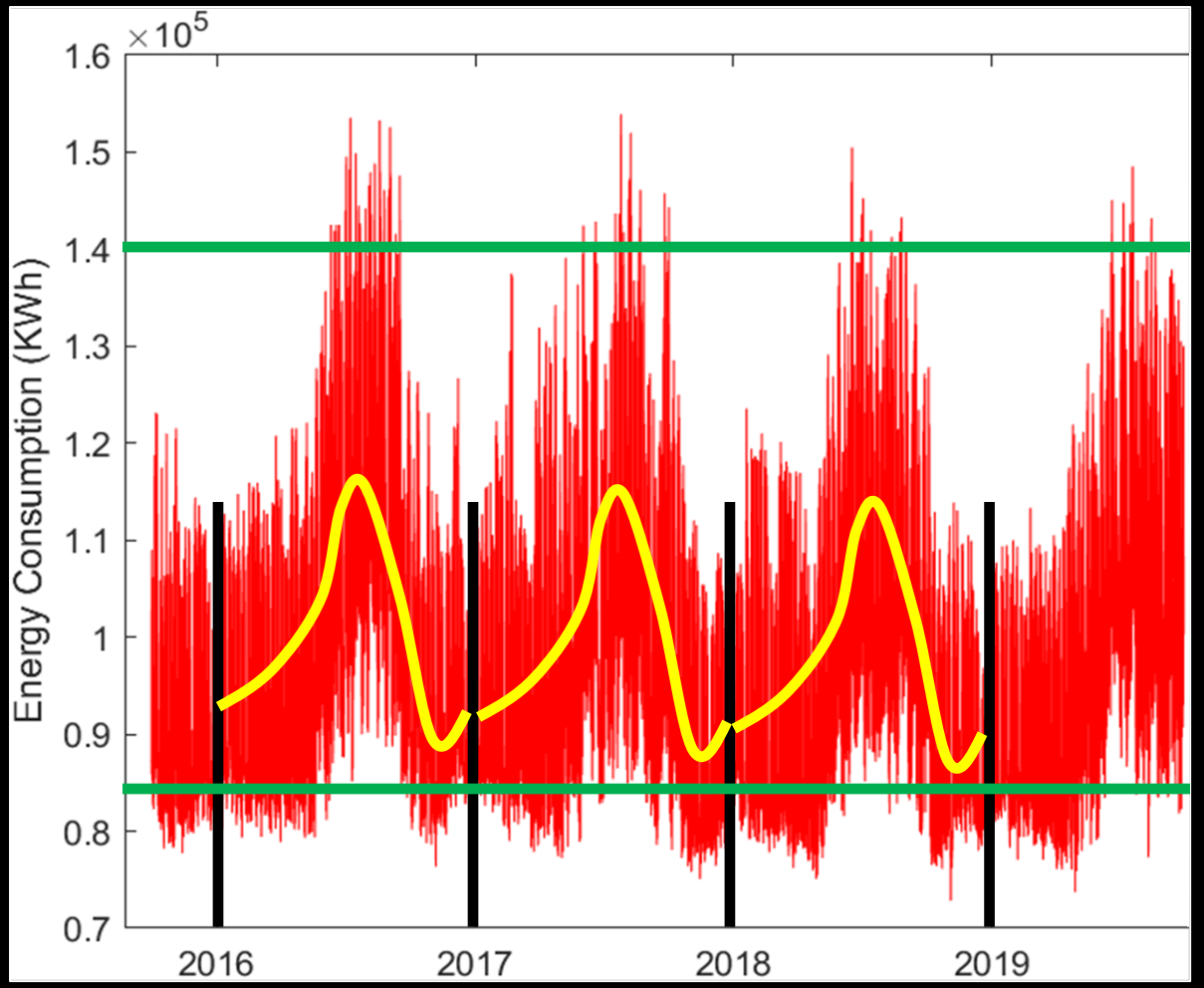
Facility Managers have a tough job

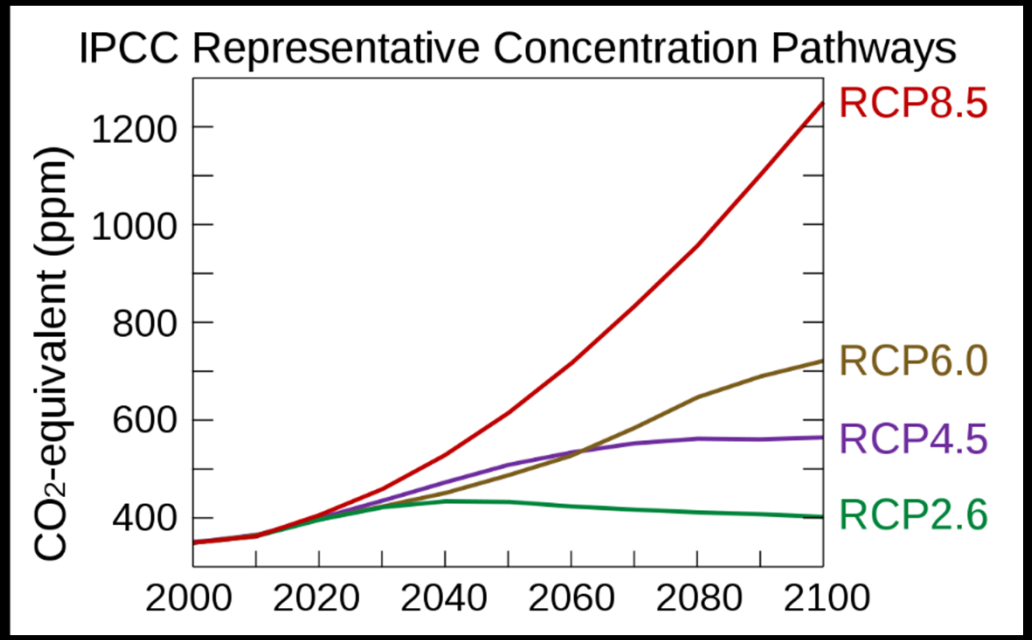
- Limited, variable, pilferable budgets!
- Contend with unexpected costs
- Stochastic elements strain budget projection accuracy

Energy use is pseudo stochastic, and affects operating budgets

- Interannual predictability
  "periodicity"
- Sub-annual uncertainty
- 30-minute resolution



The DoD recognizes climate as nat'l security threat (NDS-21)



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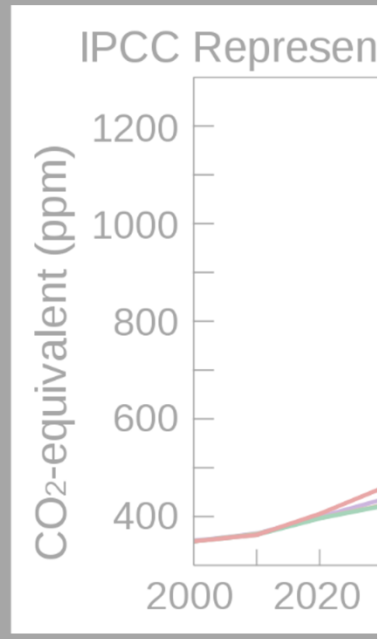


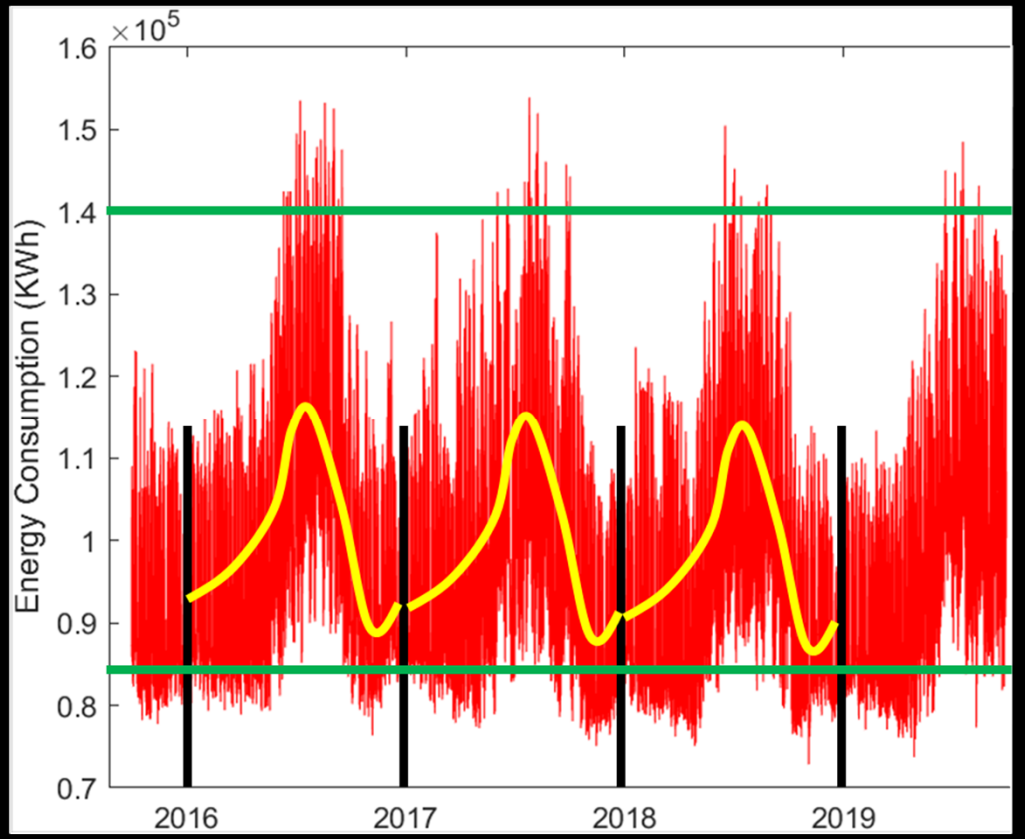
What are the determinants of energy use?

Can skillful models be developed to predict energy demand at an actionable temporal resolution?

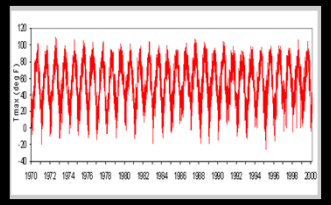
What could future energy demand look like under projections of climate change, and what are the expected costs?

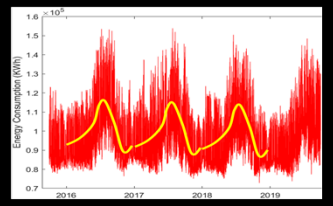
Why is Wright-Patterson AFB a suitable case study?

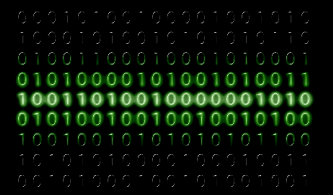
- **City equivalency**
  - Employs 30K / 26.5K facilities
- **Energy source diversity**
  - Coal, NG, commercial
- **Operational diversity**
  - Residential, commercial, industrial and community support



Temperature, periodicity, and time control energy use







Temperature

Periodicity

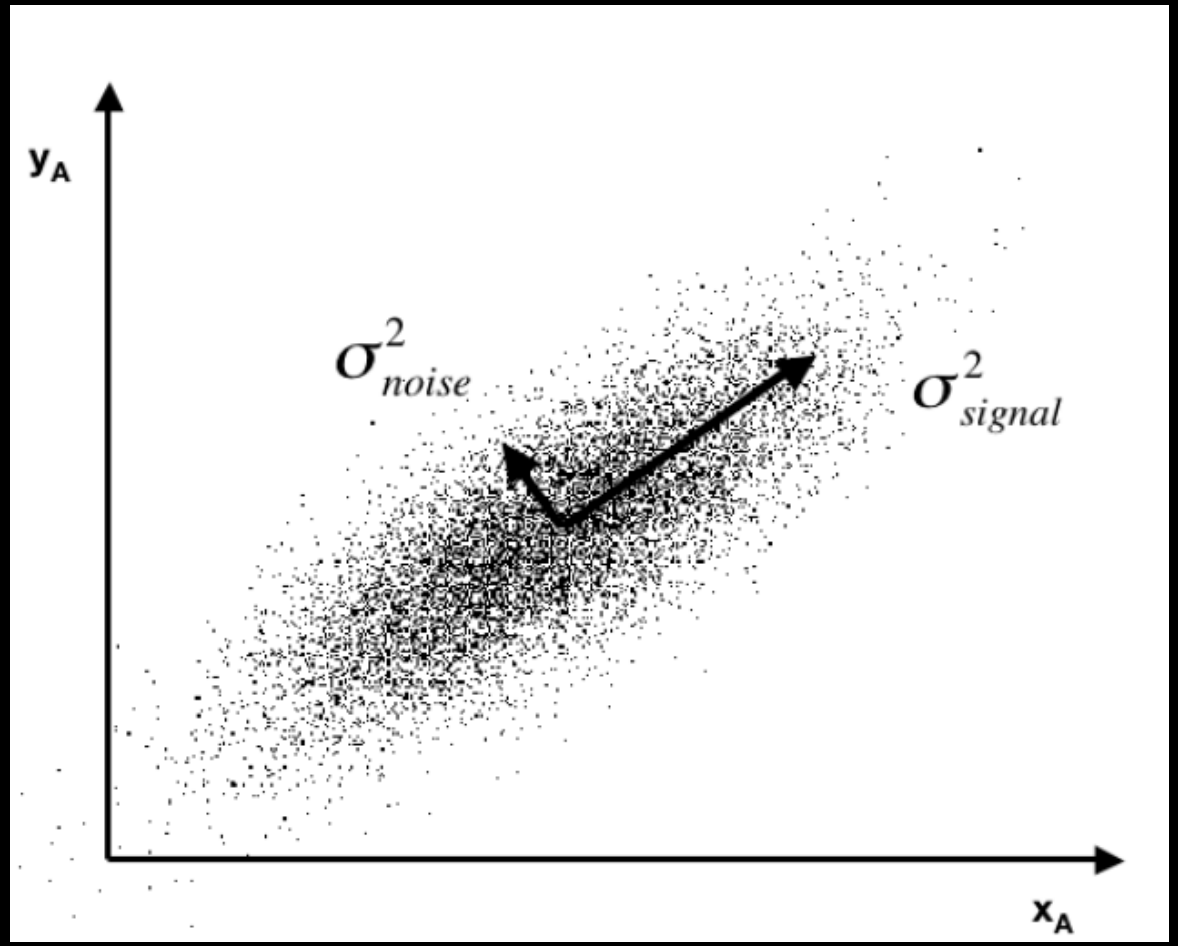
Time (30+)

Stat Model Gen (6)

Skill Comparison

Model based on principal component regression→cross validation→statistical correction

- PCR and cross validation reduce bias and eliminate multicollinearity
- Statistical bias correction corrects serial under/over prediction



Climate (temperature) and time variables are most influential for energy use prediction

- Having periodicity alone is not helpful
- Must have climate and time to account for sub-annual uncertainty

Models	Variance Explained (r^2)	MAPE	RPSS	Dimensionality Reduction	Dominant signals for PC1 and PC2 (input name, *Pearson's coefficient of correlation*)	
					PC1	PC2
Collective	0.73	6.25	0.57	30.5%	FourierTrans (0.87)	FourierTrans (0.94)

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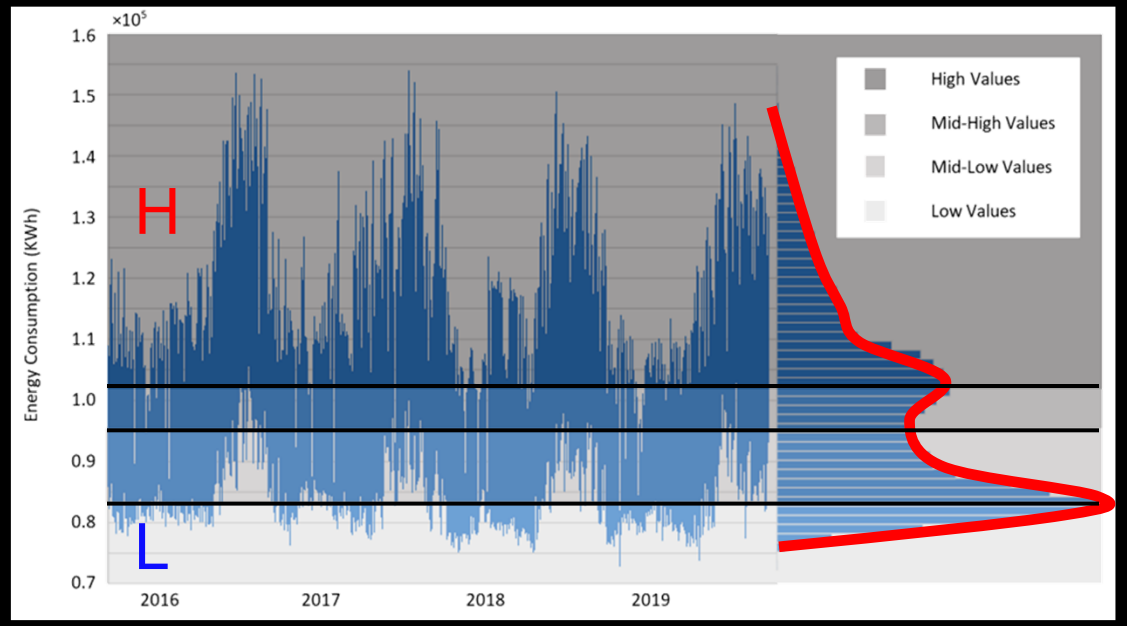
Categorical skill metrics best illustrate forecast skill for system-wide control

- Partitioned energy use enables *contingency table* skill assessment:

Did the forecast (modeled) category match the observed category?

- Relatively many hits per extreme miss



		Modeled			
		L	ML	MH	H
Observed	L	69.9	21.8	7.1	1.2
	ML	19	70.2	7.7	3.1
	MH	8.9	5.1	67.2	18.8
	H	2.2	2.9	18	76.9

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What have we learned?

- Our model explains ~75% of half-hourly energy consumption at the installation level.
- Temperature and time are most influential.

What does this mean?

- Opportunities exist to load-shed, particularly during periods of high energy demand (heating and cooling) and for facilities with low occupancy.
- Requires facilities can be individually controlled

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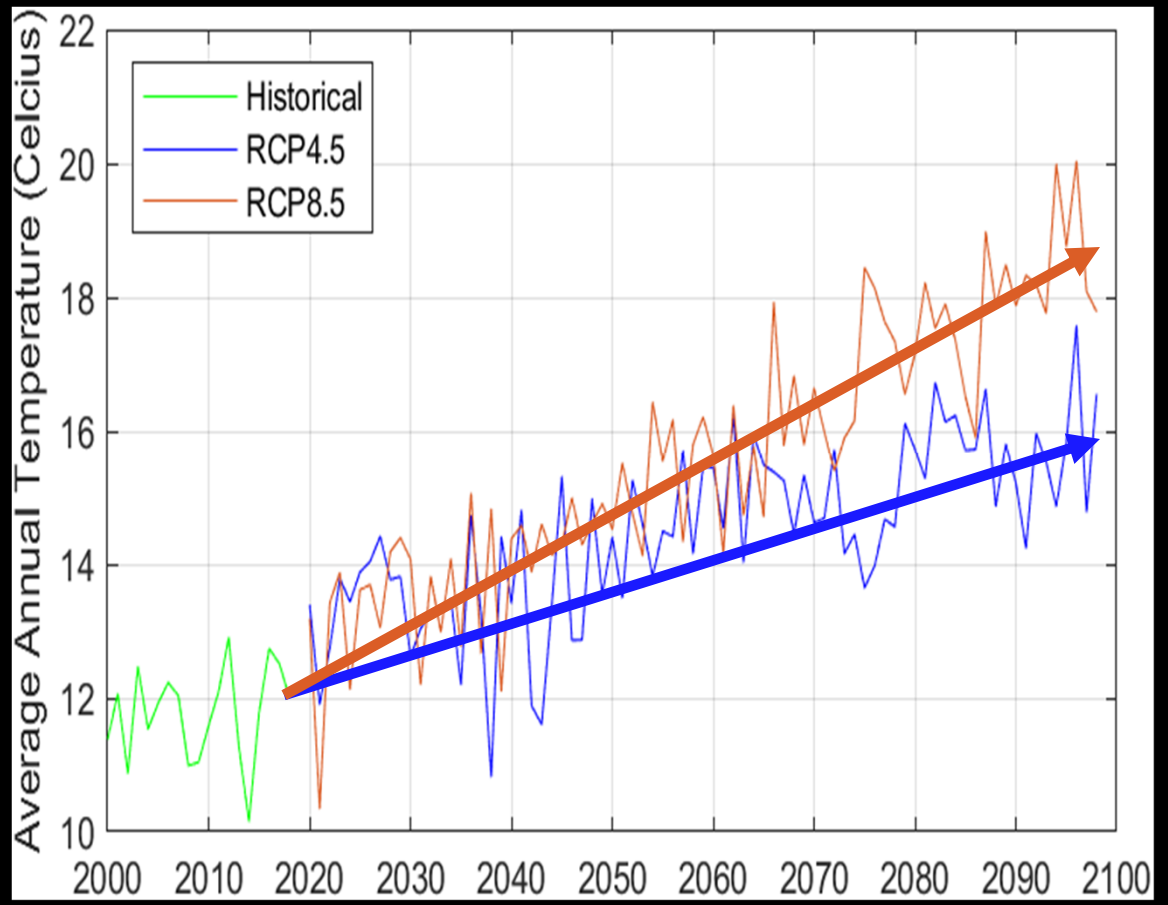
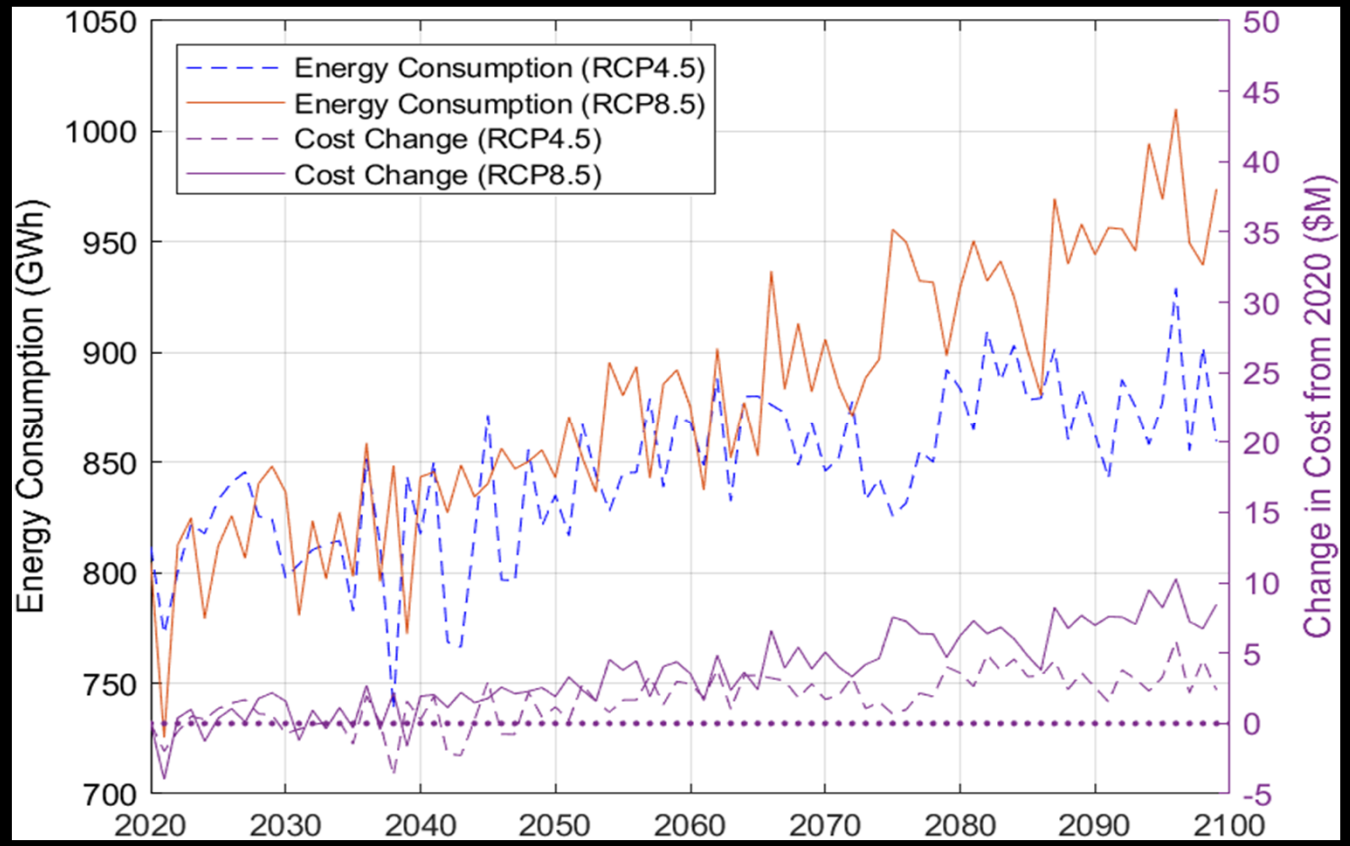
So now what?

- Predicting the past is interesting, but not compelling.
- Looking forward, we should understand how changing temperature could *affect consumption* and *cost*.
- Does increasing temperature mean increasing cost?



Energy gets expensive by the end of the century (↑$2.5-$7.5M/yr)



- 4.8% - 19.3% increase in energy use and costs by the end of the century
- Per-year increase: $40K-107K
- Both cases have permanently positive increases in energy use by 2050

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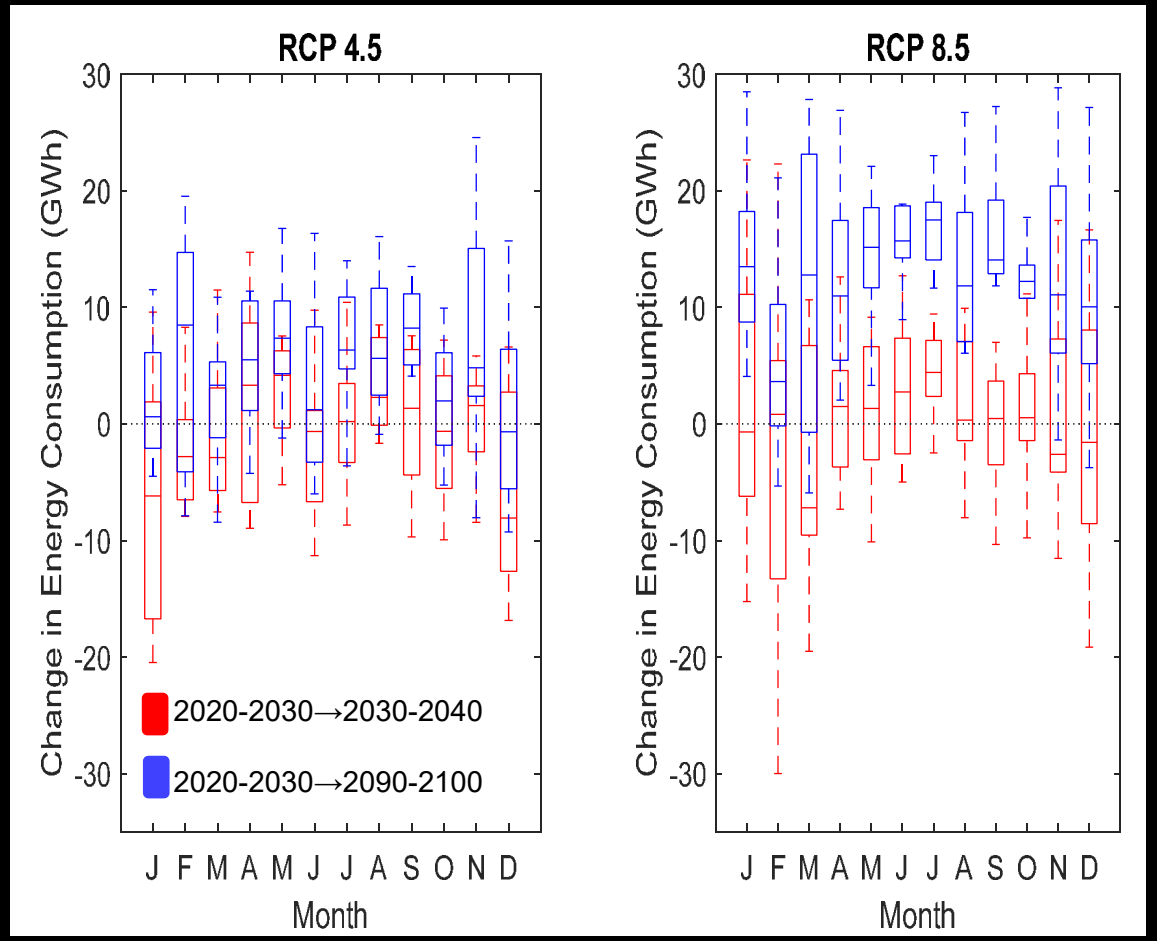
When are changes likely to happen during the year?

- Much less certainty in…
  - RCP 4.5 – less temperature increase
  - winter
- Clear increase in summer dominates overall upward trend



Change significance improves by end-of-century

Significance Compared to 2020-2030 Decade (*ANOVA test p-value*)

	2030-2040	2040-2050	2050-2060	2060-2070	2070-2080	2080-2090	2090-2100
Jan	–	–	–				
Feb	–	–		+		+	+
Mar		–			+		+
Apr				+	+	+	+
May		+	+	+	+	+	+
Jun				+	+	+	+
Jul		+	+	+	+	+	+
Aug	+	+	+	+	+	+	+
Sep		+	+	+	+	+	+
Oct				+		+	
Nov				+		+	+
Dec	–	–					

RCP4.5

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	2030-2040	2040-2050	2050-2060	2060-2070	2070-2080	2080-2090	2090-2100
Jan		+	+	+	+	+	+
Feb					+		+
Mar	–		+		+	+	+
Apr		+	+	+	+	+	+
May		+	+	+	+	+	+
Jun	+	+	+	+	+	+	+
Jul	+	+	+	+	+	+	+
Aug		+	+	+	+	+	+
Sep			+	+	+	+	+
Oct		+	+	+	+	+	+
Nov			+	+	+	+	+
Dec			+		+	+	+

RCP8.5

$p < 0.05$ $0.05 < p < 0.10$ $0.10 < p < 0.25$ $p > 0.25$

\+ positive change – negative change

Temporal inflection?

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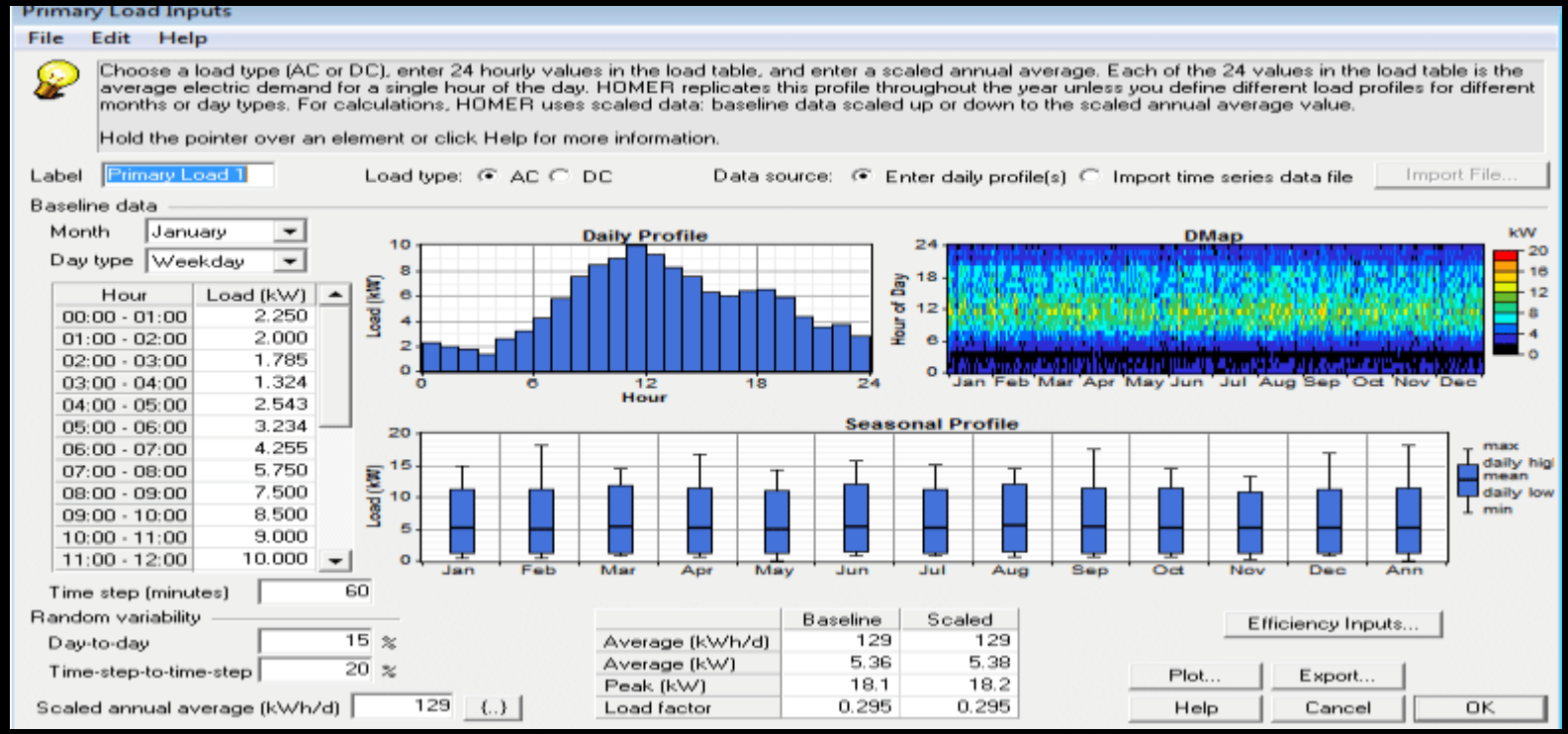
Cost change variability is small and largely remains positive

So if energy consumption and costs are expected to rise, and facility operating budgets do not keep pace, what can (should) be done?

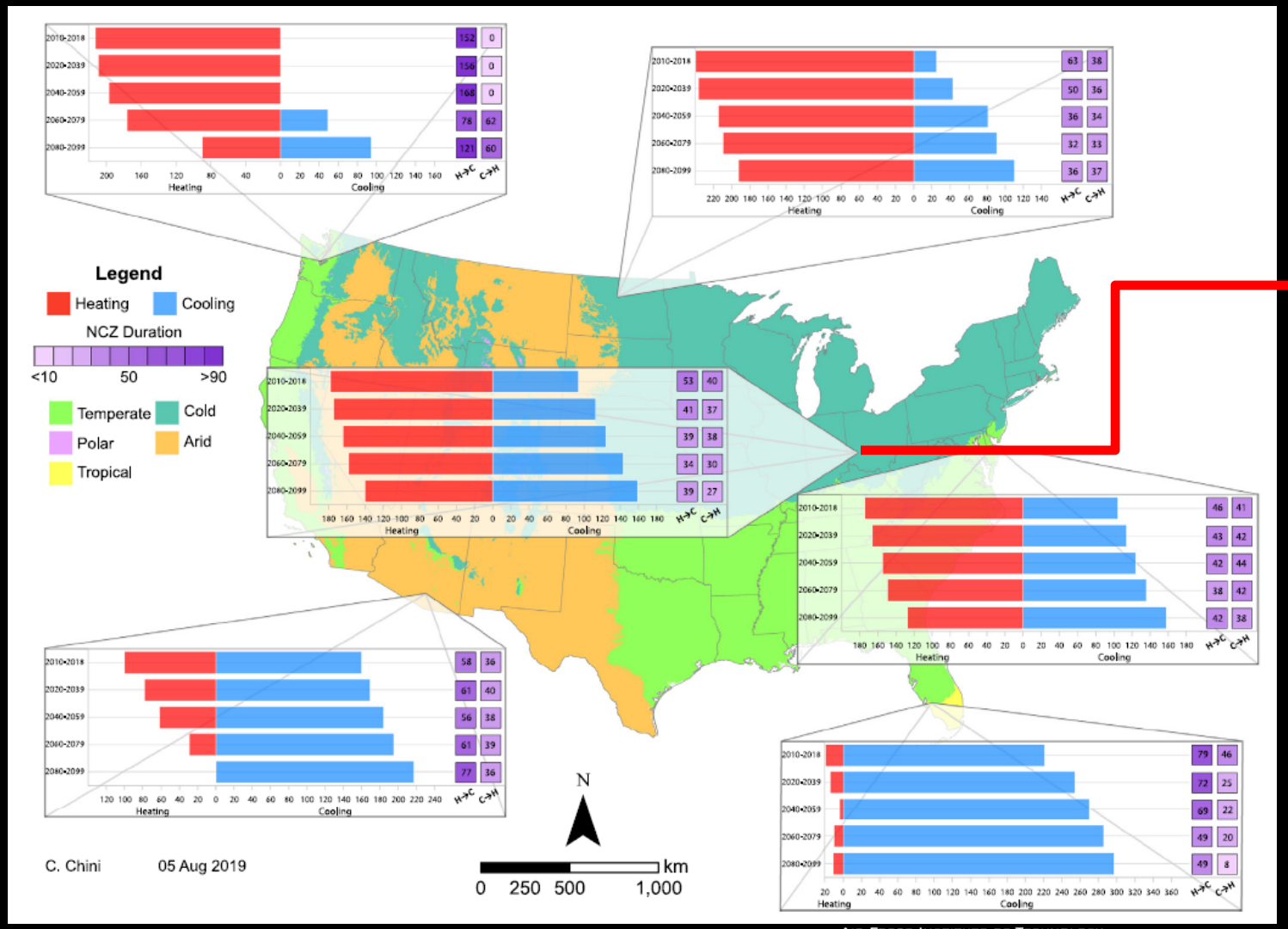
Are there mixtures of hard and soft adaptations that can stabilize year-to-year operating budgets?

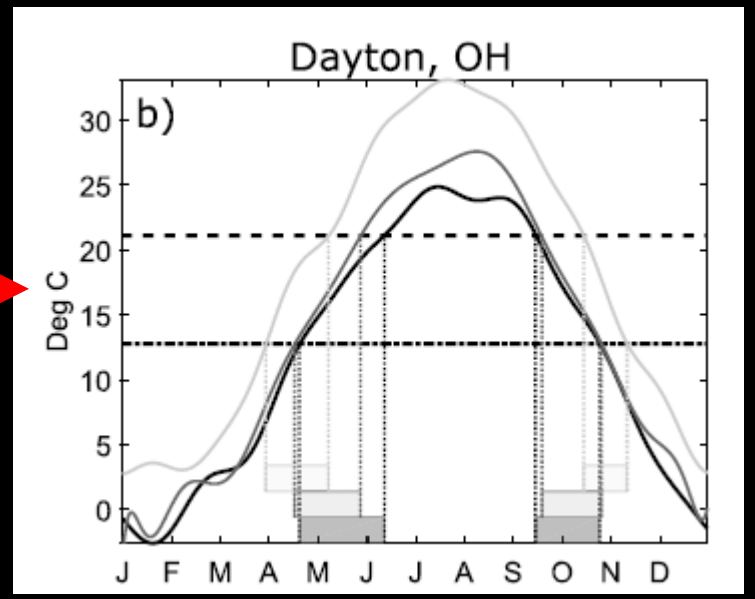
Hard adaptations: Micro and mega-grids may offset commercial demand

- Must consider return on investment (project underway)
- Generating capacity is high based on solar irradiation and cloud cover

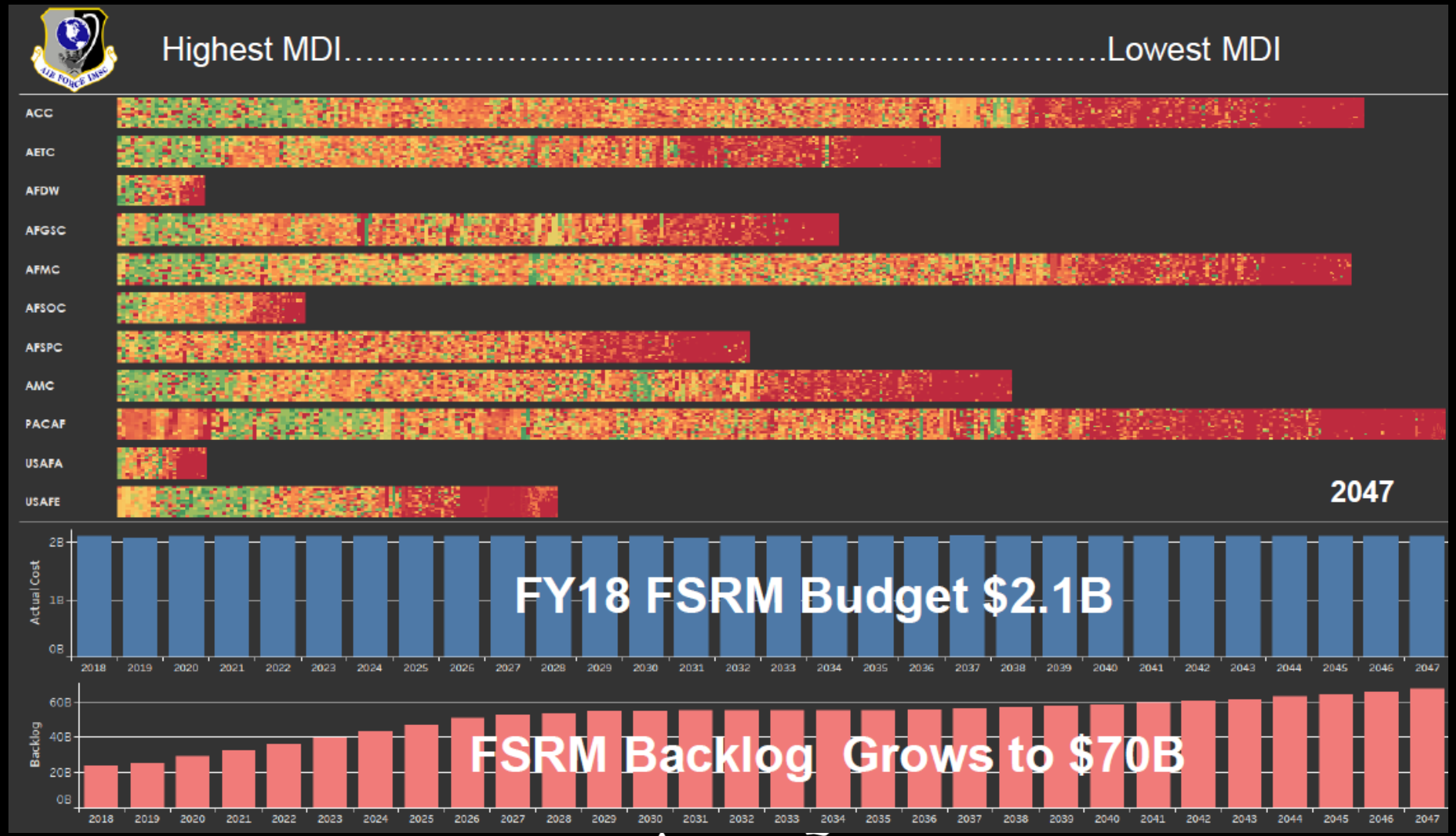


Soft adaptations: Non-conditioned ‘zones’ to reduce shoulder-season consumption





Competing priorities suggest early action is required!



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Limitations and Conclusions

- Model capable of…
  - predicting finely resolved temporal energy use
  - forecasting future demand and cost change
- But…
  - Does it change anything for the facility manager?
  - Does utility depend on the level and span of control?
- Based on our calibrated model, there is still ~25% unexplained variability
- Cost of energy and installation makeup are held constant across simulations

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So, is it worth installing meters on every facility?

- Likely not, unless…
  - You have the means, knowledge, and authority to control systems
    1. Can systems be centrally controlled?
    2. Do you understand how your people and systems use energy?
    3. Do you have the authority to manage energy use either through systems or policy?

- And if you do, consider granularity at which you collect data.
  - It's not worth paying for 30-minute resolution if you cannot manage at that scale.

Thank you

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