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Live Q&A Session 2 Building Energy Modeling and Hygiene-related HVAC Design

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Five Years Later: A Building Energy Modeling Fleet's Second Round Institutional Energy Retrofit Analysis (LV-22-C063)

Learning Objectives

1. Understand about energy retrofit decision metrics for multiple buildings
2. Elaborate how differences in weather can have a significant affect on energy retrofit decisions

Acknowledgements

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Introduction

- Conventional building energy modeling (BEM):
  - 1 building
  - Multiple energy retrofits (retrofits)
  - 1 weather history
- **Objective:** Show what retrofit performs best for a calibrated model and constant weather

- 2 **disruptions** require expansion beyond conventional BEM

  Q1: Do differences in historic weather or projected future weather change how well retrofits perform?

  Q2: Do changes to BEM change how well retrofits perform?
- New institutional BEM analyses:
  - Multiple buildings
  - Multiple energy retrofits
  - Multiple weather histories: Uncertainty of future extreme weather events and historical weather
- The new approach makes deciding what to do more difficult
  - Metrics to aid decision processes are needed

Disruption 1: Climate Change

- Future weather will not be the same as historic weather (IPCC, 2021)

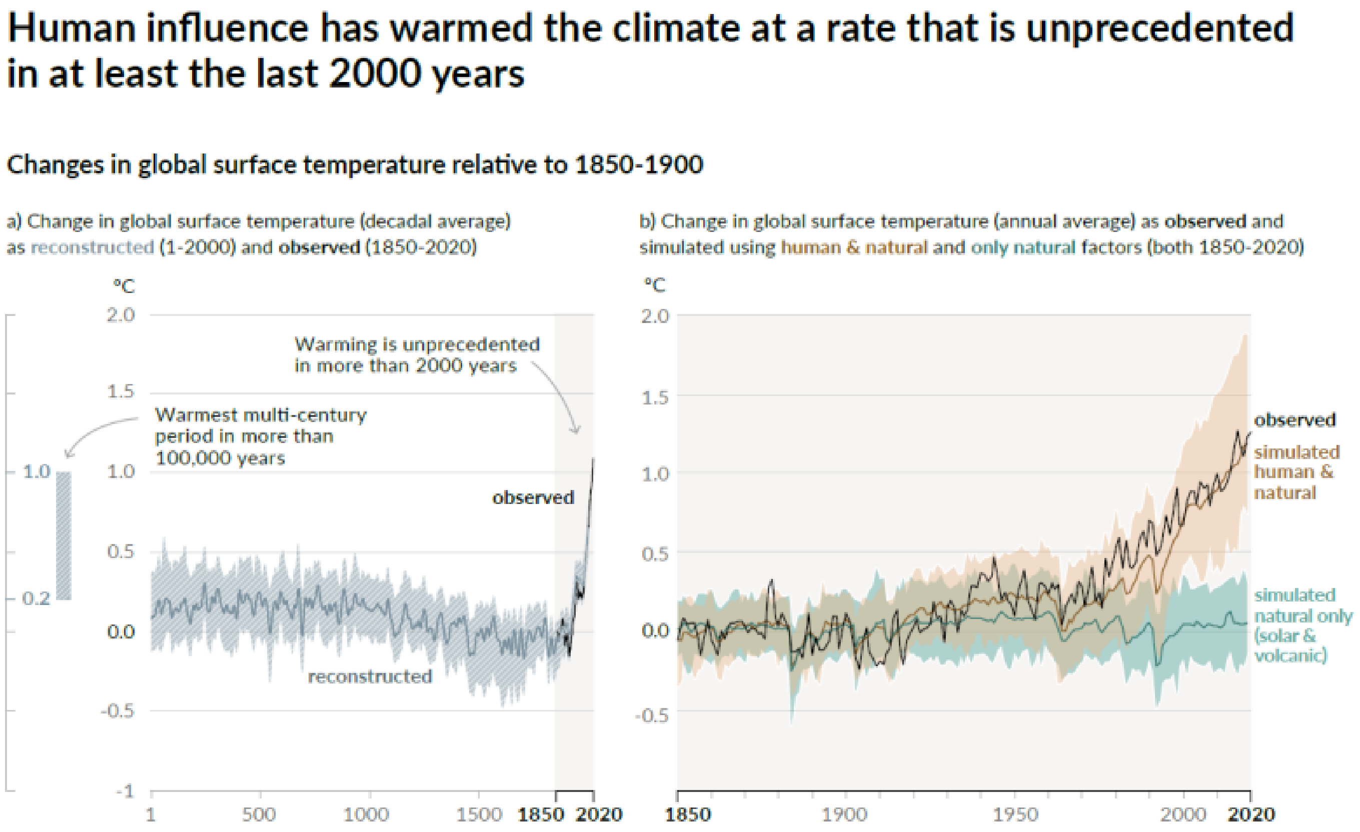


Figure SPM.1: **History of global temperature change and causes of recent warming.**

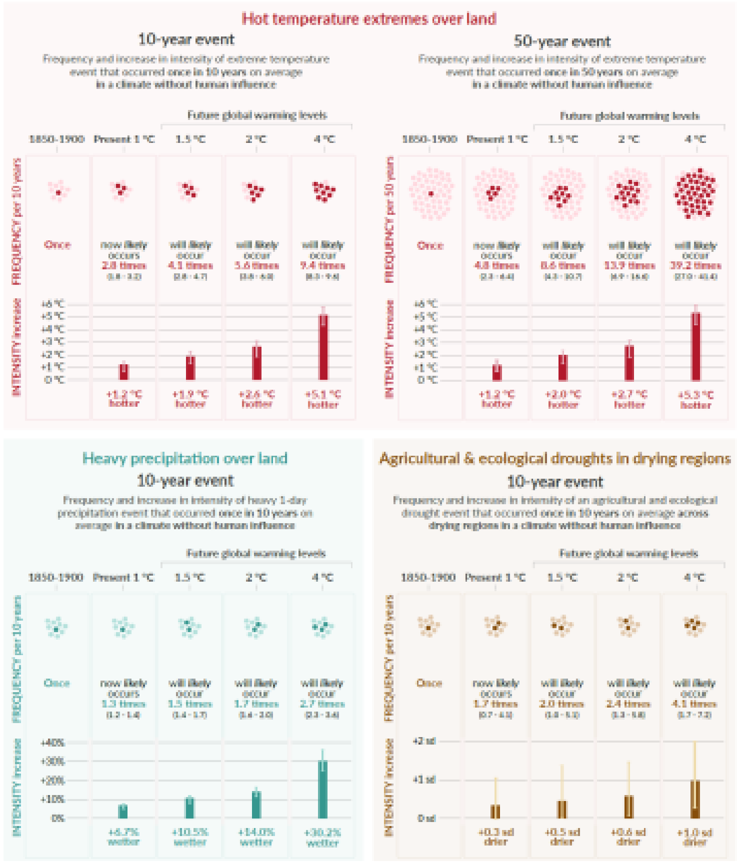


Figure SPM.6: **Projected changes in the intensity and frequency of hot temperature extremes over land, extreme precipitation over land, and agricultural and ecological droughts in drying regions.**

Disruption 2: Institutional Energy Modeling

- The future of BEM will include cross comparisons between many buildings

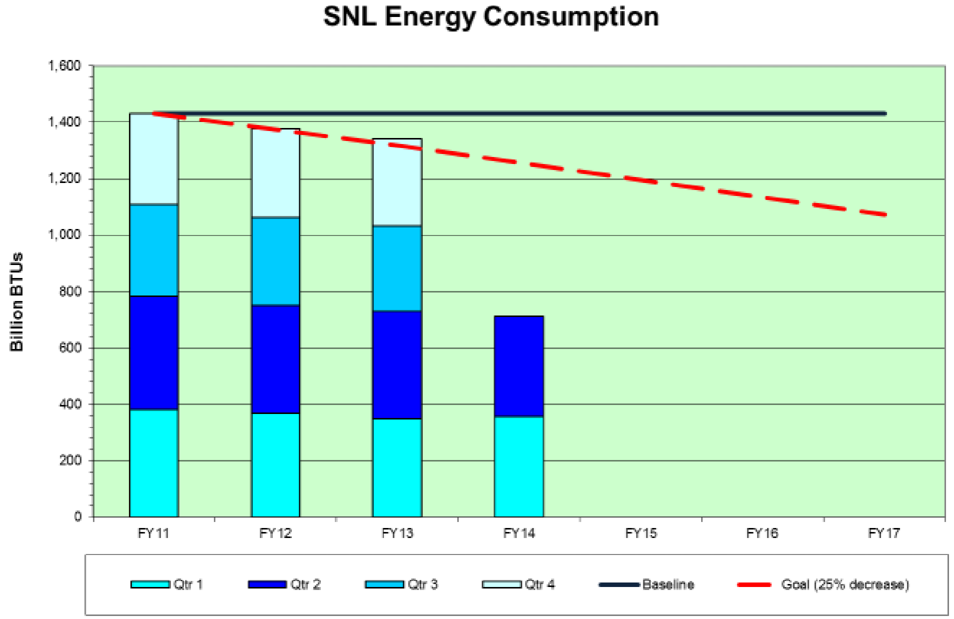
Institutional planners need to be able to synthesize energy retrofit plans across 100-1000’s of buildings on budgets that can only implement the most effective measures

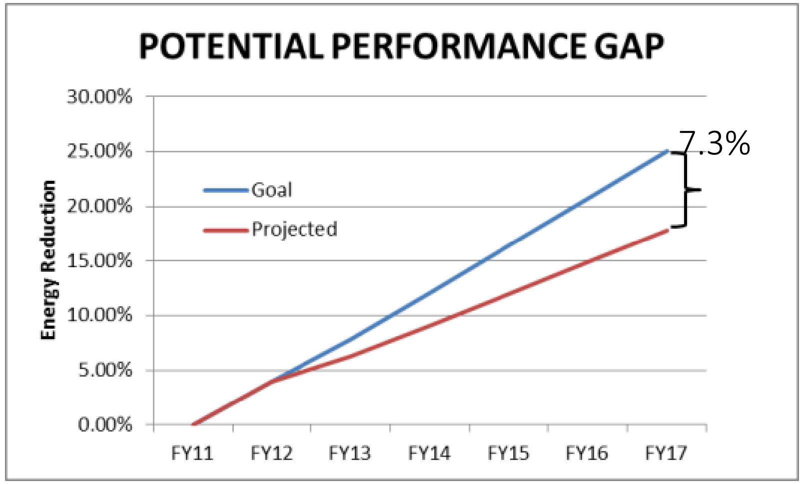
Uncertainty in energy savings is needed

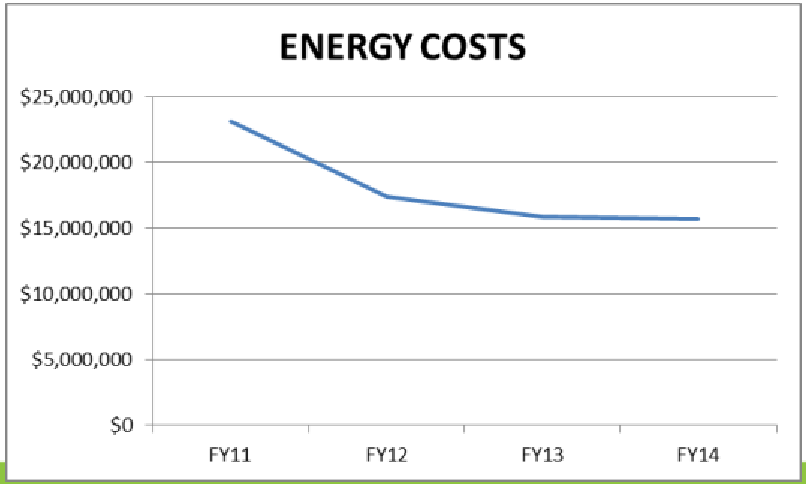
Finding the most effective retrofits is like looking for a needle in a haystack from the institutional perspective

1st Site-wide energy retrofit analyses (2014)

Institutional Transformation (IX) software using 120 BEM indicated the FY11 25% performance goal would not be met and that only 19% energy savings could be achieved without intrusive operational measures







Goal	3.9%	7.8%	12.1%	16.4%	20.7%	25%
Actual	3.7%	6.2%	9.2%*			IX Max potential = 19%

* Through first two quarters of FY 14

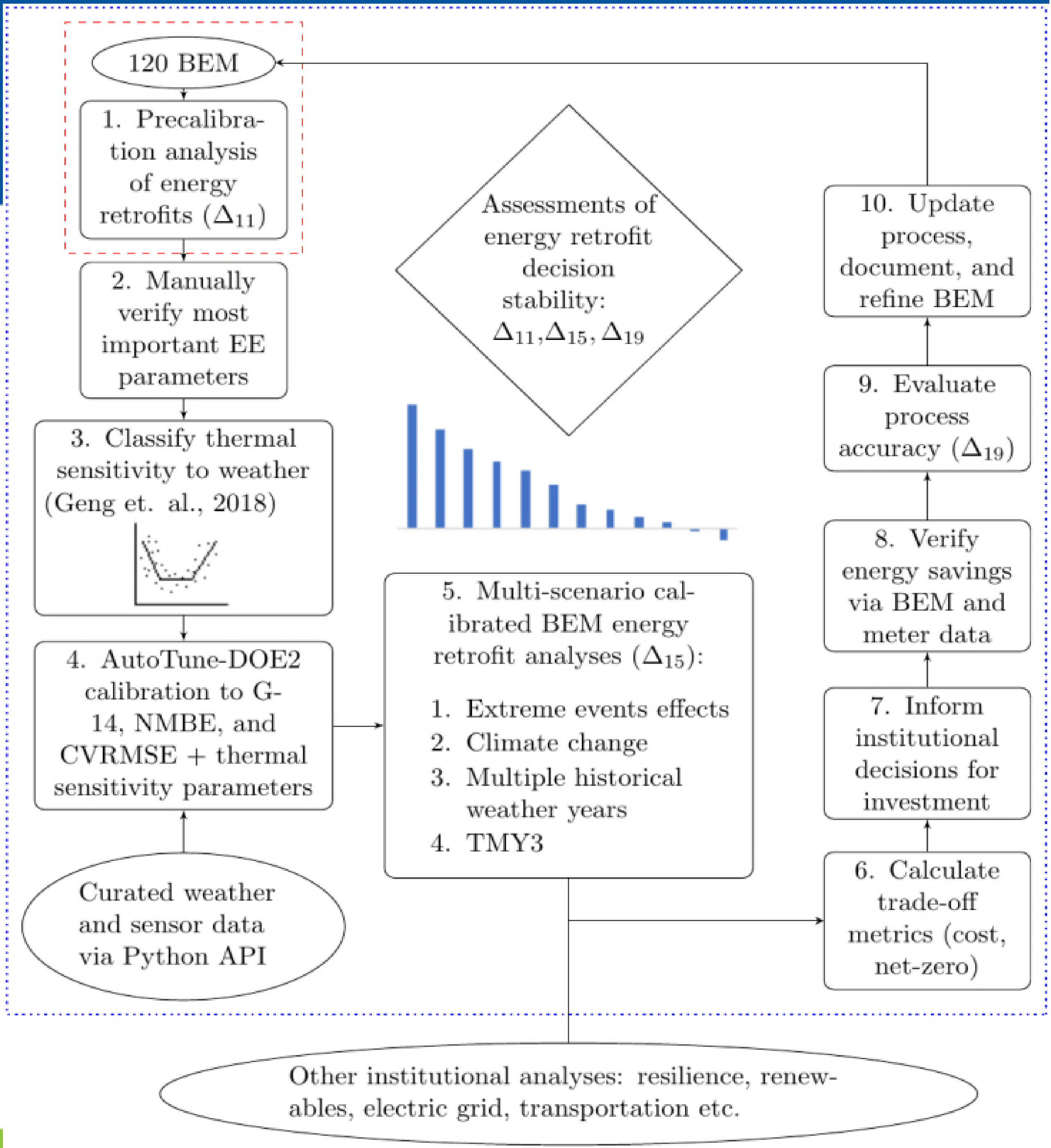
2017 IX report with general description at: https://doi.org/10.2172/1367500

5 years later…

New Energy Assessment Process

Goals:

1. Establish a culture of energy modeling that cyclically improves and maintains a BEM fleet
2. Include:
   a. Self-consistency and uncertainty analyses of retrofit decisions
   b. Post-retrofit verification of energy savings
3. Create new metrics that quantify the relative accuracy of site-wide sequences of retrofit decisions for different future weather scenarios



What do the Δ_{1s} metrics represent?

Energy savings difference between weather year w and baseline weather year ω for **uncalibrated energy models (i.e. step 1)**

Energy savings difference between weather year w and baseline weather year ω for **steps**

$$\Delta_{1s_{w,d}} = \frac{\sum_{k=d_1}^{d} A_k\left[\left(\Delta E_{1,w,k} - \Delta E_{1,\omega,k}\right) - (1-\delta_{1s})\left(\Delta E_{s,w,k} - \Delta E_{s,\omega,k}\right)\right]}{\sum_{k=d_1}^{d_n} A_k\left(\Delta E_{1,\omega,k} - (1-\delta_{1s})\Delta E_{s,\omega,k}\right)}$$

w = index over weather years,
ω = baseline weather year
b = index over buildings
s = step number (previous slide)
r = index over energy retrofits

- $\Delta_{1s_{w,d}}$ is analogous to a derivative of energy savings with respect to weather and step numbers (BEM updates). For s =1, Δ_{11} only includes differences for weather.
- Δ_{1s} will maintain a value of zero across all decisions if weather and BEM updates make no differences in the energy savings
- Δ_{1s} is expected to diverge as more retrofit decisions are made where a value represents the fraction of energy savings difference for the baseline weather year.
- The speed of this divergence provides feedback concerning how much confidence one can have in a retrofit decision

Energy Retrofit Decision Metrics Δ_{1s}

1. Choose baseline weather year
2. Calculate energy savings for all weather years available

$$\Delta E_{s,w,b,r} = E_{s,w,b} - E_{s,w,b,r}$$

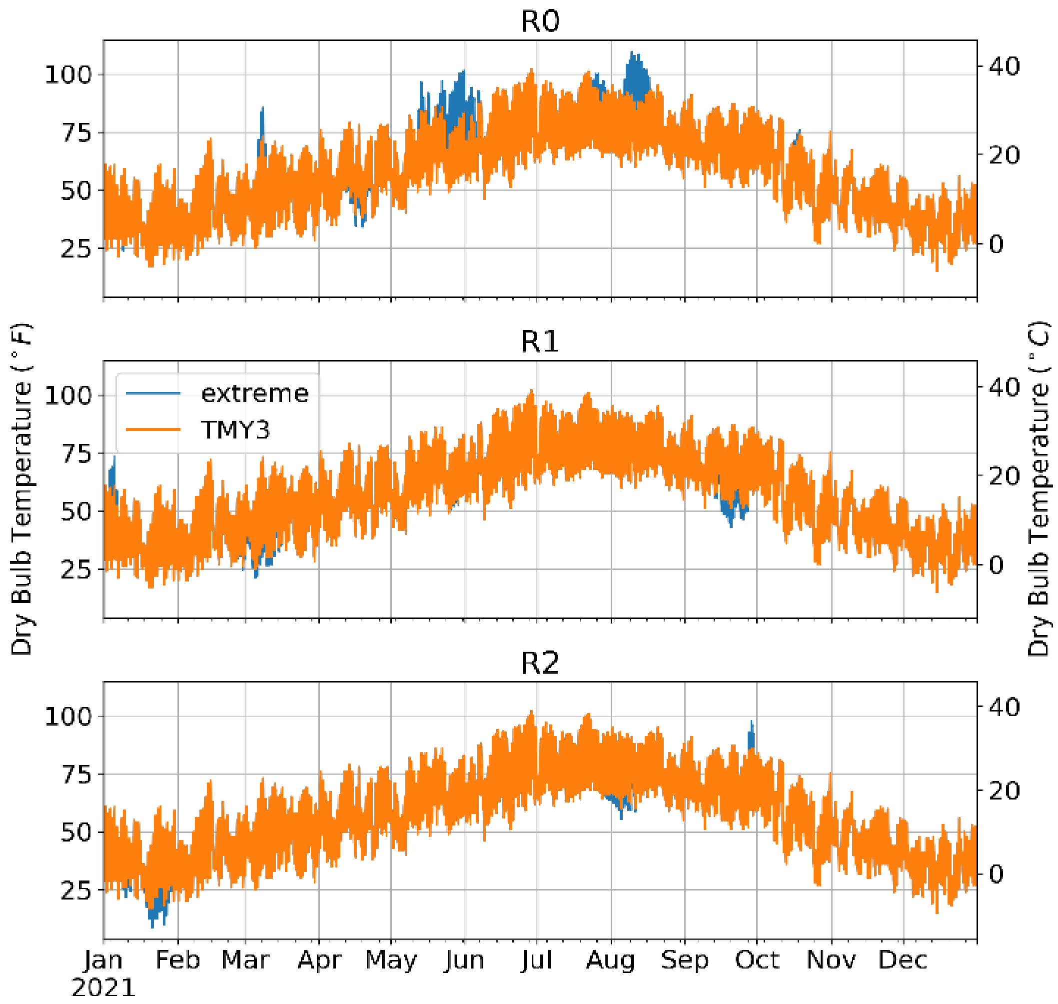
Form a new index d over the set of paired retrofit and building tuples
$D = \{ (b_1, r_1), (b_2, r_2), \ldots, (b_n, r_n)\}$
Here, (b_1, r_1) is the building and retrofit for which the most energy savings per area are realized

3. For the baseline energy year, sort energy savings per building area A_b from highest to lowest values.
4. Calculate the family of metrics below:

$$\Delta_{1s_{w,d}} = \frac{\sum_{k=d_1}^{d} A_k \left[\left(\Delta E_{1,w,k} - \Delta E_{1,\omega,k}\right) - \left(1 - \delta_{1s}\right)\left(\Delta E_{s,w,k} - \Delta E_{s,\omega,k}\right)\right]}{\sum_{k=d_1}^{d_n} A_k \left(\Delta E_{1,\omega,k} - \left(1 - \delta_{1s}\right)\Delta E_{s,\omega,k}\right)}$$

δ is the Dirac delta
A_k is the area of the building for decision d_k

Weather inputs and characteristics



Multi-scenario extreme weather simulator (MEWS) version 0.0.1 inputs: https://github.com/sandialabs/MEWS

Input	Value
Markov chain transition probability matrix	$\begin{bmatrix} 0.99 & 0.01 & 0.01 \\ 0.15 & 0.85 & 0.00 \\ 0.15 & 0.00 & 0.85 \end{bmatrix}$
Weather file	Albuquerque International Airport TMY3
Extreme heat lognormal inputs to produce $°F \cdot hr/hr$ ($°C \cdot hr/hr$)	μ = 1.800 (1.212), σ = 0.5 (0.5)
Extreme cold lognormal inputs to produce	μ = 1.000 (0.412), σ = 0.5 (0.5)
Random seed	434186856231

	CDD ($°F \cdot day$)	HDD ($°F \cdot day$)	CDD ($°C \cdot day$)	HDD ($°C \cdot day$)
2017	1491	-3353	828	-1863
2018	1696	-3840	942	-2133
2019	1485	-4235	825	-2353
2020	2336	-3205	1298	-1780
TMY3	1218	-4278	676	-2376
R0	1613	-4259	896	-2366
R1	1178	-4350	654	-2417
R2	1192	-4401	662	-2445

CDD = Cooling Degree Days, HDD = Heating Degree Days

Outputs

Example with 97 NM BEM and 2 energy retrofits – insulate roof and External Finish Insulation System (EFIS)

	Description	Area (m2)	2017 (kWh)	2018 (kWh)	2019 (kWh)	2020 (kWh)	TMY3 (kWh)	R0 (kWh)	R1 (kWh)	R2 (kWh)
1	Building 1 EFIS	1.8e+03	5.0e+05	9.5e+05	9.7e+05	9.6e+05	5.4e+05	4.4e+05	5.3e+05	6.3e+05
2	Building 2 EFIS	2.6e+03	3.6e+05	5.3e+05	5.7e+05	4.8e+05	4.6e+05	4.6e+05	4.7e+05	4.7e+05
3	Building 3 EFIS	1.9e+03	1.3e+05	2.7e+05	3.1e+05	2.9e+05	1.7e+05	1.7e+05	1.8e+05	1.8e+05
4	Building 4 Insulate Roof	9.9e+02	2.1e+04	6.1e+04	6.5e+04	6.6e+04	2.8e+04	2.8e+04	2.9e+04	3.1e+04
5	Building 5 Insulate Roof	1.6e+03	3.3e+04	6.7e+04	7.0e+04	6.8e+04	4.4e+04	4.3e+04	4.3e+04	4.6e+04
6	Building 6 EFIS	1.3e+03	1.8e+04	3.2e+04	4.0e+04	3.8e+04	2.2e+04	1.4e+04	2.1e+04	2.0e+04
7	Building 1 Insulate Roof	1.8e+03	4.4e+04	6.7e+04	4.9e+04	5.1e+04	3.3e+04	6.6e+04	2.4e+04	8.2e+04
8	Building 7 EFIS	2.9e+03	1.2e+05	7.9e+04	7.5e+04	8.0e+04	8.5e+04	8.9e+04	8.8e+04	8.9e+04
9	Building 8 EFIS	1.2e+03	1.4e+04	2.9e+04	3.3e+04	3.1e+04	2.1e+04	1.8e+04	2.0e+04	2.2e+04
10	Building 9 EFIS	1.8e+03	5.2e+04	4.6e+04	4.8e+04	4.4e+04	4.1e+04	5.8e+04	4.4e+04	4.0e+04
11	Building 5 EFIS	1.6e+03	2.3e+04	3.8e+04	4.3e+04	3.8e+04	3.4e+04	3.3e+04	3.3e+04	3.6e+04

	Description	Area (ft2)	2017 (BTU)	2018 (BTU)	2019 (BTU)	2020 (BTU)	TMY3 (BTU)	R0 (BTU)	R1 (BTU)	R2 (BTU)
1	Building 1 EFIS	1.9e+04	1.7e+09	3.3e+09	3.3e+09	3.3e+09	1.8e+09	1.5e+09	1.8e+09	2.2e+09
2	Building 2 EFIS	2.8e+04	1.2e+09	1.8e+09	1.9e+09	1.7e+09	1.6e+09	1.6e+09	1.6e+09	1.6e+09
3	Building 3 EFIS	2.0e+04	4.3e+08	9.3e+08	1.1e+09	9.9e+08	5.8e+08	6.0e+08	6.0e+08	6.0e+08
4	Building 4 Insulate Roof	1.1e+04	7.2e+07	2.1e+08	2.2e+08	2.3e+08	9.7e+07	9.6e+07	9.9e+07	1.0e+08
5	Building 5 Insulate Roof	1.8e+04	1.1e+08	2.3e+08	2.4e+08	2.3e+08	1.5e+08	1.5e+08	1.5e+08	1.6e+08
6	Building 6 EFIS	1.4e+04	6.2e+07	1.1e+08	1.3e+08	1.3e+08	7.6e+07	4.9e+07	7.3e+07	6.8e+07
7	Building 1 Insulate Roof	1.9e+04	1.5e+08	2.3e+08	1.7e+08	1.7e+08	1.1e+08	2.3e+08	8.1e+07	2.8e+08
8	Building 7 EFIS	3.1e+04	4.2e+08	2.7e+08	2.6e+08	2.7e+08	2.9e+08	3.0e+08	3.0e+08	3.0e+08
9	Building 8 EFIS	1.3e+04	4.8e+07	9.8e+07	1.1e+08	1.0e+08	7.2e+07	6.3e+07	6.9e+07	7.4e+07
10	Building 9 EFIS	1.9e+04	1.8e+08	1.6e+08	1.6e+08	1.5e+08	1.4e+08	2.0e+08	1.5e+08	1.4e+08
11	Building 5 EFIS	1.8e+04	8.0e+07	1.3e+08	1.5e+08	1.3e+08	1.2e+08	1.1e+08	1.1e+08	1.2e+08

Baseline year

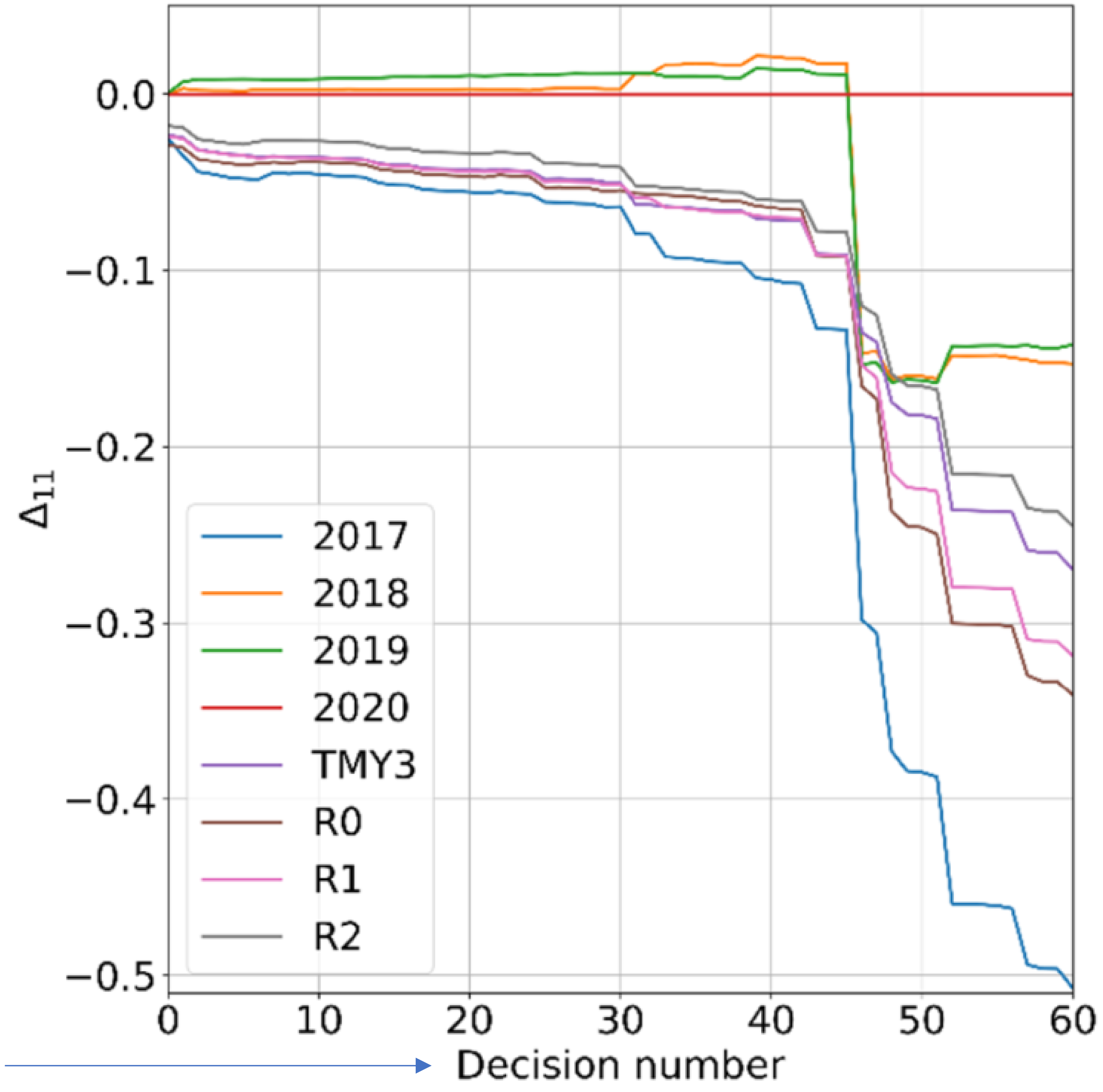
Energy Metric Conclusions

Take-aways:

1. Don't even consider past decision 40!

2. BEM engine errors on ECM's may also cause Δ_{11} to diverge from 0—We do not want to hinge decisions on numerical bugs!

3. Weather makes a significant difference!



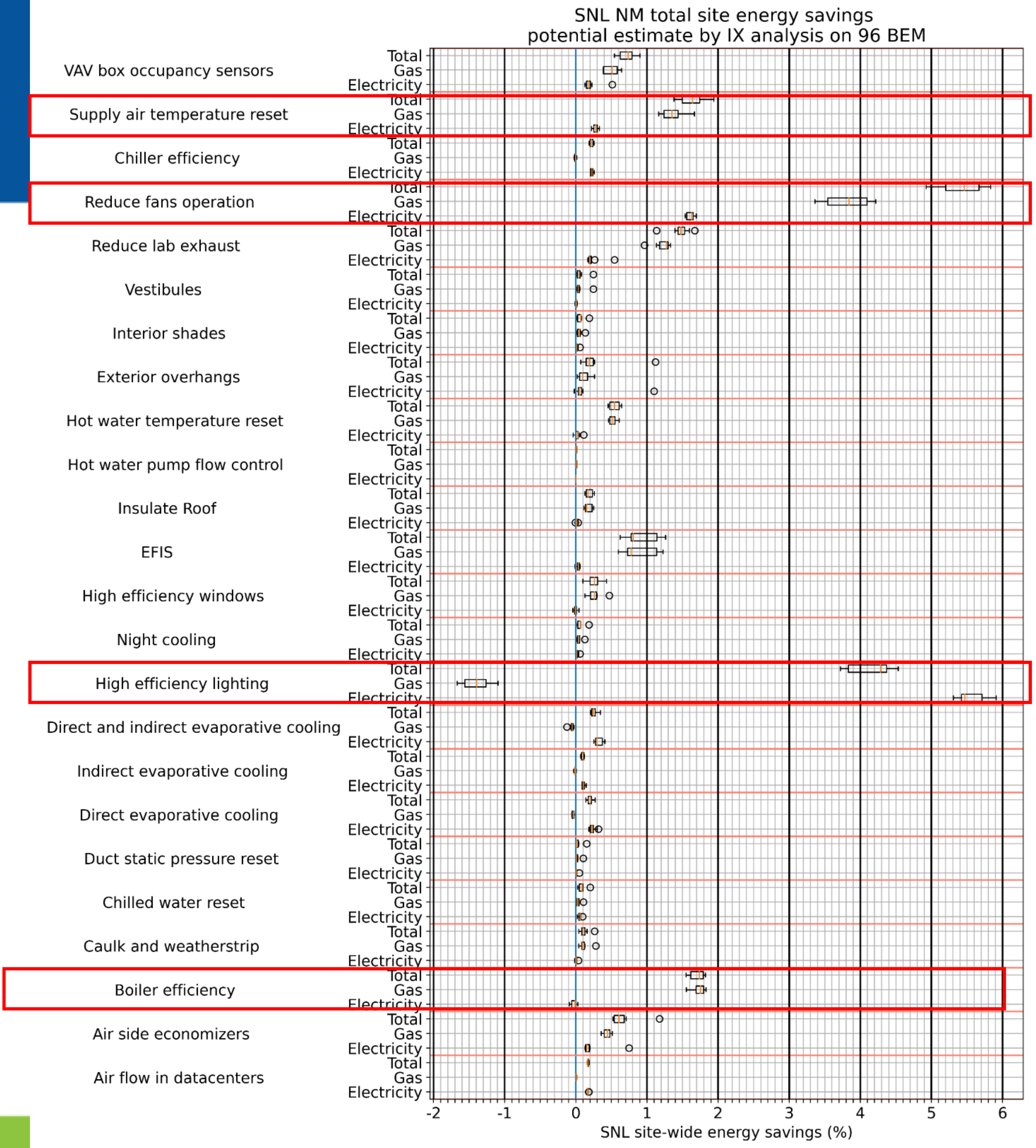
1st 60 of 130 decisions

Preview of Step 1 completion

Uncertainty bounds reflect weather differences

Most effective measures:

1. Lighting
2. Fan operations
3. Boilers
4. Supply air temperature reset



Total site-wide potential

- These numbers are the maximum potential
  - Cannot add all energy retrofits without changes in thermal behavior
- The same total potential (~19%) here as in 2013-2014 first assessment
- Changes to the BEM have not made significant differences.
- Real site potential depends on whether each energy retrofit is implementable
- This is the **maximum potential for incremental changes** that do not include CUB plant type savings or major changes to operations.

Weather	Electricity (%)	Gas (%)	Total (%)
2017	10.37	8.67	19.04
2018	9.49	10.65	20.14
2019	9.09	9.58	18.67
2020	8.80	9.92	18.72
TMY3	11.71	9.61	21.33
R0	8.64	9.52	18.16
R1	9.34	10.71	20.05
R2	8.69	10.12	18.81
Mean	9.52	9.85	19.37
Std	1.05	0.67	1.05

Conclusions

- Energy retrofit decisions are significantly affected by weather
- Uncertainty is an important part of institutional BEM energy retrofit analyses
- Decision stability metrics like Δ_{11} can reveal what decisions are robust w/r to uncertainty due to weather and BEM changes
- 5 years later, the energy assessment site-wide energy saving potential has not changed significantly despite significant changes to 120 BEM through quality checks and auto-calibrations to ASHRAE Guideline 14

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