SAND2019-5490C

Conference Paper Session 3: Building Energy Modeling in Large Institutions and Schools

First Steps to Maintain a Large Fleet of Building Energy Models

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KANSAS CITY

Learning Objectives

- Understand issues related to autocalibrating building energy models (BEM) of existing buildings.
- Recognize the complexity of continuous maintenance of large fleets of BEMs of existing buildings.

Acknowledgements

- Sandia National Laboratories Building Systems Engineering Department for 7 years of progressive thought concerning new applications about building energy modeling
- Thanks to my God and Savior, Jesus Christ.
- My wife Marina and kids Sophia, Amanda, Miguel, Francesca, Cordelia, Timothy, and Trinity

Outline/Agenda

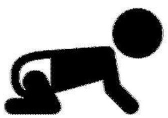
- Introduction
  - A new way of working with BEM
  - Energy Independence and Security Act (EISA) 2007 compliance
- Methods
  - Automatic preparation of models for autocalibration
  - Buildings calibrated for 2018
  - Quality checks
  - Autocalibration
  - Report format
- Results
  - Normalized Mean Bias Error (NMBE) and Coefficient of Variation for Root Mean Square Error (CV(RSME)) for 5 buildings…12 soon to follow
  - Drastic changes to parameters
- Conclusion
  - More buildings recalibrated every year
  - BEM parameter classification

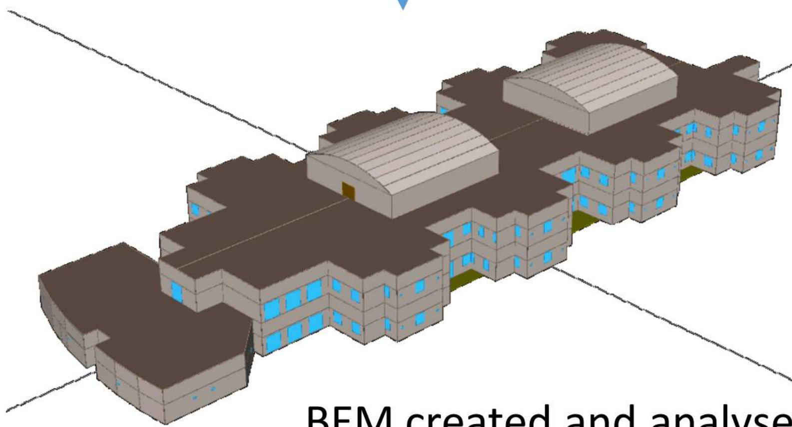
Introduction

- Potential markets for BEM expanding and changing (Hong et. al., 2018)
- Includes en-masse use of BEM on existing buildings (Villa et. al., 2017)
  - Big data, machine learning, and parallel computing may enable this by providing semi-automated methods to quickly build and update BEM.
- Auto-generation of entire campuses and cities through urban BEM is common (Nagpal and Rienhart, 2018; ORNL 2018; NREL, 2018; Chen et. al., 2017; Reinhart and Davila, 2016)
- Detailed information about the internal performance of buildings is not included in urban BEM applications

Business as usual BEM analyses – once through

1. Building Design/Retrofit Needed

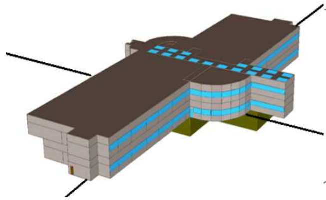


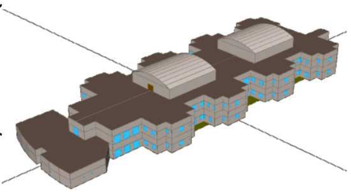


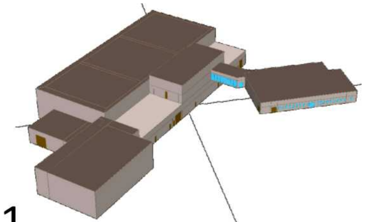
BEM created and analyses executed. Analysis conducted until post-design/retrofit analysis is complete

Model is no longer used, is inaccessible to the owner or is even forgotten

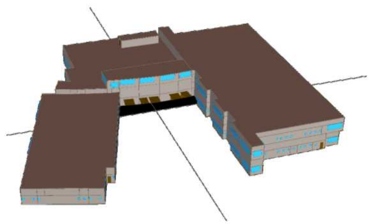
New analyses method – continuous maintenance

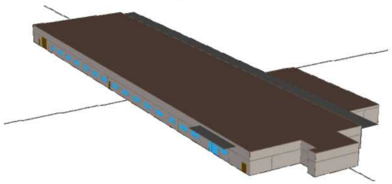


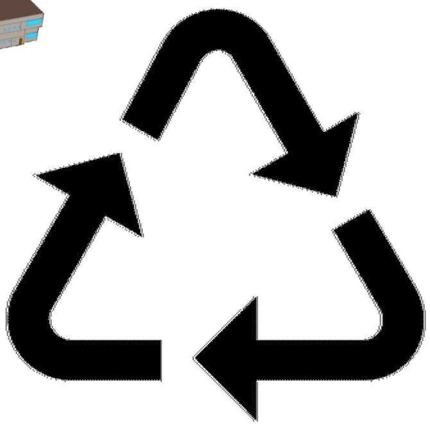




Model fleet - 121 models in our case







Continuous process to keep the model fleet accurate as buildings change

1. Building automation system data
2. Autocalibration
3. BEM model parser for fleet wide automated changes
4. Systematic manual quality checks

Continuous use cases for models

1. **EISA 2007 compliance for energy audits**
2. Building retrofit analyses (on demand)
3. Site-wide sustainability and energy efficiency assessments
4. Climate energy use assessments
5. Hybrid model/data based energy analytics

Who can afford this?

- The case for profitability is difficult to quantify
- Economies of scale
  - Large institutions (at least us) with 100’s to 1000’s of buildings are already doing this
  - Perhaps consortiums of building owners?
  - Engineering firms serving large customers
- Many new tools and methods currently being developed will improve the profitability
  - More attention is needed toward optimizing BEM modeling practice for large numbers of models

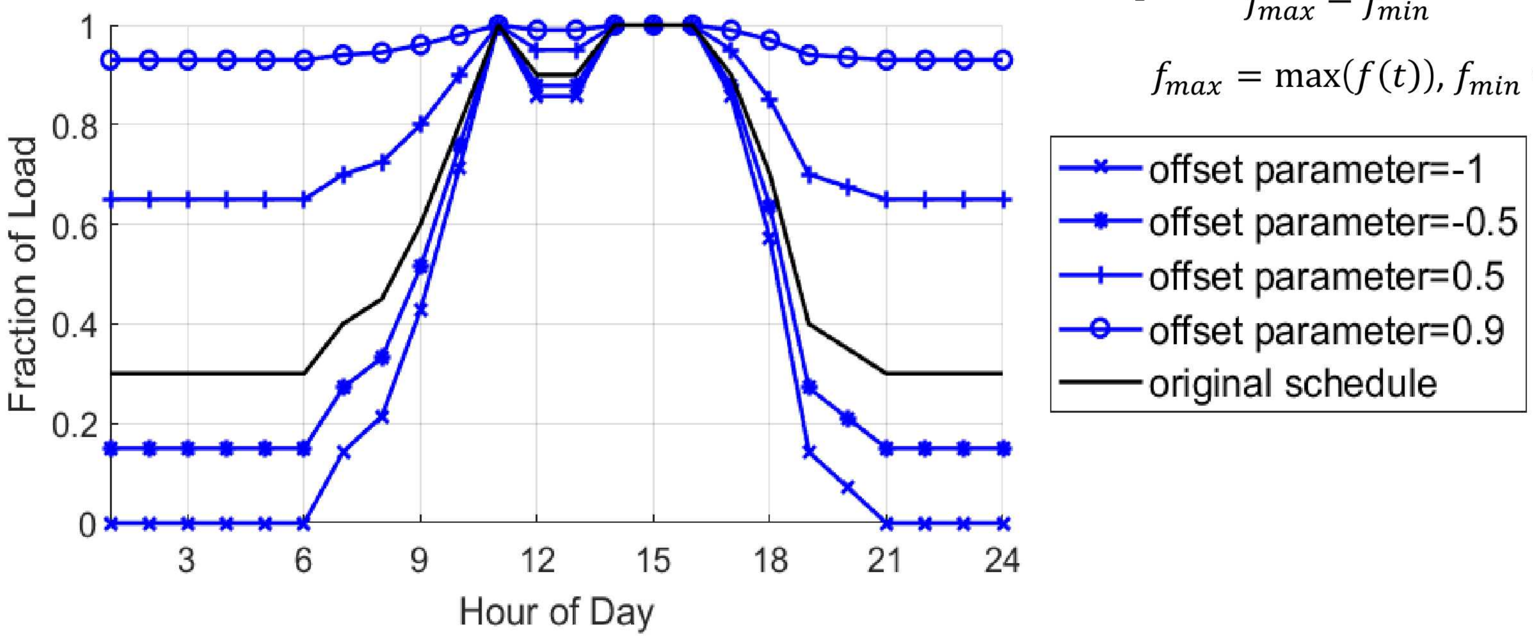
Auto-preparation of models

- Automatically insert (via software algorithms) 21 calibration parameters
  - 16 Multipliers
  - 5 schedule baseload offset shift

$$f_{new}(t) = \begin{cases} (1 - p_{off})f(t) + f_{max}p_{off} & 1 \geq p_{off} \geq 0 \\ -p_{off}f_{new_{-1}}(t) + (p_{off} + 1)f(t) & -1 \leq p_{off} < 0 \end{cases}$$

$$f_{new_{-1}}(t) = \frac{f_{max}}{f_{max} - f_{min}} f(t) - \frac{f_{max}f_{min}}{f_{max} - f_{min}}$$

$$f_{max} = \max(f(t)),\ f_{min} = \min(f(t))$$



Auto-preparation of models

- Include Building Design Language (BDL) expressions with 0 change to the model if the calibration mode is off
  - We did not perfectly achieve this

```
"SEL1 UFMat (G.N9.U10.M1)" = MATERIAL
  TYPE         = RESISTANCE
  RESISTANCE  = 24.2076
```

```
"SEL1 UFMat (G.N9.U10.M1)" = MATERIAL
  TYPE         = RESISTANCE
  RESISTANCE  = 
{if(#pa("calibCalibrateBuilding")=1) then
(24.2076)/#pa("calibEnvCondMult")
else
24.2076
endif}
```

```
  GLASS-CONDUCT = 
{1/(1/#pa("Window U-Value W") - 0.2)}
```

```
  GLASS-CONDUCT = 
{if(#pa("calibCalibrateBuilding")=1) then
#pa("calibEnvCondMult") * (1/(1/#pa("Window U-Value W")
else
1/(1/#pa("Window U-Value W") - 0.2)
endif}
```

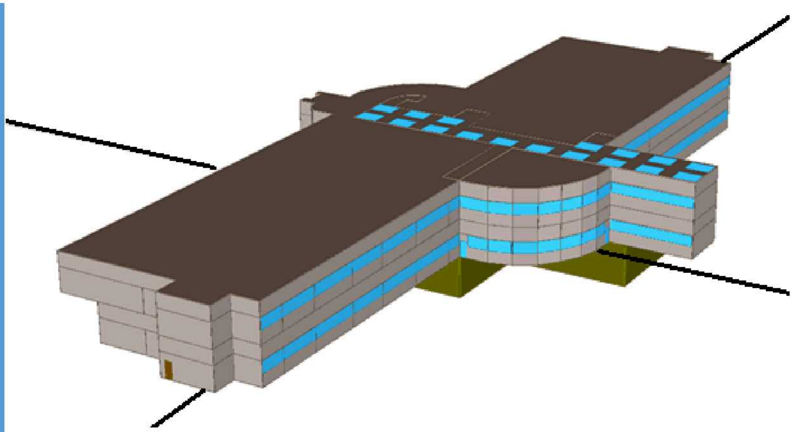
Manual preparation of models – Quality checks

- 12 hours max review of BEM with the following to compare to:
  - New energy audit report
  - Building automation system data – to verify schedules
  - Building energy data
  - Design information
  - Previous quality check report
- Change model and record corrections
- Rate model and provide spreadsheet report
  - A = ready for calibration
  - B = ready for calibration but with known issues
  - C = known issues are serious and the reviewer is uncertain whether to calibrate
  - D = calibrating is not recommended but known corrective action may correct issues
  - F = Fundamental flaws exist or simulation tool is incapable of representing the building accurately
- This process found many errors in the audited models that could not be fixed by autocalibration – it was therefore very valuable

Buildings analyzed

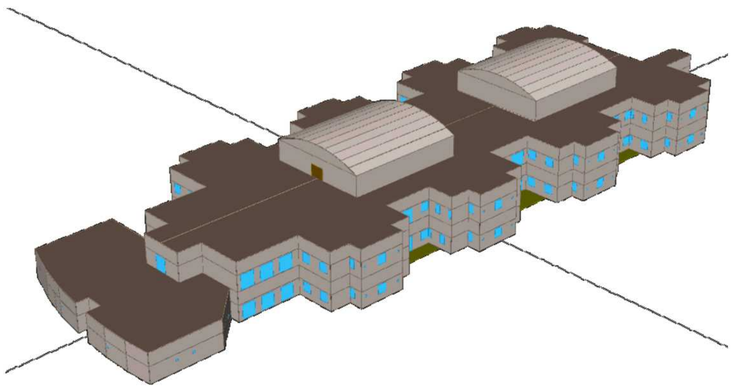
- Seventeen buildings were chosen to undergo auto-calibration in 2018 of which five were finished in time for this paper

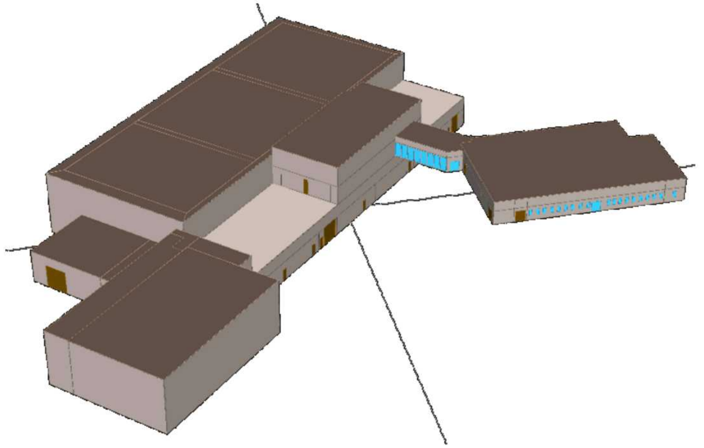
Building 1 Albuquerque New Mexico Built 1987	3 level 72,200ft^2 (6,710m^2) Light Lab with pre-cast concrete panels with exterior metal panels 2 24-7 exhaust systems. - Mixed single duct and dual duct 5.42 GWh (18,490 MBTU) electricity consumption 2017 - Calibrated on 2014 to NMBE -2.92% CV(RSME) 5.41%



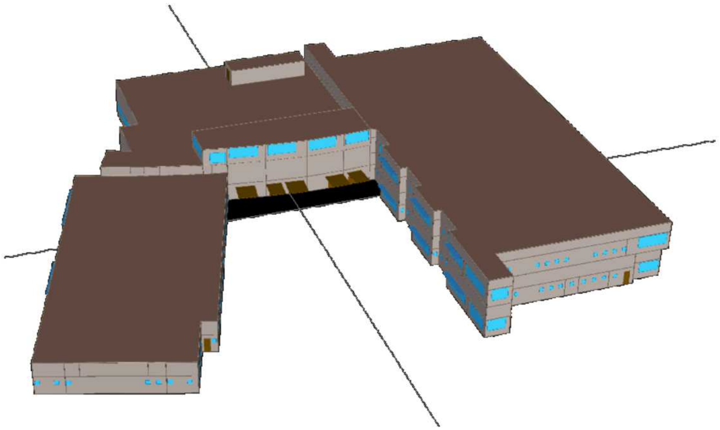
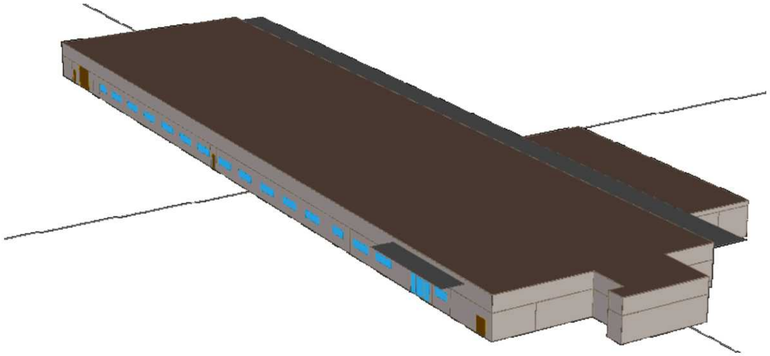
Buildings analyzed

Building 2 Albuquerque New Mexico Built 1995	• 3 Level 98,200ft^2 (9,120m^2) Light Lab with concrete masonry unit construction • 2 24-7 exhaust systems • Compressed air services • 2.26 GWh (7,710 MBTU) electricity consumption 2017 • 2,210 MCF (62,580m^3) natural gas used 2017 • Out of compliance for calibration in 2014. NMBE 5.50% CV(RSME) 6.40%
Building 3 Albuquerque New Mexico Built 1984	• 2 Level 76,100ft^2 (7,070m^2) high-bay area with office space attached by a skybridge. Mostly precast with Double tee structural walls • Compressed air services • 1.57 GWh (5,360 MBTU) electricity consumption 2017 • 4,047 MCF (114,600m^3) natural gas used in 2017 • Out of compliance for calibration in 2014. NMBE 12.05% CV(RSME) 13.00%





Buildings analyzed

Building 4 Livermore California Built 2003	• 2 Level 71,500ft^2 (6,643m^2) steel frame office building • Administrative offices and large conference room center. • Small café and dining area • 3.91 GWh (13,300 MBTU) electrical consumption 2017 • Not calibrated in 2014	
Building 5 Livermore California Built 1958	1 Level 32,600ft^2 (3030m^2) concrete office building 4-ply built up cool roof 1.82 GWh (6,210 MBTU) electricity consumption 2017 6,050 MCF (171,300m^3) natural gas used in 2017	

Autocalibration

- Autocalibration needed to reduce labor required to maintain models
- Calibration method uses the Autotune technology (New et. Al., 2012)
- Developed by extensive search for the optimal algorithm for BEM autocalibration
  - Best algorithm out of 100,000's – chosen through a benchmark dataset of 20,000 building calibration problems (Garrett et. al. 2013, Garrett and New 2015)

Autocalibration report

For this study, the final report for each building included an interactive website with the following information:

1. Documentation of the quality check process with comparison to walkthrough audit data
2. Prominent display of the final NMBE and CV(RSME) values achieved.
3. The final building energy model.
4. The building energy model before calibration.
5. Full details in result files for the final calibrated model.
6. Graph providing monthly building energy performance data of electricity versus the final calibrated building energy model performance. A similar graph for gas data if gas data is provided.
7. Spreadsheet providing all the parameter values determined by the calibration algorithm.
8. The Actual Meteorological Year (AMY) weather file corresponding to the time period in which data was collected.
9. The (measured) calibration data used.
10. Meta-information regarding the computer used, dates of run, individual who performed the analysis, contact information, and additional important notes.
11. Graph and data showing yearly end-use break-down by Heating, HVAC cooling equipment, HVAC Fans, Interior Lights, Pumps, Plug Loads, Interior Lighting, and Other loads.
12. Short notes concerning whether the end-uses are close to typical end-uses for the building type being evaluated.

Data cleanup

- The buildings modeled have periodic nonstandard changes in operation that are not appropriate for calibration
  - Building 3’s electrical use was increased 67% due to an anomalous change in operations
  - Building 4’s energy use for August-December was averaged from previous years due to similar operational concerns
  - Gas data was found to be inaccurate – this posed a major obstacle that could not be overcome for 2 buildings

Quality check results

- Quality checks
  - Building 1 None – calibrated before QC process in place
  - Building 2 A
    - Corrected average plug load density
    - Corrected supply-static pressure
    - Corrected hot water reset minimum temperature
    - Corrected chilled water design temperature minimum
    - Noted compressed air system does not have data for accurate energy schedules
  - Building 3 A
    - Corrected average lighting power density
    - Corrected average plug load density
    - Changed chillers from auto-sized to actual size
    - Corrected hours of operation from 7-5 to 6-6
    - Added 2 boilers installed in 2016, Removed old boiler
    - Noted compressed air system does not have data for accurate energy schedules

Quality checks results

- Building 4 B
  - Lack of specificity for 100ton chiller in 24/7 operation zones and HVAC systems may not be matched correctly
  - Wide-spread use of portable electric heaters but no specification for schedules
  - Could not match exhaust fan specifications in energy audit to model
  - Electric boiler capacity corrected
- Building 5 C
  - Energy audit was same as Building 4 – suspect energy audit information is invalid
  - The energy model HVAC system is a copy of building 4 – suspected need to return to the drawing board

Results

A case for cost savings (weak) and time savings (strong) can be made from our study

Building 1's monthly, daily, and hourly accuracy of the original model, auto-calibration, manual-calibration (from original), and auto-calibration (from manually-calibrated) shows generally better accuracy than manual calibration, minor cost savings, and increased scalability to cost-effectively address larger portfolios of buildings

		Original Model	Autotune (from original)	Manual Calibration	Autotune (from manual)
Monthly utility data	CV(RMSE)	8.37%	5.22%	5.23%	5.20%
	NMBE	2.66%	0.16%	-1.42%	0.66%
Daily utility data	CV(RMSE)	12.41%	9.11%	8.26%	7.53%
	NMBE	2.66%	0.16%	-1.42%	-0.26%
Hourly utility data	CV(RMSE)	19.50%	10.9%	11.54%	9.70%
	NMBE	2.66%	0.16%	-1.42%	-0.26%
Cost			$2.5k (15 hours, compute)	27 person-hours ($3.5k at $130/hr)	$2.5k (7 hours, compute)

Results

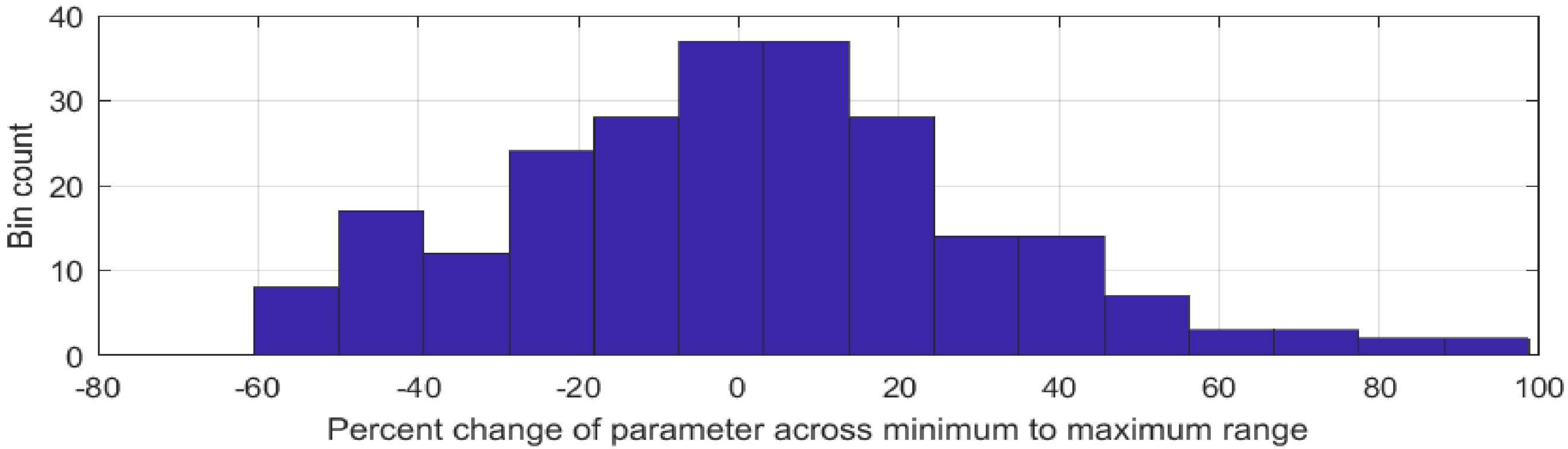
	Original				Tuned			
	Electricity		Gas		Electricity		Gas	
Building	CV(RMSE)	NMBE	CV(RMSE)	NMBE	CV(RMSE)	NMBE	CV(RMSE)	NMBE
1	8.4%	2.7%	--	--	5.2%	0.7%	--	--
2	125.9%	125.4%	81.5%	54.3%	17.3%	13.5%	37.8%	13.8%
3	13.3%	-7.9%	47.8%	-42.5%	9.5%	-0.26%	13.9%	-1.4%
4	5.6%	2.3%	--	--	4.8%	0.2%	--	--
5	29.7%	-28.7%	97.3%	-96.2%	6.5%	-1.8%	97.8%	-96.6%

ASHRAE Guideline 14 Compliant | NOT G14 Compliant

Monthly BEM accuracy pre- and post-calibration. While ASHRAE Guideline 14 is almost exclusively applied to whole-building electrical use, future versions are considering submetering, higher-resolution sampling, and the (generally) more difficult challenge of matching natural gas or water use.

Parameter variation

- Parameter variations had a standard deviation of 30%
- We think our calibration parameter scheme needs improvement
- Not enough variation for natural gas exists in the current set of parameters



Conclusion

- Autocalibration and quality checks significantly changed the 17 models we worked with out of our fleet of 121 models for this year's energy audits
- Many problems in data cleanup and automated techniques need further work
- We hope to leverage building automation system data in the future and to use autocalibration on a more regular basis
- The current set and form of the autocalibration parameters needs further work

Conclusion

- We think that we need to comprehensively classify every parameter in every model into four categories:
  1) discoverable by available data
  2) no changes needed
  3) undiscoverable by available data
  4) tuned by auto-calibration.
- The third category needs to be kept to a minimal set and can only be addressed by uncertainty analysis.
- Such classification may serve as a basis to analytically estimate whether a model is accurate.
- Significant work is needed to be able to quickly classify BEM into these categories

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Questions?

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