U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

U.S. Department of Energy Open Energy Information System (OpenEIS) Project:

Summary of Outcomes of Workshop #1, OpenEIS Algorithms, held on February 26, 2013

March 14, 2013

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Emerging Technologies

Building Technologies Office

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NOTICE

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Project Overview

This project is motivated by the belief that there is significant opportunity to achieve energy savings in small commercial buildings (i.e., less than 100K sq.ft.) by increasing access to analytical approaches that are known today, but not yet widely deployed. DOE seeks to provide a low-risk opportunity for owners, service providers, and managers to explore the use of analytical methods for improved building control and operational efficiency, and to increase market demand and adoption of commercial solutions. It seeks to increase market demand for and adoption of advanced analytics by developing a software requirements specification for OpenEIS: an open, cloud-based platform that can be used to upload and perform batch analysis of building energy and operational data.

Workshop Objectives

Workshop #1 was the first of two stakeholder workshops that will be hosted by DOE for the OpenEIS project. The objective of the workshop was to gather feedback on and prioritize the preliminary list of algorithms that the OpenEIS team developed for consideration for OpenEIS (see Appendix B). The team developed the list based on a review of literature and the team's collective experience in building analysis and controls. The team focused on algorithms that would be most effective in small commercial buildings (i.e. less than 100K sq.ft.) that perform batch analysis using commonly available building energy and operational data. The list includes algorithms that: (1) are purely analytical and provide interpretive guidance of results visualization; or (2) result in recommended actionable measures (e.g. fault detection and diagnostics). The list served as the starting point for collaboration between DOE and the workshop participants to identify a subset of high-priority algorithms that DOE should consider for implementation in OpenEIS. During the workshop, facilitator's focused on the following questions for each algorithm.

- How accessible is the required data, and how might that impact ease of implementation in the <100k sq.ft. target?
- In which building types are the algorithms most applicable (e.g., older vs. newer vintages, larger or smaller buildings in the target range)?
- Which algorithms provide most benefit to the user, and are there modifications that could make their output more useful?
- What high-value algorithms are not included on the list?

Purpose

The purpose of this document is to summarize the outcomes of the first stakeholder workshop for the OpenEIS project. The summary includes a list of participants, prioritization of algorithms, identified gaps, and common themes (i.e. recurring topics of discussion). The agenda, preliminary list of algorithms, and detailed notes from the workshop are provided in appendices.

Workshop Participants

Facilitators

George Hernandez, Building Technologies Office, Project Manager
Jessica Granderson, Mary Ann Piette, Lawrence Berkeley National Laboratory
Srinivas Katipamula, Michael Brambley, Pacific Northwest National Laboratory
Samuel Jasinski, Navigant Consulting, Inc.

Participants

Name	Organization
Steve Bushby	NIST
Mike Sohn	LBNL
Jim Braun	Purdue
Carl Blumstein	California Institute for Energy and Environment
Ram Rajagopal	Stanford
Len Pettis	California State Universities
Matt Biesterveld	Trane
Ed Spivey	EnerNOC
Mikhail Gorbounov	UTRC
Teems Lovett	
Patrick O'Neill	NorthWrite
Craig Ennis	EFT Energy
Badri Raghavan	First Fuel
John Melchert	The Weidt Group
Dave Krinkel	Energyai
Thomas Gruenwald	Siemens
Scot Duncan	Enerliance
Paul Quinn	Duke Realty
David Jump	Quantum Energy Services and Technologies
Reinhard Seidl	Taylor Engineering
Jimmy Jia	Distributed Energy Management
Tim Hayes	McKinstry
Jim Kelsey	KW Engineering
Devan Johnson	
Paul Ehrlich	Building Intelligence Group
Mangesh Basarkar	Pacific Gas and Electric
Jim Crosskey	IBM

Prioritization of Algorithms and Identification of Gaps

Participants identified market value and market impact as the most important consideration in identifying high-priority algorithms for OpenEIS. Participants also stated that generation of actionable information is a critical characteristic of the algorithms that should be hosted by OpenEIS, although there were subtle differences in what was considered actionable. For example, service providers and owners have different levels of expertise, and therefore might have different perceptions of what amounts to actionable output.

Participants prioritized the following algorithms highest, which include many of the whole-building algorithms and airside diagnostics for rooftop units:

- Heat maps or carpet plots to visualize load vs. schedule
- Time series load profiling
- Base to peak load ratios, and peak load benchmarking – with the caveat that 'good vs. bad' values should be defined
- Longitudinal benchmarking, and cross sectional benchmarking, e.g. EnergyStar EUI comparisons
- Economizer operations, adequacy of ventilation, and sensor and damper functionality
- Determination of indoor comfort, provided that humidity measurements be included with zone temperatures
- Identification of excessive mode transitions

Given the target for OpenEIS (<100k sf), participants identified the following algorithms as low priority, or as having low market impact:

- Those related to built-up systems
- PV array output tracking
- Carbon accounting

Participants identified the remainder of the algorithms on the preliminary list as less critical, although valuable either in limited cases or provided that the data are available. Participants mentioned that these algorithms might best be developed in subsequent phases, after initial release of OpenEIS:

- Metrics to characterize weather sensitivity and load variability metrics
- Cumulative sum
- Energy signatures of load vs. outside air temperature
- Algorithms requiring gas data
- Equipment short and long cycling
- Adequacy of thermostat deadbands
- System loading histograms
- VAV diagnostics based on VPACC rules
- Lighting load profiling

Common Themes Expressed Across Breakout Groups

Data availability

There was widespread consensus among participants that data availability will be critical to OpenEIS solution, particularly given the target building size of under 100k sf. Some participants suggested that even interval metered data will be difficult to come by in buildings at the smaller end of that spectrum, i.e., under 50ksf.

Where data are available, e.g., from smart meters or building automation systems, it may prove challenging to motivate owners/operators to download their data from existing sources, and upload it for use in OpenEIS. This challenge was acknowledged by the DOE project manager and OpenEIS project team. DOE relayed that this is a known issue and there are other DOE-funded projects focused on this topic.

Given that service providers are one of the target user groups for OpenEIS, and given the likely absence of permanent sensing and metering in buildings under 50ksf, workshop breakout groups determined that it may be advantageous to consider temporary loggers as in-scope data sources for OpenEIS, and associated algorithms.

Data quality

Throughout the discussions that took place in the workshop, participants emphasized the importance and challenges of ensuring high-quality data inputs to the OpenEIS algorithms. Vendors of commercial analytical tools highlighted the significant resources dedicated to verifying and maintaining data quality, and researchers and service providers noted the difficulty in relying upon 'raw' data from control system trend logs.

There were differing opinions as to whether and how OpenEIS should accommodate data quality assurance and cleansing/correction. Participants suggested several options, including:

- Providing a data quality assurance application in the initial release of OpenEIS;
- Providing user guidance as to the impact of low-quality data on the output of the algorithms; and
- Inviting 3rd party developers to contribute data quality applications to supplement the initial release of OpenEIS.

As the OpenEIS project progresses, the OpenEIS project team and DOE project manager will determine how issues of data quality should be addressed. One solution may be another application or algorithm that analyzes the data for validity.

Data interpretation

Several participants discussed the importance of accommodating diverse data formats, taxonomies and naming conventions, and the practical implications relative to automated processing of data in the OpenEIS algorithms. At the more automated (and complex) end of the spectrum of possibilities, OpenEIS might automatically import the data from an historian, and interpret which data streams should be used as input to which algorithms; at the less automated end of the spectrum, the platform may rely upon the user to identify which data fields should be used as input to which algorithms. These issues will be explored in further detail in the second workshop, which is planned for May.

Definition of the target audience and primary use cases

Participants noted that there are many potential audiences for OpenEIS, including owners and their representatives, as well as service providers. These audiences have diverse skills, data analysis needs, and preferences, impacting which algorithms would be of highest value.

In addition, there are diverse ownership and management models for buildings in the under 100ksf size range. The models will drive the use cases and users for OpenEIS that will offer the most market value.

Breakout groups suggested that identifying the highest priority algorithms to 'seed' OpenEIS, and defining the software requirements specification could benefit from more granular definition of the target audience and primary use cases.

Next Steps

DOE will host a second stakeholder workshop in May 2013 to solicit feedback on the data types and formats that the OpenEIS platform should support.

Appendix A – Workshop Agenda

8:00 – 8:30:	Welcome, Introductions
8:30 – 9:15:	Project Overview, workshop overview and objectives
9:15 – 9:45:	Q&A
9:45– 10:00:	Break
10:00 – 11:00:	Algorithms overview
11:00 – 12:00:	Breakout 1, whole building electric, gas, and combined fuels
12:00 – 1:00:	Lunch, Room 1144
1:00 – 2:00:	Breakout 2, airside RTU AHU Dx, other htg/clg system algorithms
2:00 – 3:00:	Breakout 3, built up systems, plants and BAS, other bldg systems
3:00 – 3:45:	Breakout 4, identify gaps, additional algorithms
3:45 – 4:00:	Break, return to main room, 1144
4:00 – 4:45:	OpenEIS team report key findings, breakout highlights
4:45 – 5:00:	Wrap up, thanks, and next steps

Appendix B Preliminary List of Algorithms

Breakout Session #1a, Interval Whole Building Electric Analyses

1. *Load vs Schedule Visualization*

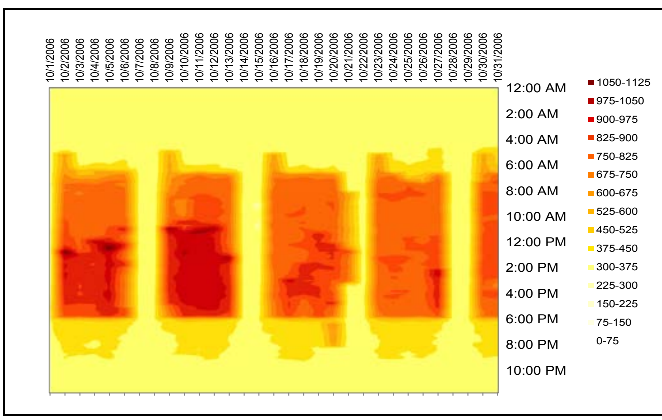
Description: Provides carpet plot or heat map (see appendices for sample plots) of load and time, with interpretive guidance (e.g., winter schedule should be shifted)

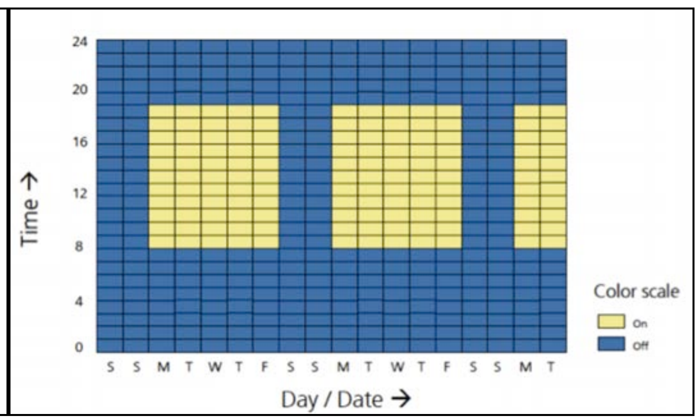
- Automated routine to compare load changes to schedule/expectations; or
- A simple visualization with interpretive guidance, intended to reveal 'hot spots'

Info Gained: Whether loads change correctly based on time of day, and whether schedules are implemented

Required Data:

- Interval electric meter data (hourly or sub-hourly); and
- Building occupancy schedule





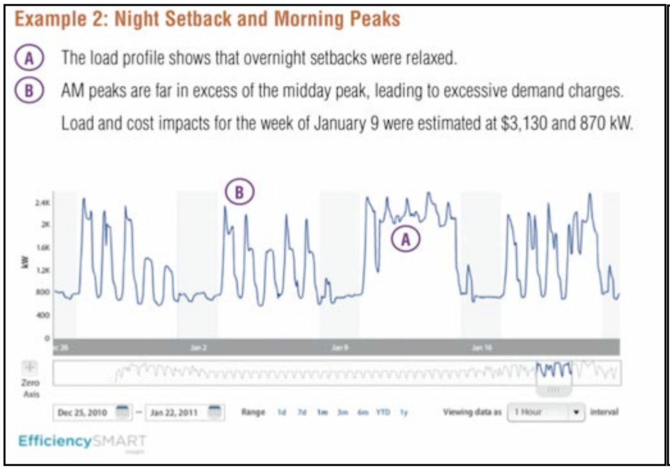
2. *Time Series Load Profiling*

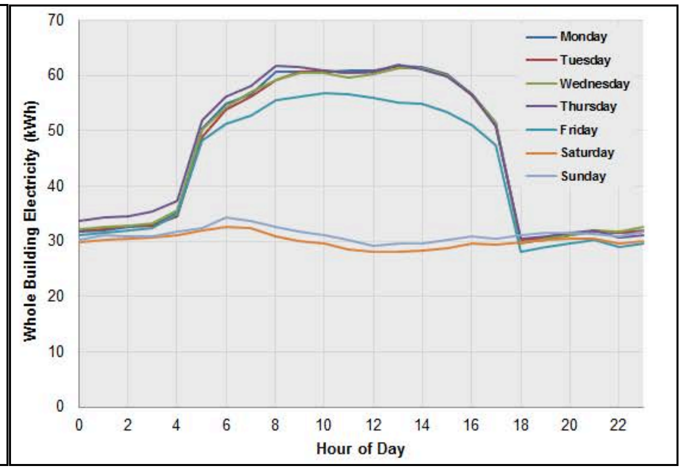
Description: A simple plot of metered whole-building load versus time, with interpretive guidance

Info Gained: When and how much energy is being used; persistence and magnitude of nighttime setbacks, timing of the peak, weekend shut-down (similar to #1, potentially supports more granular investigations, no 'hot spotting')

Required Data:

- Interval electric meter data (hourly or sub-hourly); and
- Building occupancy schedule





3. *Base-to-Peak Load Comparison*

Description:

- Visualization with rule of thumb guidance on what to look for; and/or
- Calculate average base-to-peak load ratio over a given time period and provide interpretive guidance of result (e.g., closer to 1 is less desirable)

Info Gained: Whether there is significant base load during unoccupied periods both during weekdays and weekends

Required Data:

- Interval electric meter data (hourly or sub-hourly); and
- Building occupancy schedule

4. *Sensitivity of Electricity Consumption to Weather*

Description: Provide rank order correlation (ROC) between paired load and outside air temperature, based on the Spearman rank order correlation coefficient, and provide interpretive guidance of result (e.g. 0.7 may be high for commercial buildings[1])

Info Gained: Whether there may be problems with insulation, or outside air intake, or system efficiency

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[1] Coughlin, K., M.A. Piette, C. Goldman, and S. Kiliccote. Statistical Analysis of Baseline Load Models for Non-Residential Buildings. ***Energy and Buildings*** 41 (2009) 374–381.

Required data:

- Interval electric meter data (hourly or sub-hourly), and
- Building zip code for outside air temperature (OAT) from feed or user input

$$r_s = 1 - \frac{6\left(\sum D^2\right)}{N\left(N^2 - 1\right)}$$

where D is the difference between each pair of ranks

5. *Benchmarking Normalized Peak Electric Load*

Description: Compares peak load to rules of thumb benchmarks and provides interpretive guidance (e.g. 5 W/sf average based on CEUS data for selected small commercial types)

Info Gained: Comparing power consumption per unit area (W/sf) with benchmarks and identifying potential reductions in demand charges and utility costs

Required data:

- Interval electric meter data (hourly or sub-hourly), and
- Building area

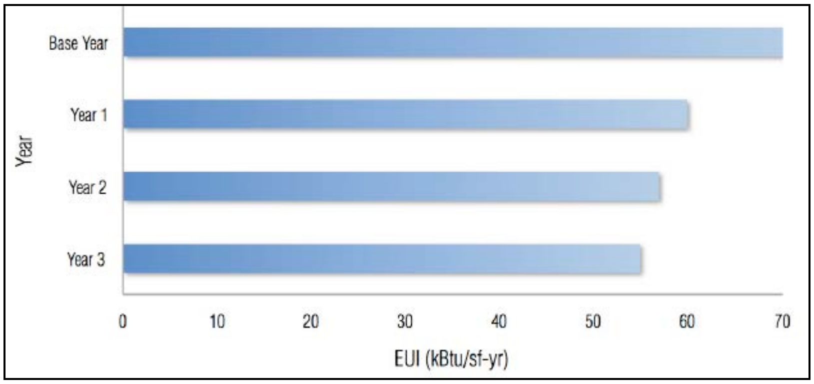
6. *Longitudinal Benchmarking*

Description: Plot of monthly or annual usage, normalized by square footage and/or degree days, usually as a bar chart with interpretive guidance (e.g., consumption in year 3 increased compared to baseline after 2 years of decreasing consumption, indicating a possible change in operations or equipment that should be evaluated)

Info Gained: Consumption trends and relative magnitude compared to a base year

Required data:

- Interval electric meter data, monthly or annual consumption,
- Outdoor air temperature (OAT) corresponding the energy consumption, and
- Building area (in square footage)



7. Load Variability

Description: Computes a coefficient of variation metric based on hours of the day and compares result to a rule of thumb threshold to provide interpretive guidance (e.g., variability above .15 is considered high for commercial buildings[2], whereas under 6% may indicates low variability and predictable loads for small buildings).

Info Gained:

- Regularity of control and operations, and
- Impacts on demand response (DR) participation

Required data: Interval electric meter data (hourly or sub-hourly)

$$VAR = \frac{\sqrt{\frac{\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2}{N-1}}}{\bar{x}}$$

where $\bar{x}$ is the average hourly load in the period,
and N is the number of days in the period

[2] Coughlin, K., M.A. Piette, C. Goldman, and S. Kiliccote. Statistical Analysis of Baseline Load Models for Non-Residential Buildings. ***Energy and Buildings*** 41 (2009) 374–381.

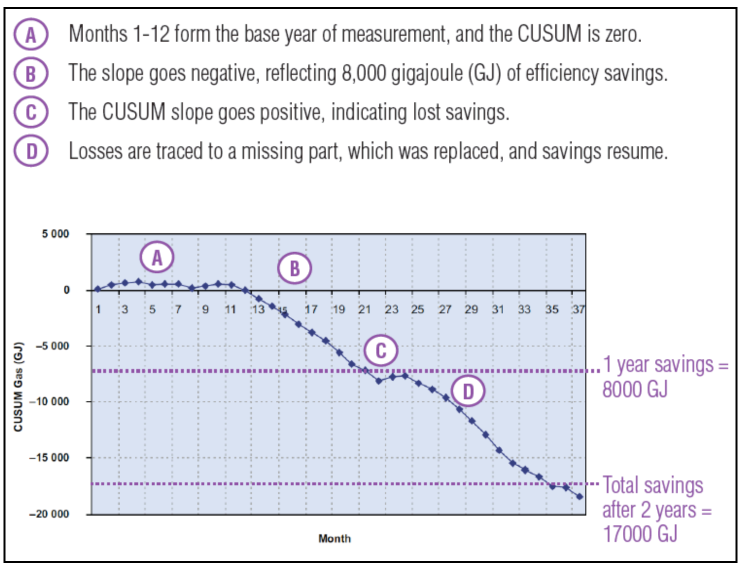
8. *Cumulative Sum (CUSUM) Analysis*

Description: Plot of cumulative difference between metered and baseline use as time progresses with interpretive guidance (e.g., positive slope in January indicates efficiency savings that may be attributable to operational or equipment improvements)

Info Gained: Cumulative aggregated savings relative to baseline the slope of which indicates whether performance is increasing or decreasing relative to baseline

Required data:

- Interval electric meter data (hourly or sub-hourly), and
- Outside air temperature (for baseline, for example from a regression model)



9. *Energy Signature*

Description: X-y plot of load versus temperature with interpretive guidance (e.g., Measures to raise building cooling balance point could result in energy savings)

Info Gained:

- Building balance point,
- Magnitude of slopes, and
- Indication of potential control instability, if data show a high degree of scatter

Required data:

- Interval or monthly electric data, and
- OAT or degree days corresponding to the energy consumption data

Breakout Session #1b, Interval Whole Building Gas Analyses

10. Load vs Schedule Visualization

Description: Provides carpet plot or heat map (see appendices for sample plots) of load and time, with interpretive guidance (e.g., winter schedule should be shifted)

- Automated routine to compare load changes to schedule/expectations; or
- A simple visualization with interpretive guidance, intended to reveal 'hot spots'

Info Gained: Whether loads change correctly based on time of day, and whether schedules are implemented

Required Data:

- Interval gas data (hourly or sub-hourly); and
- Building occupancy schedule

11. Time Series Load Profiling

Description: A simple plot of metered gas load versus time, with interpretive guidance

Info Gained: When and how much gas is being used; persistence and magnitude of heating setbacks, timing of the peak, seasonal reductions (similar to #10, potentially supports more granular investigations, no 'hot spotting')

Required Data:

- Interval electric gas data (hourly or sub-hourly); and
- Building occupancy schedule

12. Energy Signature

Description: X-y plot of load versus temperature with interpretive guidance (e.g., Measures to reduce slope could result in heating energy savings)

Info Gained:

- Building balance point,
- Magnitude of slopes, and
- Indication of potential control instability, if data show a high degree of scatter

Required data:

- Interval or monthly gas consumption data, and
- OAT or degree days corresponding to the energy consumption data

Breakout Session #1b, Combined Gas and Electric Analyses

13. Carbon Accounting

Description: Emissions calculated by carbon intensity per fuel (electricity or natural gas) use

Info Gained: Building carbon footprint

Required data:

- Interval gas and electric meter data (hourly or sub-hourly),
- Building location information for utility generation look-up

building energy use.

Step 2: Convert energy use to GHG emissions.
Multiply energy use by the emissions factors.

Step 3: Convert emissions to CO_2 equivalents.
Multiply emissions by the GWP values.

Step 1		Step 2			Step 3
Energy Source	Energy Use	CO_2 Emissions (kg)	N_2O Emissions (kg)	Methane - CH_4 Emissions (kg)	CO_2e Emissions
Electricity	187,600 kWh	= 0.589 *187,600 = 110,500 kg	=8.9x10^{-6} *187,600 =1.7 kg	= 1.1x10^{-5} *187,600 =2.1kg	= 1 * 110,500 kg CO_2 + 310 * 1.7 kg N_2O + 21 * 2.1 kg CH_4 = 111,000 kg CO_2e
Natural Gas	6,920 therms	= 5.4 *6,920 = 37,400 kg	= 1.1x10^{-5} *6,920 = 0.08 kg	=5.4x10^{-4} *6,920 = 3.7 kg	= 1 * 37,400 kg CO_2 + 310 * 0.08 kg N_2O + 21 * 3.7 kg CH_4 = 37,500 kg CO_2e
Total CO_2e (kg)					= 111,000 + 37,500 = 149,000 kg CO_2e

Step 4: Plot emissions over time. Aggregate multiple sites

14. EUI Benchmarking/Labeling

Description: By making web services call to Portfolio Manager, for example, enable building energy consumption to be benchmarked against peers.

Info Gained:

- Whether building qualifies for the ENERGY STAR Portfolio Manager star,
- Evaluation of performance relative to peers

Required data:

- Gas and electric consumption data (can be aggregated from hourly data or utility bills)

- Building zip code
- Building type, occupancy information, other input characteristics...

Breakout Session #2a

15. Air-Side Diagnostics for packaged rooftop units (RTUs) and built-up Air Handling Units (AHUs)

Description: Large RTUs and AHUs (>7.5 ton in some case even >5 tons) are required to have air-side economizers, which may fail to perform as designed and lead to increased energy consumption. In many cases, the failure goes undetected because mechanical cooling compensates for the failure of the economizer and the failure does not direct impact the comfort of the occupants.

Info Gained: There are number of air-side economizer faults that can be detected. These faults can be grouped into five categories:

1. Non-modulating damper
2. Temperature sensor problems (including missing and out of range sensor values)
3. Economizer operating when it should not (conditions not favorable for economizing)
4. Economizer not operating when it should (conditions favorable for economizing)
5. Ventilation greater than needed, and
6. Inadequate ventilation

Required data: The measured data required to detect faulty economizer operations include:

- Mixed air, return air, and outdoor-air temperatures (and enthalpies for enthalpy-controlled economizers)
- Damper signal,
- Supply fan on/off status, and
- Heating and cooling on/off status or heating and cooling valve signal
- The measured data can be at any interval but preferably 1-minute (1-minute, 5-minute, half-hourly, or hourly, etc.).

Breakout Session #2b, Heating and Cooling System Analyses

16. Equipment Short Cycling

Description: Provides time series plot of equipment load and interpretive guidance (e.g., frequency of cycling indicates that actuators may be worn/wearing too quickly) or an automation to flag cycles shorter than a desired time threshold.

Info Gained: Whether loads cycle too frequently

Required data: system status or a control signal, at least one-minute frequency

17. Equipment Long Cycling

Description: Provides time series plot of equipment load and interpretive guidance (e.g., Long on-times indicate that equipment may be undersized or capacity has degraded) or an automation to flag cycles longer than a desired time threshold.

Info Gained: Whether system stays on too long and is not responsive to changes in load

Required data: System status or a control signal, at least five minute frequency

18. Zone or Room Thermostat Deadbands

Description: Small differences between the heating and cooling set points may lead to excessive cycling between heating and cooling modes increasing the overall energy consumption.

Info Gained: By checking the heating and cooling set points and the zone/room temperatures the actual deadbands can be inferred and suggestions provide to make changes

Required Data: Zone temperatures and zone heating and cooling set points

19. Comfort Conditioning

Description: Compares indoor temperatures against defined ASHRAE comfort ranges and indicate when the comfort conditions are not being met

Info Gained: Whether the building is too hot or too cold or outside the ASHRAE comfort range

Required data:

- Time series history of indoor zone air temperature, and
- Hours of occupancy

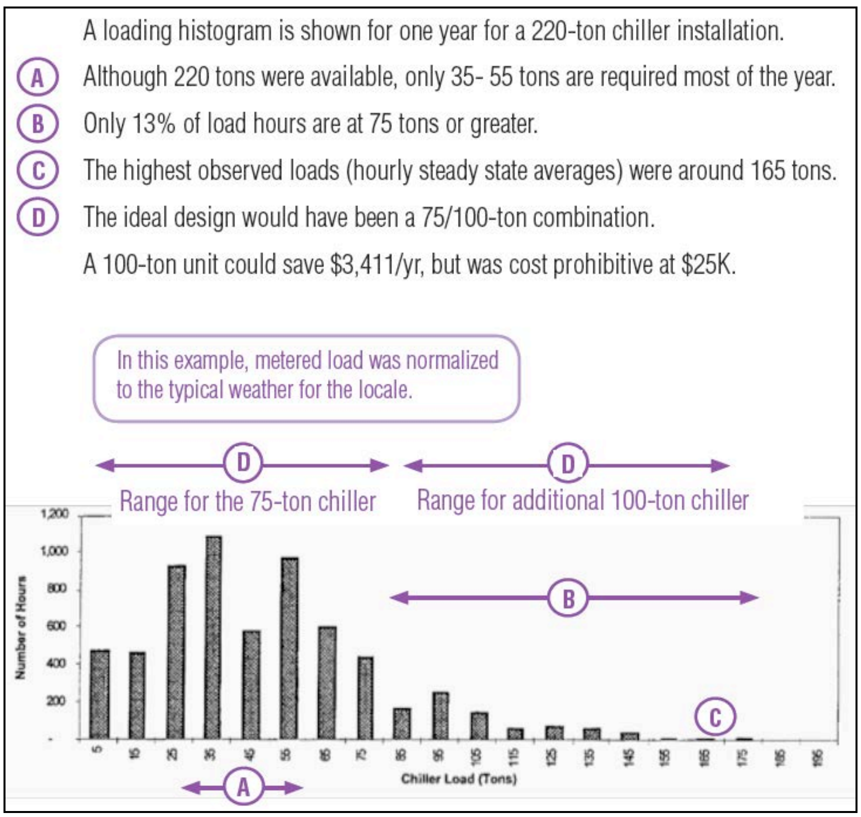
20. *Loading Histograms*

Description: Provides histogram of hours-at-load vs load, potentially combine with sizing to determine under-loading and sequencing opportunities to identify optimal equipment sizing and potential cost/energy savings

Info Gained: Multi-unit sequencing, under loading, retrofit potential

Required data:

- Time series history of system load (in tons, BTU/hr), and
- System capacity information



21. *Excessive Mode Transitions*

Description: Detects/indicates when the total number of mode transitions (i.e, mode changesper hour) exceeds a predetermined threshold

Info Gained: Whether there are too many mode switches

Required Data: Number of mode transmissions per hour

22. VAV Diagnostics Airflow Rate Check

Description: Detects/indicates issues such as

- Scheduling conflict with AHU,
- Tuning problem with airflow feedback control loop,
- Airflow sensor failure,
- Damper stuck or failed,
- Damper actuator stuck or failed,
- Supply air static pressure too low,
- Undersized VAV box,
- Sequence logic error, or
- High maximum airflow setpoint

Info Gained: VAV box Performance Assessment Control Charts (VPACC) which display CUSUM of errors between process output and alarm limit

Required data:

- Airflow rate error,
- Absolute value of airflow rate error,
- Temperature error, and
- Discharge air temperature error

Breakout Session #3a

23. Diagnostics for Built-up Systems with Central Plants and Building Automation Systems

Description: Although built-up systems with central plants and BASs are less common in buildings sizes less than 100,000 sf, some buildings in this size range may have these systems. There are a number of commonly occurring operational problems that plague these buildings. Most of these operational problems can be automatically detected using the data from the building automation systems.

Info Gained: The list of problems includes:

Water-Side Distribution Measures

1. Problems with chiller distribution loop temperature difference (delta-T)
    1.1. Chilled water loop delta-T (the difference between the return and supply water temperatures in the building/secondary loop) lower than the normal operating range.

2. Problems in boiler distribution loop temperature difference (delta-T)
    2.1. Hot water loop delta-T (the difference between the supply and return water temperatures in the building loop) lower than the normal operation range.

3. Opportunity for chilled or hot water temperature loop reset or better loop temperature set point
    3.1. No chilled water loop supply temperature reset.
    3.2. No hot water loop supply temperature reset.[3]
    3.3. High chilled water supply temperature set point.
    3.4. Low chilled water supply temperature set point.
    3.5. High hot water supply temperature set point.

4. Opportunity for water loop differential pressure (DP) reset
    4.1. No chilled water loop DP reset.
    4.2. No hot water loop DP reset.
    4.3. High chilled water loop DP set point.
    4.4. Low chilled water loop DP set point.
    4.5. High hot water loop DP set point.

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[3] The chilled water loop reset and hot water loop reset diagnostic algorithms were separated because the configuration, threshold and tolerance could be different.

Air-Side Distribution Measures

5. Lack of discharge air temperature reset and poor discharge air temperature set point
   5.1. No discharge air temperature (DAT) reset schedule or the reset is disabled/overridden.
   5.2. High DAT set point.
   5.3. Low DAT set point.

6. High/low duct static pressure and lack of static pressure reset schedules
   6.1. No duct static pressure reset.
   6.2. High duct static pressure set point.
   6.3. Low duct static pressure set point.

7. Excessive variable air volume (VAV) system reheat
   7.1. Low discharge air temperature and majority of terminal units in heating mode.

8. Simultaneous heating and cooling.

9. Excessive reheat at the zone terminal boxes.

10. Outdoor air intake not reset to zero (no ventilation) during morning warm-up or cooling.

Other Measures

11. Unscheduled or poorly scheduled HVAC, lighting and exhaust equipment operation, such as continuous operation or operation during unoccupied periods
    11.1. 24-hour or unoccupied period fan operation.
    11.2. Unoccupied period chillers operation.
    11.3. Unoccupied period boilers operation.
    11.4. Unoccupied period lighting operation.
    11.5. Any system that is ON during unoccupied period.
    11.6. Exhaust fans running 24x7 or during unoccupied periods.

12. Improper control loop tuning, for valves, dampers, fan and pump speeds, etc.
    12.1. Valve or damper controls hunting to meet set point.
    12.2. Fan or pump speed control oscillation.

13. Faulty sensors

14. Detecting improper overrides of set points or actuators
    14.1. Overridden control set points.
    14.2. Overridden dampers or valves actuator.

15. Variable speed equipment running at constant speed.

16. Optimal start/stop not working properly.

17. Improper set points.

Required data: The BAS should have most of the measured data required to detect the above faults.

Breakout Session #3b, Other Building System Analyses

24. <u>Photovoltaic (PV) Monitoring</u>

Description: Time series plot of PV array output, potentially overlaid (i.e. co-plotted) with whole building electric meter data

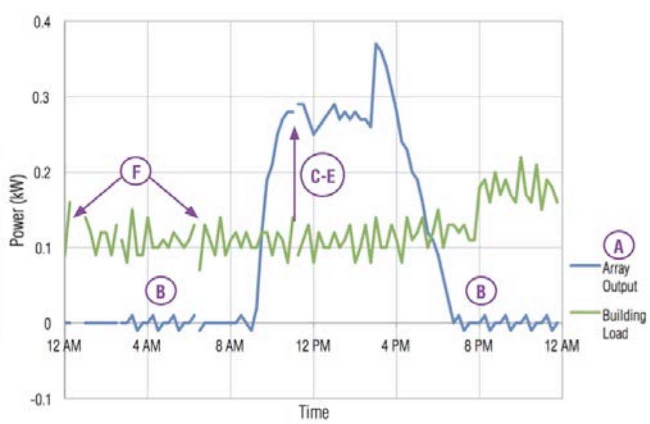
- Measures renewable energy generation,
- Accounts for displaced conventional electricity, and
- Monitors PV array condition

Info Gained: Quantities of renewable energy and power generation, displaced conventional electricity, and potential degradation of array condition

Required data: Time series PV array power generation data

(A) Daily energy yield from a PV system is tracked for a month. Weather conditions such as cloud cover cause variability in daily production totals.
(B) Partly cloudy conditions result in lower output.
(C) Overcast conditions result in even lower output.
(D) In this month, the lowest daily output is 20% of the highest.

(A) Building load and PV array output are plotted for a 24-hour period.
(B) At night, PV production is zero, and all building power is purchased from the utility.
(C) Daytime load is entirely met by PV output, and utility costs are avoided.
(D) "Net" power is PV output less the building load.
(E) The utility credits the owner for generation that exceeds site use (i.e., "net" power).
(F) Short gaps in data may be common depending on the data acquisition system.

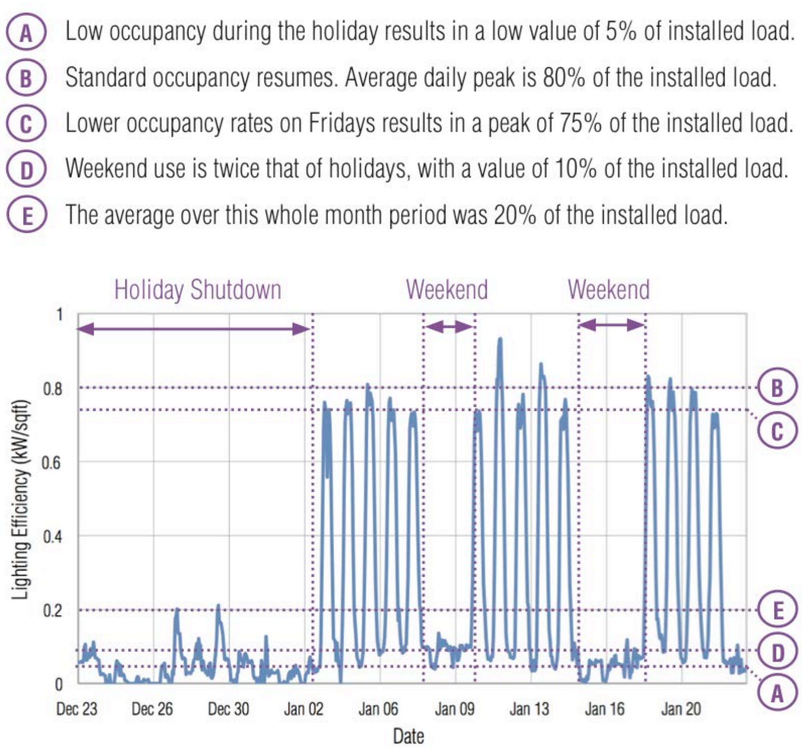


25. <u>Lighting Load Profile Efficiency</u>

Description: Time series plot of lighting system status or demand

Info Gained: Effectiveness of lighting operations and control strategies; switching frequency, potentially excessive overnight use, occupancy or schedule-based control.

Required data: Time series plot of lighting system status or sub-metered demand



Appendix C Detailed Notes from Each Breakout Group

Group 1

Summary

- Users should have guidance on how to interpret their data and how to solve the problem.
- Small data intervals is preferred but difficult to get.
- Need to be clear who the target audience is if not them provide information on what background knowledge is needed to use the application.
- Have a type of financial analysis
- Operating schedule should be user input or flexible enough
- Account for uncertainty of data, changes in building operation, occupancy, weather dependency of data, and gaps in data
- What is the baseline to compare the building data to?
- Flexibility of algorithms in terms of the type of fuel used
- Including occupancy data in algorithms will give fewer false positive.
- BAS is not the only source of equipment data. Newer buildings would have BAS also an issue if smaller buildings have BAS. BAS data might not be enough for some of the algorithms.
- How is the setpoint determined and is the setpoint correct?
- Business policy can establish set points, and actual set points can be compared to the policy
- Have a savings metric

Breakout Session #1

Algorithm Subgroup 1a – Interval Whole Building Electric Analysis

- Time interval of data is important - monthly data generally available.
    - Data in smaller time intervals is hard to get and varies by fuel. 15-min interval data is a project in itself, most end users will not do it.

- Should point to potential causes of issues shown by interval data.
- The analysis display should show the most recent data instead of past data.

- Data for small buildings are more difficult to acquire.
  - InterNOC acquisition of the data is not a problem with larger buildings.
  - Smaller buildings need to consider the mechanism of installing meters in their buildings.
  - The most cost effective method for metering is with a demand response program.
- Who is the intended audience?
  - For each algorithm/analysis used there needs to be information on the type of user or background knowledge required to use the algorithm/analysis.
  - Provide suggestions on the background of intended users.
  - Provide help with sequential use of tools (e.g. program wizard)
    - Users are able to recognize input data synergies across tools.
- Some type of financial analysis is needed.
  - Building owners might need to project a quick return on investment for their building retrofits.
  - Engineers need analysis of financial benefit.
- Decide on fixed operating hours. This would make it easier to fix and identify faults in scheduling.
  - Algorithms should allow for input in operating schedule rather than rely on equipment schedule.
  - Some companies will change the schedule for extended hours then forget to change back.
- The tool requires:
  - Analysis of how building operation is affected by weather.
  - Accounting for uncertainty in data, and use of confidence intervals
  - Tracking changes to building operation (e.g. maintenance, upgrades, annotated issues, etc.).
  - Monitor occupancy through building records or badge-in data (not useful for buildings below 100K sq. ft). Power use or number of toilet flushes can be used to track occupancy.

- Baselines used to compare building data to, needs to be justified.
    - Tools to compare buildings across a portfolio (e.g. Portfolio Manager) are needed. The tool should be flexible and possibly "smart".

- Alg 6: location data (i.e. zip code) needed as input for weather effects, need to find data for benchmarking
- Alg 1: high value, 3-color heat map has better visibility
- Alg 3: user expertise is needed
- Alg 4: important for baselining
- Alg 5: need to know building type and occupancy
- Alg 6: very high level might not be useful, add histogram across portfolio
- Alg 7: useful for demand response, niche tool
- Alg 8: group had different perspectives ranging from not useful to should be the primary used tool.
    - User must understand nuances of the algorithm.
    - Useful for quantifying savings. Could be used for building portfolio.
    - Some skepticism because of occupancy effects
- Alg 9: suggestion to explicitly use a change point model

- Frequency distribution can be added to 3 or 5 to help identify peaks and where to spend time making changes.

Algorithm Subgroup 1b – Interval Whole Building Gas and Combined Fuels Analysis

- Alg 10, 11, 12: Flexibility in fuel used. Same plots can be produced for different types of fuel.
    - Hourly gas meters are sometimes installed
- Alg 13: EPA regional tool for different power regions, simplifying and smoothing issue of using regional data

- Do building owners really care about this?
- What do the results mean?

- None of the algorithms help evaluate demand response actions (e.g., load curtailment and load shifting)
- Clear specification of formula is valuable
- Determining thresholds for statistical algorithms can be non-trivial
  - Reliability should be specified
  - Need to categorize risk
- Need ways to handle gaps in data from utilities and other sources
  - Minimum data requirements needs to be specified for each algorithm
  - Could automatically scan data to see if they meet requirements
- Flexibility in selecting time period or season
- Interactive visual displays (e.g., setting threshold line)

Breakout Session 2

Algorithm Subgroup 2a – Airside Dx for RTUs and AHUs

- Data accessible sometimes
- Missing occupancy and CO_2
  - Where will you measure CO_2? Some say in zone, some say return air
  - Will get fewer false positives with occupancy and CO_2
  - Some discussion that CO_2 is too unreliable
  - What does it mean to measure occupancy?

    - What if we are over ventilating? Do we need to know occupancy.
- Mixed air temp is hard to measure
    - It is useful in evaluating the damper position
- You can know if you have sensors out of range
    - Whether something is operating when it should or should not is easy to detect
    - Measuring if you have greater or inadequate ventilation is difficult to measure
- Collect supply air temp set pt, if you have it.
- For faults listed in the breakout session – can you see it in 15 minutes?
- Are these measurements available?
    - 15 minute data is too big an interval for some of these analysis, systems that are scanning for faults that are not listed
    - You may be able to get to 5-minute data
    - Some people use 15 min data for 2 hrs – then call it a fault.
    - Other people say it depends
- It is feasible to add new sensors
    - Short term implementations –this can be temp monitoring for Cx.
        - Consider targeting this toolkit to the vendors who provide these Cx services.
    - We probably need a reduced set of variables for owners to set these sensors up – Need to hire someone
    - For a small bldg it is expensive to do this measurement
    - Some tension in the group wanting small bldgs but with permanent BAS with sensors.
    - Use rule of thumb to figure out their energy costs and what they might invest for efficiency
    - Maybe they need a visual inspection of the condenser and simple visit to see if there is a problem.
- List of RTU problems
    - High priority FDD – detect whether a fault detect – total unit power and out side temp.

- 4 priorities are
- a – economizer,
- b – restricted air flow,
- c – low refrigerant charge
- d – proper ventilation

- Is RTU kW worth it? Maybe not but require it embedded in future
- As time goes by more data will become available.

Algorithm Subgroup 2b – Heating and Cooling System Analysis

- Are data available for bldgs less than 100ksqft.
  - If you've got these systems, they probably have these points
  - You need a control system like this for small air handlers
  - BAS are present in newer bldgs – 1992 and newer have them
    - Older ones have a package unit that won't let you schedule it because it is internal to the unit
  - Cypress Environmental systems have optical readers for rooftop units and variety of products to retrofit these
- One thing that is not here is schedule
  - Can we identify if equipment is running when the bldg is unoccupied.
  - Use data from whole bldg to know if there is no night setback or after hour operations
  - Are there VFDs in bldgs that are around 100ksqft?
    - Detect VFDs that are running 100%
  - Simultaneous heating and cooling – consider open but heat, boiler on
  - Consider unable to meet static pressure
- Which is most important?

  - Maintain comfort, if occupants are uncomfortable the occupants will let building managers know
  - RP 1633 – they took these data visual systems to operators and got ideas back which were most useful
    - Operators always want to see a location map – where do I go to fix this problem?
  - How are we doing relative to setpoint? Is the setpoint correct?
  - Scheduling and night set back
  - Are the sensors relatively accurate – are they consistent, do they flat line?
  - When you have good data – eliminate simultaneous heating and cooling
  - Consider the economizer
  - Loading histogram – that is hard to get – high uncertainty on these ton measurements.
- VAV systems
  - Want high minimum air flow set pts
  - Need to also evaluate static pressure too high – (low shows, but not high)
- Consider also the data acquisition systems and sensors that are being used. There can be problems with calibrating sub meters.
  - How we do we conduct sensor validation
  - Relative calibration
  - Which sensors tend to be inadequate
- What would you measure in zones if you could?
  - At PNNL 1000 wireless temp sensors were installed
  - PNNL said it eliminated heaters under the desk
- Do you need custom algorithms for diff HVAC systems – duct static reset, supply air reset, you need an algorithm that suggestions you are evaluating the sequence of operations. You need resets…
  - most the time they will not implement static pressure reset
  - but we need a tool that can implement these analysis

- Should OpenEIS be able to set up the analytics like duct static reset evaluation

Breakout Session 3

Algorithm Subgroup 3a – Dx for Built-Up Systems with Central Plants and BAS

- Business policy can establish set points, and actual set points can be compared to the policy
- BAS may not have all the data required for the algorithms
    - Chiller data might be on a separate control system
    - 1-min and 5-min data maybe pushing the capabilities of BAS.
    - Varying ability to export / communicate capabilities
    - Problem getting data out of older system
    - Establish minimum requirements on BAS.
- Firewalls are issues for data acquisition
- Naming convention needed if applying algorithms to different buildings
- These algorithms apply to larger buildings in the < 100K sq. ft. category that have BAS

George: *Aps should include where the algorithm should and should not be applied. Consider night setback. Not applicable to multi-family high-rise residential*

- Sequencing of equipment - equipment staging reports.
- Condenser water temp reset
- kW per ton vs. kW useful
- Speed on every VFD

Algorithm Subgroup 3b – Other Building System Analyses

- Some submetering of lights, maybe seeing more in the future
- Additional lighting system capabilities (e.g., daylighting control)
- Control systems for lighting are even more diverse than BAS

Breakout Session 4 - Gaps

- Can the tool provide a way to help estimate how much savings are available from fixing an problem?
  - Can the tool collect data as savings from past data?
  - Examples – the database has examples of savings from previous buildings
  - This may not be in the round but in future

- Other Gaps –
  - Some owners are concerned with peak demand charges
  - What piece of equipment is driving the peak
  - When did it occur and ratchet the peak
- Enthalpy lock out with economizers
  - Algorithm that is site specific
  - Simultaneous humidification and dehumidification
- Detect when systems are overridden
  - Can be overridden off or overridden on
- Can we collect performance data at systems - kW/ton at system level, not just the chiller, pumps, tower, everything
  - Pumping kW/gallon
  - W/cfm

- Could develop a set of curves to model the cooling plant to model pumps, towers and chillers to get the lowest kW/ton
- We need a set of industry standards to identify the standards to compare our building against.
  - Maybe my pump data are high because I have a high rise.
- Water – if someone has an algorithm – yes – Some example of work on this has lead to detection of leaks
- Consider energy by end-use if you have submetering
  - FirstFuel – derives end-uses
  - If there were submeters – you could measure and develop benchmarks and compare your actual building to similar buildings and evaluate if there are retrofit opportunities. Perhaps you track those pie charts over time.
- Extrapolate savings to annual savings? How do we do it?
- How much will we reduce operating costs.
- Perhaps a matrix of extrapolation to annual savings.
- PG&E UT- are there lessons learned?
  - George thinks the UT does not do what we need to do. – CEC is funding things that are too specialized. It may not be scalable.
  - Steve Bushby mentioned the UT and how is this similar- what has been learned.
- Utility of OpenEIS will depend on how user-friendly the system is.
- George reiterated - Primary purpose of the tool is the get algorithms to the market.
- We need to be clear about who the audience is – there may be different ideas on who the audiences
- We did not discuss the need for machine-readable /xml tariffs.
- We need to also consider owners and decision makers – tools for owners to evaluate whole building data. Give them a chance to browse their data.
- Calf solar initiatives – tools for engineering

Group 2

Summary

Most participants encouraged DOE to only consider algorithms that provide actionable information. Definition of actionable information is – clear guidance on what the problem is and what can be done to correct the problem.

Most participants also indicated that openEIS platform should support data quality and reliability. They indicated that without good data it will be "garbage in garbage out."

Breakout Session 1

- Data Quality: all intervals present, reliability?
- Nice to have, occupancy schedules for Outside lighting, Occupant specific lighting. For each kW point, you should have the occupancy schedule associated with that point
- Some participants where against carpet plot as there is nothing actionable but the operators need suggestions on what to do!
- An example image on board (see attached picture), was discussed as an approach to shape and tail off shape. There are other ways to analyse the data and communicate the actions to the operators.

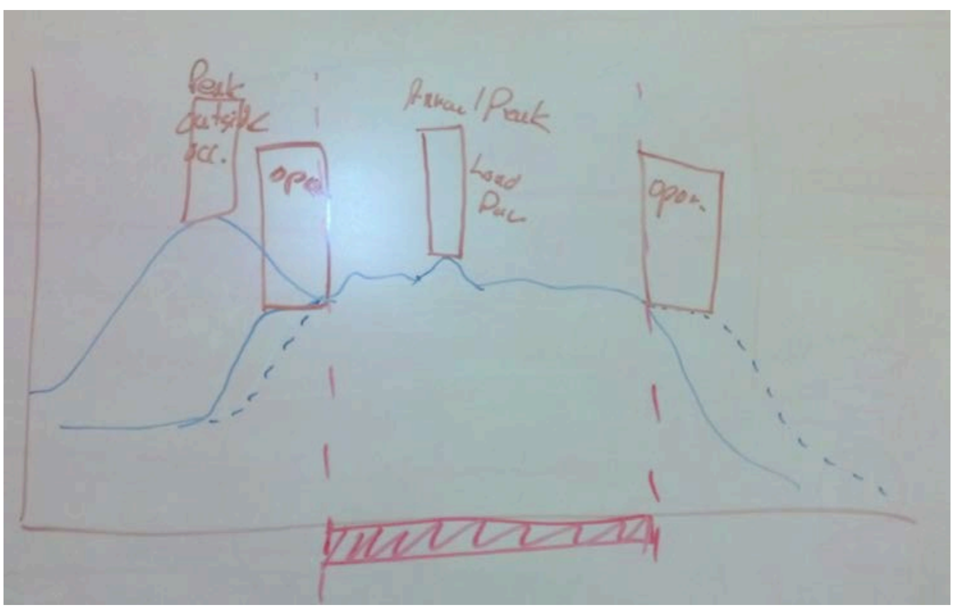


Figure 1: Participant example of load shape analysis and especially useful checks from an owners' perspective

- There was also discussion about the ASHRAE 1633, where they are looking at preferences to visualize the data; the preliminary indications are the operators like the information presented thru floor plans, time series, Pie Charts, benchmarks against our own buildings, etc.
- High level overview (i.e. carpet plot) that shows area of inefficiency and lets the user zoom in is one way to present the information.
- Suggested Algorithms:
    - Building starting early
    - Building finishing too early
    - Building peak at dd/mm/yyyy
    - Need load duration graph
    -
- Think of schools that start up after summer that needs to be accounted for in baseline. Example of Saturday bump due to basketball game, how much does that game cost.
- One participant indicated that all of these algorithms need a benchmark for comparison.
- Operators want green, orange, red as opposed to a number – simple indicators of something is wrong.
- The feedback that the ASHRAE project 1633 is getting is, don't limit me to one thing. Look at the high level first and if a problem is identified then dive deeper. This is the key to successful user engagement.
- The platform should provide weather data; it should not be responsibility of the building operator.
- Considering simultaneous displaying gas and electricity at the monthly level enables a more powerful comparison but interval gas data is not typically available.
- If you don't have good data on gas consumption, other data can be used to imply gas consumption, e.g. supply air temperature setpoint.
- One participant wanted the use statistical process control or bin analysis.
- Algorithm 7 not important other than DR cases, load duration curve more useful.
- Algorithm 13 carbon accounting is universally considered not necessary.

- Consider separating outputs based on target stakeholder.
- Development of the UI should not be the focus of this project. Private industry has this already but communication format is of crucial importance.
- Consider adding bad energy data rule (missing a certain percentage of readings or zero readings).
- All algorithms need to absolutely minimize false positives.

Breakout Session 2

- Rooftop units (RTUs) behave differently than air handling units (AHUs), as RTUs may cycle more often.
- Get data from newer units is relatively less difficult, older units may require up to 6 months for a network card and to set up the hardware.
- 7-ton units or lower may not be cost effective for adding additional sensor measurements.
- Reliability: Data must be thoroughly validated before it is used; sensor placement can have a huge impact on efficiency of unit. Sensors may not be calibrated.
- Actionable data, do I have bad temperature sensors, e.g. has this value not changed in 24 hours.
- Some must have checks discussed:
    - Temperature not reaching setpoint
    - Airflow not reaching setpoint
    - Static pressure not reaching not setpoint
    - After hours demand exceeds occupied demand period based on hours of each (based on when building should be at temperature)
    - Check if the heating or cooling setback when the incorrect direction. Usually a sign of a bigger problem.
    - Missing temperature data rule.
    - How many exceptions did you have this month (compare it with last month)
    - A generic routine that tracks something against its setpoint
    - Have you a multi-stage device that is not using all stages.
    - VAV that runs at 100%

  - Setpoint locked in.

- Algorithms 16 & 17 are great.
- Algorithms 18 & 19 are very important typically lack data. Need to account for packaged terminal heat pumps.
- UC Berkeley Center for the Built Environment CBE study for quality of indoor environment might be more informative than a single setpoint reading. It is a more holistic consideration of indoor environmental quality that addresses several aspects of comfort, beyond temperature.
- Algorithm 20 important
- Algorithm 21 important
- Algorithm 22 great if data is available as is the case direct digital control (DDC).

Breakout Session 3

- Plant loops should not just track delta T in isolation? This requires a sophisticated user for analysis due to the complex nature of the system interactions.
- Over pumping the secondary loop is worth considering.
- BMS alarms are not configured in general.
- Algorithms 23.3.1-5 conceptually difficult to implement
  - Heat exchanger efficiency of the system rule
  - A generic scheduling rule
  - Multi-staging of boilers compared against control sequence of operation and is the equipment operating correctly?
  - Evaporator approach temp, condenser approach temperature.
  - Provide a kW/ton for chillers, pumps, towers.
  - A generic status rule that can be applied to 24 and all equipment. In the case of 24, you should measure it against something, for example kW/sf.
- There a consensus that this group of algorithms are difficult to implement without a number of false positives. Far more complicated that economizer rules, 3a more applicable for buildings larger than 100k sf.

Breakout Session 4

- Occupancy detection is useful to have but not realistic given the <100k sf criterion.
- Sensor validation rules should be applied to all data points. A generic baseline comparison routine is also useful to have.
- Mapping of data from different data sources is difficult. Need a “standard” way to name and map data points into the openEIS platform. See attached picture of an example approach.
- A matrix to map the data needs with application would be useful to have.

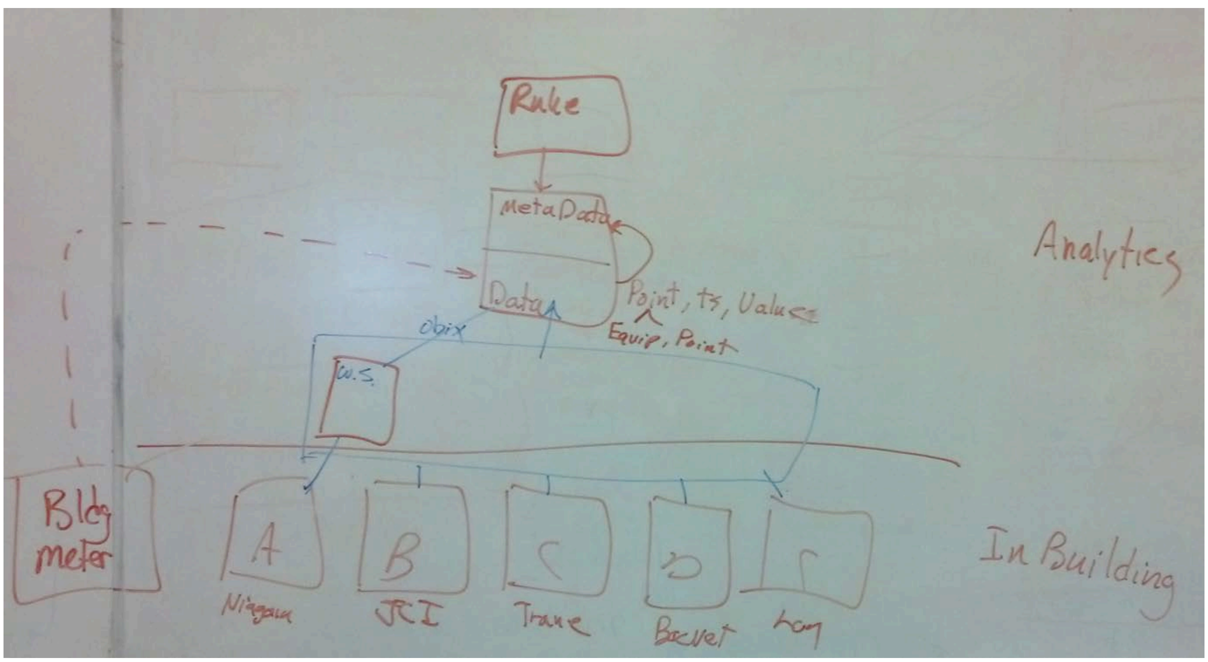


Figure 2: Participant conceptualization of a means to map data names and points for use in the OpenEIS solution.

Group 3

Summary

- Accessibility and applicability are size driven.
  - Small commercial buildings in the < 100K square foot range are segmented into three categories: < 25K sq.ft.; 25K to 50K sq.ft.; and 50K to 100K sq.ft.
  - The data required for any of the algorithms in DOE's preliminary list will be sparse in buildings below 50K sq.ft. and become more accessible beyond that threshold.
  - Data from a BAS is not unheard of, but still not common in buildings between 50K and 100K sq.ft.
- The most useful algorithms on DOE's preliminary list are those that address scheduling and economizer operation.
- The algorithms on DOE's preliminary list would become more useful if disaggregation of whole building data and temporary sensing are used.
- Data integrity is of critical importance for the OpenEIS solution, but should be considered separately as a significant topic on its own.

Breakout Session #1

Algorithm subgroup 1a – Interval Whole Building Electric Analysis

- The whole building algorithms listed in this group could be applied for any utility.
- In most buildings in this range, only monthly utility bill data will be available, not interval.
- 15 min. interval data is not prevalent, but is most useful and accessible for little to no added cost. Monthly data is most common. Hourly data is not common – 15min or monthly is what you tend to get.
- Clear winners in this group include: 2, 3, benchmarking over time (5 and 6), and 8 (not necessarily taken all the way to CUMSUM).
- Algs. 1 and 2 are different representations of the same analysis, and 1 is preferred.
- Alg 4 is not useful as it is defined, but could be very useful if disaggregated into different loads. This was true of weather sensitivity metric as well as energy signatures.
- Alg 7 is useful for demand response, but not widely used.
- Alg 9 is useful (often used in other calculations), except for buildings with few weather dependent loads.
- Issues of data quality and cleansing should be considered separate from the algorithms themselves.
- Third parties rarely are able to serve buildings below 50k sf bc of the economics.

Algorithm subgroup 1b – Interval Whole Building Gas and Combined Gas and Electric Analysis

- Alg 14 is a clear winner.

- Interval gas data is not available to run Algs 10 and 11 because there is not business case for gas utilities to provide it.
- Alg 12 would be useful if disaggregation techniques were applied.
- Alg 13 is not very useful because end-users are not often carbon-driven, but it would be simple to develop.
- Consider ownership and management models – campuses are different from individual buildings, or those commonly owned/managed.

- Carbon is less useful, financial impacts would be more relevant to the target audience.
- Benchmarking requires more data than currently notes in cases where the building is for example served by district sources.

Breakout Session #2

Algorithm subgroup 2a – Airside Dx for RTUs and AHUs

- Data accessibility varies within this range of buildings.
  - < 50K sq. ft. – typically use RTUs < 4.5 tons that do not use full economizers, and have packaged control systems that are not integrated with anything islanded packaged units with t-stats will be most common.
  - Title 24 may drive the market some, in mandated FDD for >4.5 tons
  - 50K to 100K sq.ft. - data will be accessible for some buildings in this range through BMS.
- The data required are generally those required for control of AHUs, so in BAS will be trendable is available, but not always accessible without add-ons.
- Algs 5 and 6 are useful and widely employed.
- 1 min. interval data is very short, 5 min. interval data is more common and adequate.
- Consider issues of bottlenecking or overloading the BAS with DAQ and trending at high frequencies.

Algorithm subgroup 2b – Heating and Cooling System Analysis

- Algs. 16 and 17 are not necessarily energy savers, unless load and time of day data are also considered; however big impact on maintenance, and useful – actual diagnostics depend on the specific equipment.
- Alg 21 is very useful if the data is available – large energy impacts from excessive mode transitions. Damper data is typically a control signal/value, nota feedback value. If you can get damper position from the BAS, you'll typically also be able to get data on modes.
- Alg 19 would be useful, but zone humidity data is not commonly collected (candidate for temporary sensing). If time of day and schedule were considered, Alg 19 could be useful in establishing a night setback strategy.
- Alg 18 involves too many variables to be useful and doesn't provide enough info in a vacuum. In recent times there has been a trend to narrow rather than expand deadbands, given importance of comfort.

- Deadband vs. schedule information could be very useful.
- Combining Algs. 16, 18 and 19 could be useful.
- Alg. 20 will be hard to execute because Btu meters are uncommon, but would be useful if there is a simple workaround. It would be particularly useful for informing decisions about retrofits for part-load capabilities. This one is best suited for larger buildings with chillers and BAS.
- Alg 22 has a lot of potential upside, but only if the baseline is error-free (which is difficult to determine, and not at all a given, based on the faulty operation of so many VAVs).
- Many VAV boxes are not digital.

Breakout Session #3

Algorithm subgroup 3a – Dx for Built-Up Systems with Central Plants and BAS

- Buildings <50K sq.ft. will not have BAS, and only some buildings between 50K and 100K sq.ft. will have BAS (especially educational and healthcare buildings).
- These algorithms require metered flow data, which is not common, but the technology to do so is affordable.
- Most buildings <100k sf won't have VAV or plants
- There are a number of water-side systems/equipment that are more appropriate for this building size range than those listed (explored in Breakout #4)
- The air-side approaches are all good stuff: 5 and 6 are high priorities.
- The approaches listed in the "other measures" may be the best stuff so far – Strategies to address proper scheduling and economizer operation are the must-haves for OpenEIS.
- Market segmentation would be helpful – determining at a more granular level which building types do/not have BAS.

Algorithm subgroup 3b – Other Building System Analyses

- Alg. 24 is a niche application that won't do any harm, but should be a low priority.
  - PV is not likely to be installed in buildings in this range outside of CA and NJ, although that is slowly changing.
  - PV systems will have built-in monitoring already.
- Lighting is very important because it is such a significant load in buildings, but algorithms will be hard to execute.
  - Lighting is not typically sub-metered or controlled well.
  - Lighting data is not accessible (candidate for temporary sensing).
  - Lighting strategies should include consideration of occupancy.

Breakout #4 – Gaps

- A simple, smart way of disaggregating whole-building data by load – would be extremely useful for top-down views of performance, as well as analyses that are grounded in temperature dependency.
- Missing water-side systems:
    - Condenser water management (i.e. loop optimization)
    - Heat pumps
    - Changeover VAV
    - VRV and VRF
    - Self-contained systems
    - Energy recovery and outdoor air management
    - Participants noted that some of these systems comprise much smaller market share
- An algorithm to determine whether Demand Controlled Ventilation would be effective in a building is a clear winner if temporary sensing could be used.
- Plug loads and process loads.
- Combination of Algs. 16, 18, and 19.
- Alg. 20 would be useful if a workaround to missing Btu meter data is available.
- Refrigeration algorithms (for food service and grocery stores)
- Domestic hot water (but what would the algorithms be?)
- Water consumption