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# Workflow and Resources for Facility Operations Analysis

By

**Matthew Garr, John Kunz,  
James O'Donnell, and Tobias Maile**

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If you would like to contact the authors, please write to:

*c/o CIFE, Civil and Environmental Engineering Dept.,  
Stanford University  
The Jerry Yang & Akiko Yamazaki Environment & Energy Building  
473 Via Ortega, Room 292, Mail Code: 4020  
Stanford, CA 94305-4020*

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## Abstract

Commercial building facility managers buildings typically lack standard workflows and contextual data required to identify and analyze systems with potential for energy or performance improvement. This paper presents a six-step workflow for graphical analysis of performance data from large commercial facilities. The workflow was developed over three years and applied by Stanford graduate students with little previous energy or building operations background. The students identified many examples of appropriate and anomalous Heating, Ventilation, and Air Conditioning (HVAC) system behavior when applying the workflow on tow mid-size multi-function commercial buildings. Specifically, they plotted and interpreted energy system performance data from a Building Management System (BMS), classified individual time segments of the measured data as consistent, partially inconsistent or inconsistent with functional intent, and then reported the data and assessments with graphics and summary tables.

The motivation for this work is the lack in practice of effective methods for building operators, occupants, designers or researchers to analyze and interpret the operating significance of the vast amount of energy performance data now sensed at high temporal frequency in modern buildings. Our successful analysis cases show that relatively untrained analysts can use the workflow to make substantive conclusions about operating modes by comparing measured performance data with system functional intent. The results suggest that, when applied effectively, the new proposed process will lead to reduced energy consumption and provide organizational benefit in terms of reduced utility bills.

## 1. Introduction and Context

Buildings consume 40% of primary energy use in the US, and are a major source of US and world carbon emissions[1]. While buildings provide valuable services, up to 30% of the energy used in commercial facilities is wasted. This waste is largely due to a range of operational factors such as improperly maintained HVAC equipment, rapid cycling in control systems, and sub-optimal operating schedules[2].

Building managers are seldom able to properly investigate and address the underlying problems, even when motivated to find and investigate such problems, and provided access to instrumentation, data storage, and automated software tools. These managers lack standard workflows and contextual data required to identify and analyze systems with potential for energy or performance improvement. From an organizational perspective, such ad-hoc workflows result in excessive energy consumption and excessive utility bills. Lacking effective analysis tools, building data analysts must be highly trained, and often rely on years of industry expertise in analyzing energy and system performance data. More data therefore creates a scale problem. We were motivated to develop semi-automated methods to allow analysts to interpret the operating significance of measured data, and compare it to assumed system functional intent.

To address this problem, we developed an analysis process and accompanying suite of software tools, and specific building information sources that non-systems experts can use together to interpret operating energy performance data. Twelve student groups used and tested the tool suite for three years and analyzed data from two buildings. Using the tools and methods in a class for three years, we have refined the tools and information sources and developed our analysis workflow for use by students and other non-specialist analysts -to successfully identify and report operational energy component and systems problems.

Other investigators report many strategies to allow facilities managers to identify and address sources of energy waste, including: rudimentary performance metrics [3,4]; building commissioning[5] and ongoing or continuous commissioning [6]; using models and energy simulations to analyze energy performance on an ongoing basis [7–9]; monitoring system performance using energy information systems [10–13]; implementing automated fault detection and diagnostics [14]; and the use of energy signatures representing typical system performance relationships [15]. However, facilities managers who oversee commercial building systems do not consistently use these strategies in practice. There is a widespread vision that lifecycle commissioning is too resource-intensive given the expected benefits [13], and despite the existence of comprehensive energy management planning frameworks, such as ISO 50001 for large scale facilities [16] , informed by facilities managers[17], few formal workflows effectively integrate communication between building managers and stakeholders at the strategic and operational levels of organizations [18], or integrate analysis strategies into a building manager's day-to-day job.

Therefore, despite advances in data collection and storage, and processes such as ongoing commissioning, building operators lack theoretically founded reproducible methods that are applicable in commercial buildings to monitor and manage building energy system operation. Facilities managers are unable to effectively use the large volumes of data collected and stored by modern Building Management Systems to determine whether facility operation is aligned with comfort objectives and

energy efficiency. Thus, lacking effective analysis tools and methods, facilities managers and building energy analysts must be highly trained, and often rely on years of industry expertise and “rules of thumb” in analyzing energy and system performance data [19].

This paper introduces our workflow and associated sources of contextual data and discusses its use in a class on energy system analysis that we offer at Stanford University. First, it describes the analysis context for the workflow and introduces the six-step workflow itself. Second, the paper describes the retrospective validation of the workflow based on class deliverables and discuss it. Finally, before concluding, the paper comments on challenges and limitations of the workflow.

We intend the paper to be useful to facilities managers seeking methods to analyze building performance data, academic researchers wishing to verify or discover analysis best practices, and to the community of Energy Information System (EIS) tool developers who can use the paper’s results to inform future feature sets in commercially available tools.

## **2. Research Methods**

The authors developed the workflow working closely over three years with student analysts at Stanford University. The workflow was refined as students asked questions, sought clarification of processes, or contributed their own ideas to the workflow. Each step was therefore developed in order to meet the needs of an inexperienced building analyst, from selecting systems and analysis points (step 1 of the workflow) to documenting and discussing findings (step 6).

The workflow was validated by comparing student analysis results during from 2009 and 2011 case studies where students analyzed the building systems in the Y2E2 building at Stanford University. Using the mature workflow in 2011 students identified more problems, critically analyzed more performance problems, and studied more data plots, despite analyzing fewer data points. The authors take this as preliminary evidence of the power of the workflow that should be tested through additional empirical studies.

## **3. Case Study: Predicting and Measuring Building Energy Use Class**

In 2009, we introduced a new Civil and Environmental Engineering course at Stanford in which graduate students analyzed the operational and energy performance of existing facilities. Over three years, students analyzed two facilities. They identified many examples of both appropriate and anomalous operating conditions and suggested opportunities for energy savings and improved building operations. The class served as an effective laboratory to develop and test new analysis methods, including the workflow that is the subject of this paper.

In 2009 and 2011, the class analyzed the Yang and Yamazaki Environment and Energy (Y2E2) building on the Stanford campus. In 2010, the students analyzed a large facility in Santa Clara County. The former, Y2E2, is a 166,000 square foot, three-story multi-function building opened in 2008. Though it includes a highly energy-efficient design with innovative features such as a night-flushing system, many of the systems were not effectively commissioned. The building does not perform as initially expected due to a combination of use patterns that differ from expectation and systems that do not behave or perform

as expected [20]. Y2E2 has an extensive sensor network that stores measurements from 2,370 data points once per minute. The building includes offices, computer and wet labs, public areas, circulation spaces, classrooms and services such as telecommunications and a kitchen [21].

The Santa Clara County facility was built in 1989 and recently retrofitted with nearly 300 sensors and an updated control system to support research and future energy-saving retrofits. The building has traditional HVAC systems including, a number of major constant and variable air loops that connect to water loops with chillers, cooling towers and boilers. These aged systems provide a rich opportunity to find opportunities for improvement. The building includes offices, residence spaces, public areas, circulation spaces, and services such as telecommunications, recreation areas and a kitchen[22].

### 3.1 Prerequisites and Contextual Information Sources

In order to use the analysis workflow in this paper, analysts require a basic understanding of HVAC system design and operations, and access to building with system-specific information. Most student analysts had previously taken a basic class in building systems. The class also identified four information sources that significantly enhanced the efficacy of analysis activities. These sources of required building and system-specific information were a facility data manual, a description of HVAC control and sequence of operations, facility manager/building manager interviews and previous diagnostic records.

A facility data manual, describes major building systems, names and locations of sensor data points, units of measure, minimum and maximum reasonable as well as setpoint values, system schematics, and descriptions of control strategy and logic. Data manual information is drawn from building drawings, specifications, control systems, and interviews. As such they represent a good starting point for students to understand a facility's systems and their expected operations. However, since energy systems designers typically create data manuals without explicit guidance from operators about how they want to use the data manual to interpret data, these manuals often provide little guidance for which systems to analyze for maximum impact.

The sequence of operations document typically describes the HVAC control and sequence of operations. This document, typically authored during the design phase, explains the logic for BMS functions. As such, it is often an essential resource for understanding how the facility's designers initially intended the systems to operate. Often, however, facilities managers change the building control logic over time, and it becomes necessary to access the BMS logic or talk with managers to determine precisely how the systems are programmed.

Analysts may have previously investigated performance of other building systems, and documented their findings or recommendations for corrective actions or further investigations. Continuing earlier related analysis allows the opportunity to check how well previously-existing problems were fixed and discover new issues.

The documents discussed above are static, as they do not reflect any changes done to the building and its systems after completion. As mentioned earlier the functional intent may be changing over time and it is cumbersome to understand the latest status based on these static documents. Over time, we

recommend that the format of these documents should become more dynamic to reduce the need to talk to facility or building managers [23].

Facilities managers or building managers often have tacit knowledge about facility operations history and intuitions about where performance problems may be found. Therefore, we interviewed managers to help select high-value systems, understand functional intent and current design, and identify realistic recommendations.

With the aforementioned prerequisites in mind, this paper now outlines a new analysis process to evaluate the performance of commercial building systems.

#### **4. Analysis Workflow & Resources**

Through reviewing effective cases of building system evaluation from three years of use, we identified a six-step analysis workflow, as shown in Figure 1.

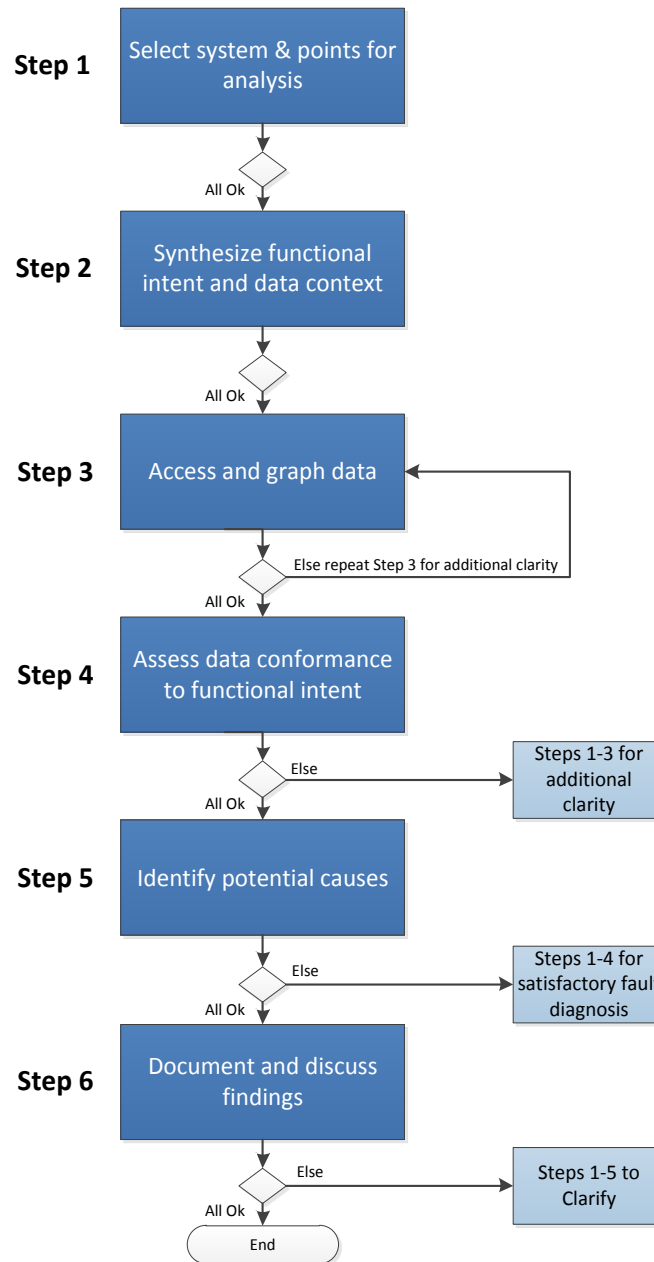


Figure 1: The six-step workflow begins with step 1. In this step, analysts identify candidate systems in the facility data manual. Such systems are typically large energy consumers, systems with high potential for energy waste, a recent history of problems or simply those recommended by facilities managers based on intuition. In Step 2, analysts synthesize functional intent using available information that normally includes a system diagram from a facility data manual, a sequence of operations, and facility drawings. Furthermore, a building manager must fully comprehend system operation and system operational strategy. In Step 3 the analyst first selects an analysis timeframe -- typically a year, multiple months or weekly -- and then creates appropriate plot types based on available data. During Step 4, the analyst enhances generated plot types by adding overlays to show ranges of expected functional intent and unexpected performance and by adding a green, yellow, or red traffic light to indicate conformance of data to functional intent. In step 5 building managers focus on yellow and red conditions by performing what-if analysis of functional intent to predict what potentially-faulty assumptions in step 2 could explain unexpected observed data. Finally, in Step 6, the analyst identifies goals and issues of the intended stakeholder audience and summarizes assumptions and findings of step 1-5 for that audience.



The workflow need not be linear. Rather it invites looping to earlier steps and iteration. This new process systematically focuses building managers on intended functional intent and deviations or inconsistencies from functional intent. In doing so, the process enables building managers to leverage available data and quickly identify and investigate problems, faults, malfunctions and sources of energy waste. Most importantly, this process also requires that, where necessary, building managers communicate relevant information up the organizational chain to pertinent stakeholders, e.g., financial controllers [19].

The sections below show details of steps 1-6 including examples.

#### 4.1 Step 1: Select System and Points for Analysis

The first step is to decide which system(s) to study and select specific data points to analyze. For example, a team might select systems and subsystems from those listed in a facility Data Manual table of contents, such as that shown in Figure 2.

CHILLED WATER SYSTEM.....	3
TEMPERED CHILLED WATER (CHWP-B2 / CHWP-B3).....	5
STEAM SUPPLY AND STEAM CONDENSATE RETURN.....	7
HEATING HOT WATER SYSTEM (HX-1, HWP-B1, HWP-B2) .....	8
TEMPERED HOT WATER (HWP-B3 / HWP-B4).....	10
AIR HANDLING UNITS (AHU-R1, AHU-R2, AHU-R3).....	11
EXHAUST FANS (EF-R1, EF-R2, EF-R3, EF-R4, EF-R5, EF-R6) .....	14
...	

**Figure 2: Excerpt from a Facility Data Manual table of contents, which an analyst can review to select a system and associated points for analysis.**

Every analyst has a time budget for an investigation, whether a student doing a class project, a design engineer or an operating engineer with responsibility for performance of multiple buildings. The first step allows the analyst to identify the study that will have the greatest impact for the sponsor of the work given the time available. Ideally, the analyst will initially identify two or three systems that prior design experience suggests will have the biggest impact on energy performance, then do the analysis of subsequent steps, then return to this step and, so long as time remains, iteratively add a few new systems to the analysis set and complete the rest of the analysis and interpretation workflow. Step 1 is complete when the analyst team has created a list of the systems and associated data points to analyze that relates to the initial motivation to do the study, is big enough to be interesting and yet small enough to be manageable with the available time. A typical analysis scope consists of one or a few systems and the relevant data points.

## 4.2 Step 2: Synthesize Functional Intent

Once a system is selected, the analyst must gather information relevant to understanding its functional intent and operating details. Such information includes system specifications, energy flow, set points, units, conversion factors used in the BMS, minimum, maximum, and intended values, operating modes, system and zone relationships, available sensor points and databases, and building control history.

For example, one facility's Data Manual included a textual description of a supply fan system, shown in Figure 3:

*The facility spaces are ventilated and provided temperature control by a large, centralized supply fan system. Outdoor air is drawn in through a heat exchanger and driven by a supply fan SF1, SF2 or SF3. This air is directed to any one of six, vertically oriented groups of spaces. Each flow passes over a cooling coil, heating coil and delivered to the zones. Return air is mixed, driven by an exhaust fan EF1, EF2 or EF3 back to the heat exchanger.*

Figure 3: After gathering contextual information, the analysis team must represent information clearly to make sense of it. Student groups created Figures 4-6 to synthesize functional intent from disparate data sources.

SF1 Zone/System	Device	Point Type	ID	Source	Units	Set Point	Notes/ Problems
Zone 1	Space	SpaceAir-Temperature	172	Sensor	°C	20.5°C ± 1.5°C (Spec.Doc.)	
Zone 2	Space	SpaceAir-Temperature	173	Sensor	°C	20.5°C ± 1.5°C (Spec.Doc.)	

Figure 4: This table shows a mapping between zone, device, point type, point ID, data source, unit, set point and notes / problems. The group created a table consisting of all data points related to the supply fan system, a frustrating process that clearly exposed the fact that architectural, functional, Building Management System, engineering specifications and data were distributed across a large and poorly integrated set of functional specifications, models, procurement specifications and product specifications.

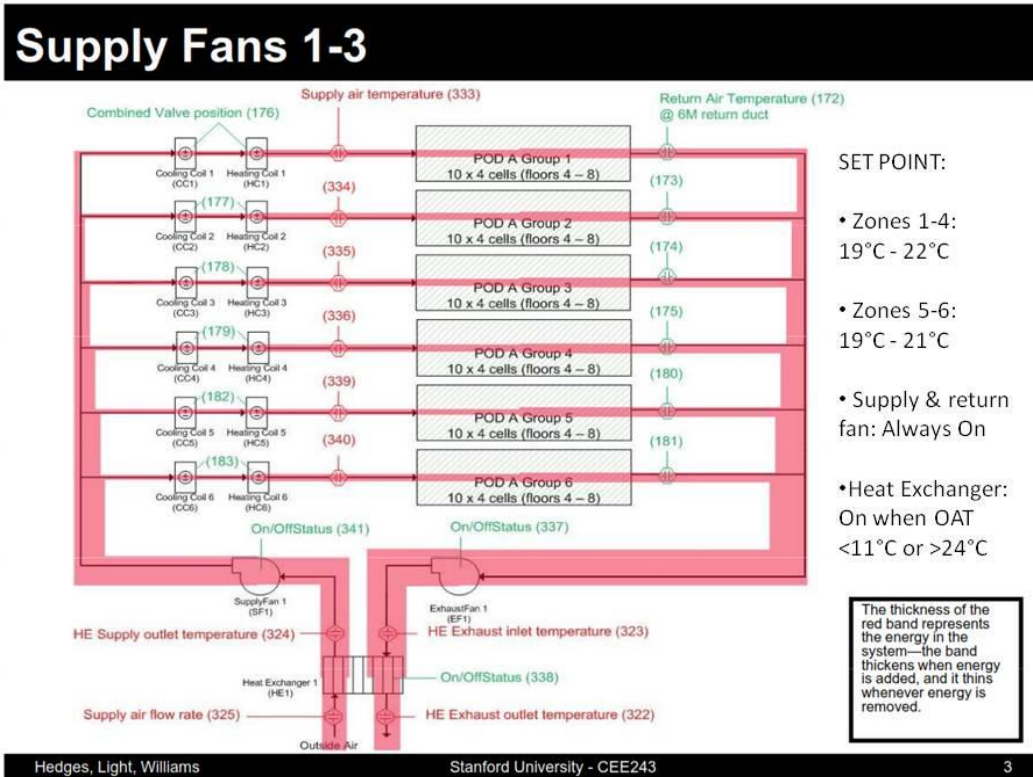


Figure 5: System schematic for supply fans with color overlay showing expected energy flow. This diagram includes setpoint and system function information from the Data Manual and Facilities Manager, a schematic from the data manual, and an overlay made in PowerPoint based on an understanding of HVAC system function.

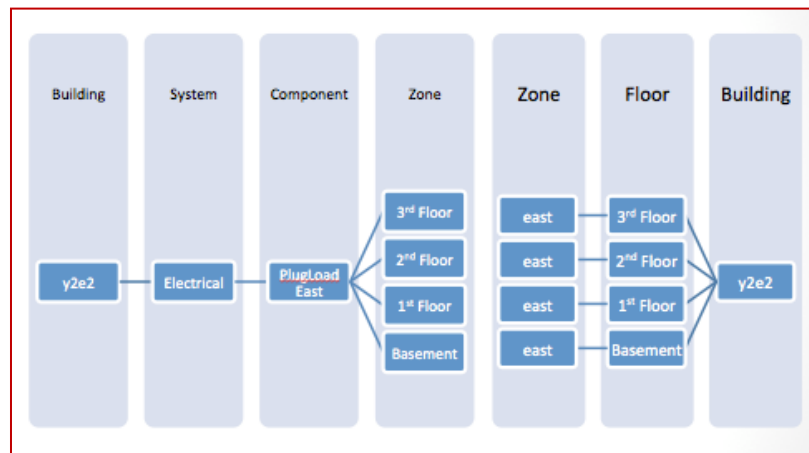


Figure 6: Linked building object and building zone hierarchies for plug loads in a building. This hierarchical network view shows how building systems, zones and components relate to each other. Lines represent relationships between elements at different levels of detail, e.g., Buildings include Systems; Components serve Zones.

### 4.3 Step 3: Access and Graph Data

After synthesizing functional intent, the analyst must access and graph measured data. Time-series, x-y scatter, and carpet plot graphs can each provide different insights. Analysts need to choose appropriate

time resolution (frequency of data), time scales (period length shown in the graph), and time periods (comparing the same points across different time intervals). Generally, time-series plots are best for evaluating performance over time, scatter plots for interpreting relationships and carpet plots to show missing data and daily operating schedules.

Analysis teams used the SEE IT tool [25] to access and graph data. Often, a group created more than one plot type showing a single data point over different time intervals. For example, in Figure 7, for a zone return air temperature, the team created a time-series plot for a six-month period, and then a scatter plot showing the relationship between return air and outside air temperatures for a one-week period.

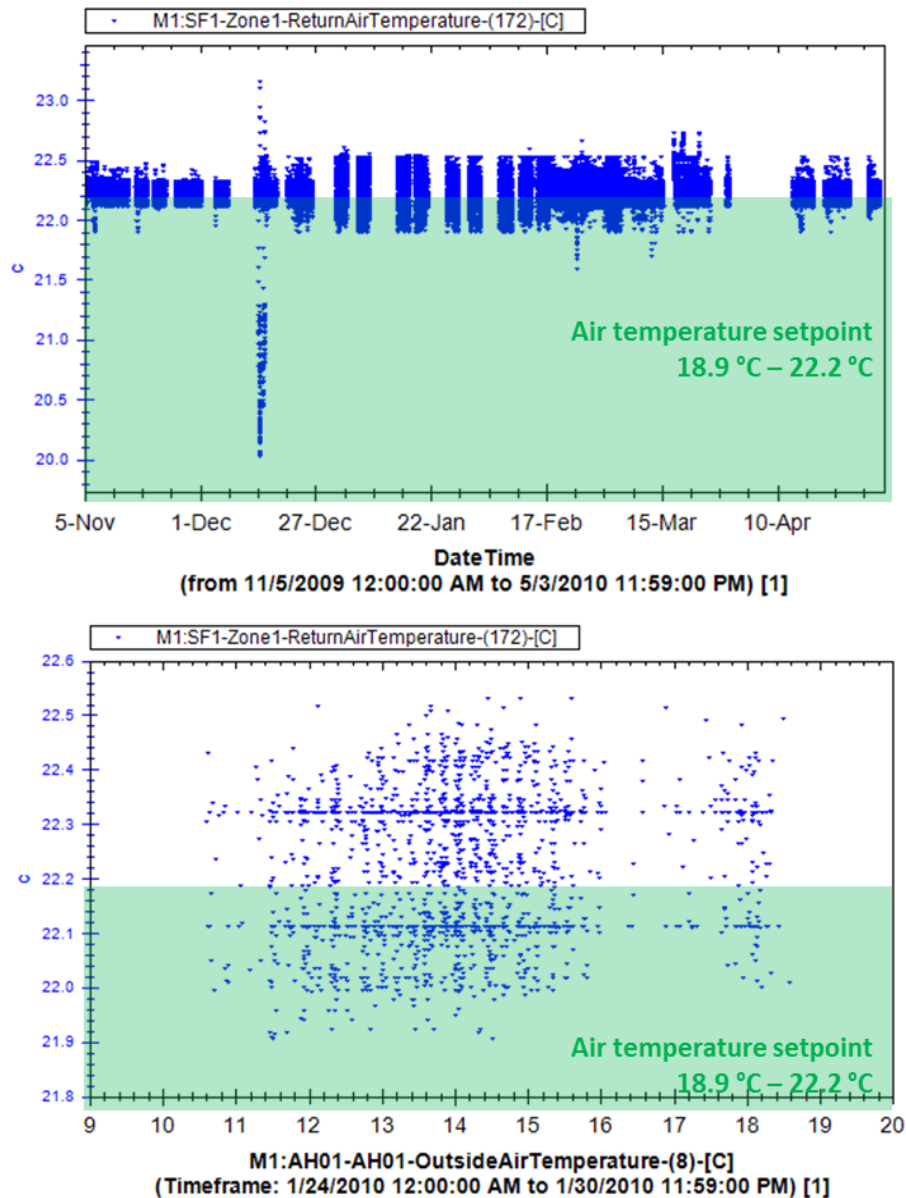


Figure 7: The figures above show data classified according to a green/yellow/red “traffic light” system with respect to functional intent. At top, a green light indicates acceptable behavior, as valve position and flow rate correlate. At center, a yellow light indicates problematic data, as some data lie below the functional intent dead band. At bottom, a red light indicates that hot water loop temperature was always well below the 180°F expected setpoint.

The group then added a plot of supply air temperature to the scatter plot. They built on the fact that the BMS database allows them to extract and relate data from multiple selected monitored points, in their case supply air temperature and space air temperature on a by-zone basis. Further, having a table of data points associated with the zone under analysis allowed the group to look across multiple aspects of the system to assess the extent to which different systems worked together or against each other.

Though general analysis guides such as BuildingEQ [15] suggest particular plots, they do not map directly to the points in a specific building. Choosing the best graphs and time periods therefore remains

judgmental. Step three is complete when the analyst has created graphs showing one or more views of the data points identified during step one, showing operating modes for the time period under study.

#### **4.4 Step 4: Assess Data Conformance to Functional Intent**

In step 4, the analyst must judge whether the data shown in the graphs conform to functional intent. As shown in Figure 8, we use a traffic light convention to represent conformance of measured data to intent [26]: green light represents full conformance; yellow light represents minor conformance failure and red light represents significant problems. We find it useful to overlay a translucent green box on a time-series or scatter plot to show the expected variable or setpoint range, as shown in Figures 6-7. Once an overlay of intent is in place, it is simple to visually assess conformance. In other situations, no simple visual representation of intent may exist. For example, if a valve's functional intent is that it will not adjust by more than 10% per minute, the analyst must visually check conformance with such rules or develop a novel view.

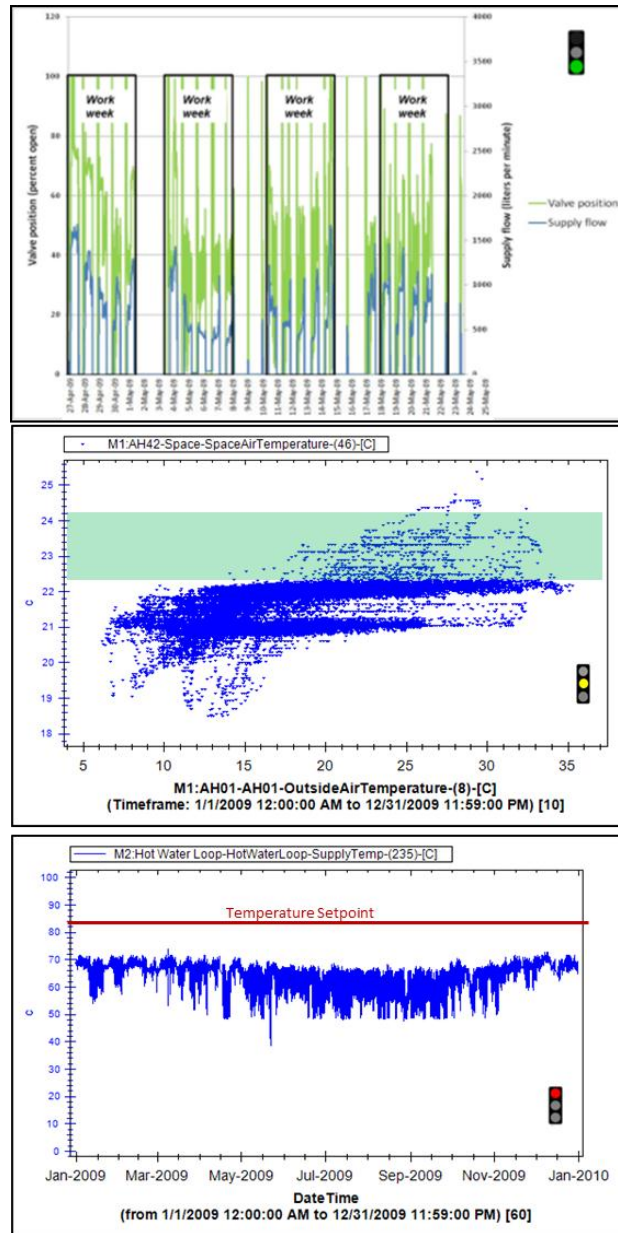


Figure 8: An example wiki page that contains analysis for a number of systems and is available for review by other interested stakeholders. This table of contents serves as a summary or dashboard of building energy system performance.

#### 4.5 Step 5: Identify Potential Causes

For systems where performance is assessed “yellow” or “red” in step 4, the analyst tries to identify potential causes that may be causing the deviation from intended performance. In doing so, the analyst relies on the understanding of functional intent gained in step 2, as well as analysis guides, personal knowledge about building systems, and discussion with more experienced analysts. It is often appropriate to return to step 2 when prior understanding proves insufficient.

The analyst creates a list of potential causes that may be leading to measured performance that deviates from functional intent. If the analyst can test the causes, the list will also include evidence that

supports or refutes the various causes. Step 5 is complete when the analysts have reached the limit of their ability to continue to analyze the system performance, given ability and available information.

#### 4.6 Step 6: Document and Discuss Findings

The first step in documentation is to identify the intended audience and the data and findings that might be helpful. Typically, an audience includes a building engineer, a manager, sister analyst teams looking at other systems and future analyst teams who will evaluate the impact of interventions or perform periodic reviews. Creating a record of findings is vital to provide a clear and permanent evidence-based assessment of system performance. We use slide decks and a wiki to explain analysis methods [27], findings and recommendations when presenting analysis outputs to organizational stakeholders and in doing so completed the communication requirement of the most up-to-date standards [21]. For example, Figure 9 shows the contents for the wiki report of one team after it analyzed a set of systems and components. The wiki summarizes building energy systems and points that the team investigated, assumed functional intent, data findings shown as graphs, conformance and discussion of possible causes and corrective actions. Since it is sharable and editable, the wiki facilitates multi-stakeholder understanding of system and component design, intent and status over time.



The screenshot shows a wiki page titled "Final Report: Group 1" with a navigation bar at the top containing "Article", "Discussion", "Edit", "History", "Move", and "Watch". Below the title is a "CONTENTS [hide]" section listing the following items:

- 1 Main Chilled Water Loop System
  - 1.1 2011 Chilled Water Consumption (tons), Chilled Water Flow Rate(GPM), and Outside Air Temperature (°F)
  - 1.2 Main Chilled Water Loop System 2009 and 2011 Comparison
- 2 Tempered Chilled Water Loop System
  - 2.1 2011 Tempered Chilled Water System Supply Temperature, Set Point, and Valve Position
  - 2.2 Tempered Chilled Water Loop System 2009 and 2011 Comparison
- 3 2009 Main Chilled and Hot Water Loop System Problems
  - 3.1 2009 - 2011 Data - Main Hot/Chilled Water Set Temperature Points 'Issue, Modes of Operation, Cause, Repair, and Recommendation's
  - 3.2 Traffic Light Designation Summary
  - 3.3 2009 - 2011 Space Temperature Data Issue, Modes of Operation, Cause, Repair, and Recommendation - GREEN
  - 3.4 2009 - 2011 Data - Out of Range Temperature Values Issue, Modes of Operation, Cause, Repair, and Recommendation - GREEN
  - 3.5 2009 - 2011 Low Minimum Flow Rates Issue, Modes of Operation, Cause, Repair, and Recommendation - GREEN
  - 3.6 2009-2011 Data - Missing Data Issue, Modes of Operation, Cause, Repair, and Recommendation - RED
  - 3.7 Main Chilled Water Loop System Diagram
  - 3.8 Main Hot Water Loop System Diagram
  - 3.9 Hot Water/Chilled Water System Object Hierarchy
  - 3.10 Current Status Assessment of 2009 Identified Problems
- 4 CO2 Abatement Potential
- 5 Group 1 - Coursework Summary
  - 5.1 Representative Office 145
  - 5.2 Chilled Water Utility - GREEN
  - 5.3 2009 Status Problems
- 6 Guide for Users
- 7 ORID
- 8 Estimated Time Spent in CEE 343 Course

Figure 9: Results of retrospective validation illustrating different metrics from final student deliverables. We interpret the observed increase in three categories as an improvement in the ability of non-expert student analysts to do meaningful energy data analysis and interpretation work and we interpret this finding as suggestive evidence of the value of the workflow for the non-expert analyst.

## 5. Analysis Workflow Validation: Example Analysis Case

In order to retrospectively validate the workflow we looked at the final class deliverable, the presentations of each student group. Figure 10 shows that the number of problems identified, the number of issues analyzed and the number of plots presented all increased between the first year and the third year we taught the class. Interestingly an opposite trend is shown by the number of data points used in the plots. While we did not include the second year for this validation since the students



looked at a different case study with significantly different level of available data (overall the number of available points was one tenth that of that of the other case study).

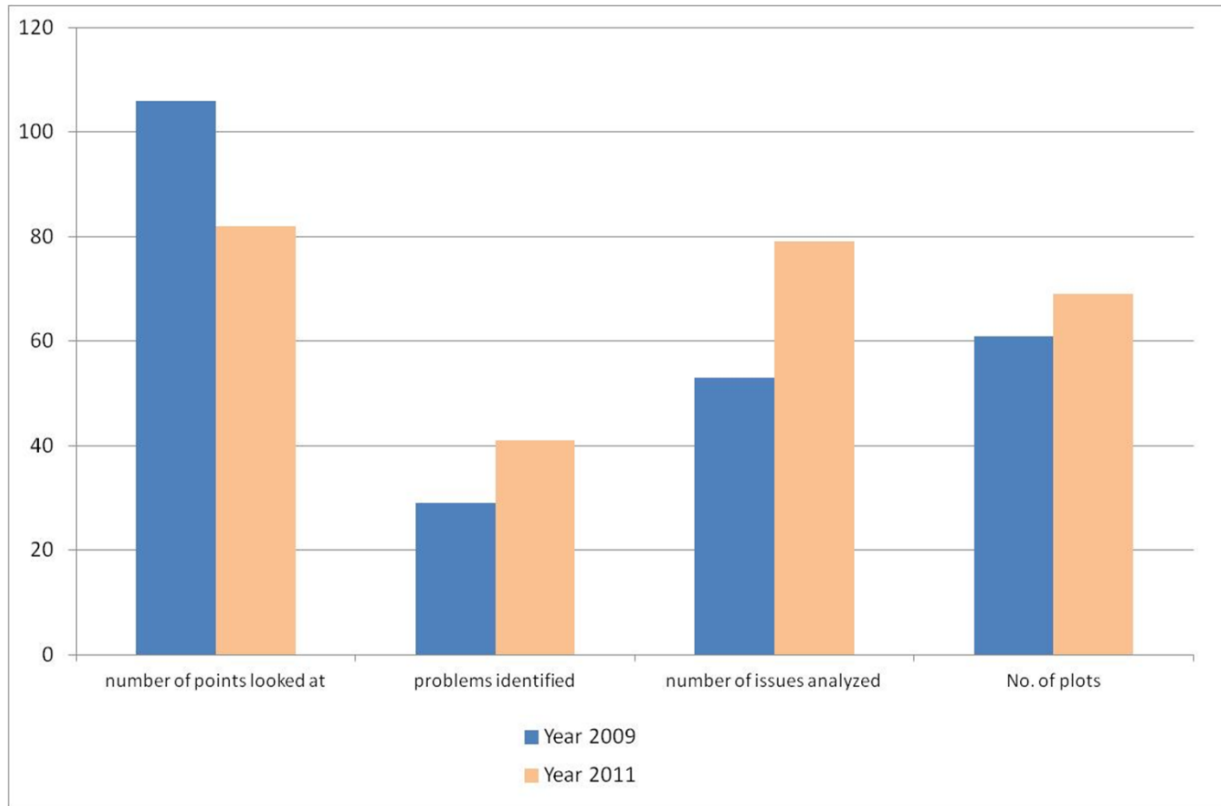


Figure 10: this figure summarizes available contextual data for the Supply Fan #1 (SF1) subsystem for one facility in table format. Figure 5 shows a schematic system diagram of components and their functional relationships, and overlays energy flows through the system. Finally, Figure 6 shows a hierarchical structural representation of building HVAC systems elements at different levels of detail according to the building object hierarchy as defined by Maile et al. [24]. Step 2 is complete when the analysts feel comfortable they understand the system's functional intent, but they may need to return to this step to clarify their understanding if in subsequent steps, they have difficulty interpreting the conformance of measured data to intent.

We do acknowledge that through looking only at the resulting deliverable, we focused only on a subset of the student work and do not directly measure the actual process of the students getting to these results. The decreasing number of data points used in plots suggests that the students focused much more on the important aspects than plotting as many data points as possible. We believe that the workflow described in this paper helped students to focus more on what was important hence less data points that are irrelevant to specific problems or issues. Lastly, the toolset of the students increased though better plotting tools and more available plot types. The students in the third year also used the new variety of the plot types compared to only time series plots in the first year.

Another aspect of this validation is that in the third year more data was available in both the measured data and previous results of students. It is unclear at this point how this increased data availability is influencing these results.

Finally, the fact that twelve different student teams over three years were able to use the workflow and create analyses of interest to the building operators and managers further suggests its applicability in the hands of novice users. The building operators reviewed every analysis and recommendation of every team, which they never would have done if they found the analyses trivial or misleading, and they implemented many of the suggestions of the student teams. While lacking detailed data, significant improvements have been implementing in the buildings and energy saved and thermal comfort improved. We interpret this as additional evidence of power of the workflow framework, even in the hands of novice users. The fact that the teams successfully applied the method on two multi-function commercial buildings is evidence of its generality for this class of building.

All those aspects show that the workflow as part of the class did help improve the outcome of the student work.

## 6. Challenges and Future Research

While the workflow allowed student analysis teams to identify many instances of a wide range of problems, we see a number of challenges and opportunities for future improvement:

- Challenge: Data manuals and other information sources are often incomplete or out of date making it hard to determine true functional intent, and how that functional intent changed over the history of the facility.
  - Recommendation: Create a process to document history of setpoints and log of building manager's changes. One promising technique would be to use a wiki like webpage for this documentation [23].
- Challenge: Better methods are required to communicate among stakeholders including analysts, commissioning, operational and facilities management teams over time to provide structured recommendations
  - Recommendation: Use a wiki to enable human-stakeholder understanding, or possibly some sort of editable and searchable database, which facilitates human use and some automation
- Challenge: Functional intent information is often partial or missing. Current fragmented resources include a system concept, BMS data manual, generic references such as BuildingEQ and inquiries of other stakeholders
  - Recommendation: During the design process of a monitoring system, create an integrated representation of functional intent, design, context and evolving operating history. A definition or standard format to document functional intent should also be developed.
- Challenge: There are insufficient methods to predict the impact of changing the functional intent or operating conditions. For example, a building manager typically uses judgment but not reliable methods or good data to predict impacts on objectives.
  - Recommendation: New simple and easy to use methods must be developed.
- Challenge: Our validation of the analysis workflow is based on a single case study.
  - Recommendation: Test the workflow on more case studies and on identical data sets rather than on growing datasets.

## 7. Conclusion

This paper presents a six-step analysis workflow developed to allow inexperienced analysts to find performance problems in commercial building systems. Over three years, student analysts discovered a wide range of performance problems that were previously unknown to building managers. The workflow shows promising results in its present form as illustrated through our retrospective validation and the positive feedback and interest of the building managers and organizational stakeholders and thus complies with the latest energy management standards.

The workflow uses existing documentation of building data and context information as well as existing software tools to help the analyst to investigate an increased amount of measured performance data. The authors briefly discussed an online wiki, which is an environment for sharing facility information including functional intent, facility performance data, analysis artifacts and analysis results. As such, it aims to integrate the disparate sources of information and provide a central repository for analysis teams and building managers to effectively interact.

The workflow has not been used for either small, e.g., residential, or mega projects, e.g., a large hospital, nor have it been used in high-energy applications such as a process plant. However, the results described in this paper provide evidence that the method can work with hundreds to thousands of monitored data points.

Currently, the workflow terminates with recommendations for consideration by building owners. However, it currently lacks the crucial additional predictive analysis of the energy and financial impacts of what-if interventions, since there are not yet prediction methods that novices can apply and create believable results.

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