CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Summary of the Energy Analysis of the First year of the Stanford Jerry Yang & Akiko Yamazaki Environment & Energy (Y2E2) Building

By

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Summary of the energy analysis of the first year of the Stanford Y2E2 building

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Abstract

The Stanford University Jerry Yang and Akiko Yamazaki Environment and Energy Building (Y2E2) completed its first full year of operation in 2008. The 166K square foot building was designed to accommodate a multidisciplinary set of researchers and students from several schools departments and "inspire faculty, staff, students and visitors to take the next steps toward a sustainable future." Following analysis of energy simulation predictions based on a building information model (BIM), building designers added energy saving features including natural ventilation, heat recovery, central atria for light and circulation, and "night flushing" or opening rooftop windows in the atria to allow hot building air to escape to the outside on cool evenings to be replaced with outside air. In addition, the building was built with 2,370 HVAC system measurement points each of which is sampled by a computer-based data collection system each minute or 1,440 times per day, which represents about 3.5M samples/day for the building. We led the Stanford CEE243 graduate class in the Spring of 2009 that analyzed (some of) the measured building energy system data, made predictions using energy analysis tools, compared measured, predicted and expected data value, attempted to interpret measured values as conforming or not to design intent, and made some recommendations to the owner. Findings of the class study included that students with no prior background could successfully access and interpret measured energy performance data from the data acquisition computer; overall building energy use met code objectives but dramatically exceeded initial design objectives; some HVAC components and systems worked well and others did not work as planned, and a gifted set of eleven students together worked about a thousand hours to interpret only about ten percent of the available data, which strongly indicates that the current process to access and interpret data is not sufficiently routine and automated to allow effective continuous energy system commissioning on a significant commercial scale.

Key words:

BIM, building, energy analysis, energy monitoring, Energy use, energy prediction, measurement

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Introduction

We taught the Stanford CEE243 Predicting and Measuring Building Energy Use for the first time in the spring of 2009: http://www.stanford.edu/class/cee243/. Eleven graduate students had only general knowledge of building systems at the start of the course and no knowledge of how to access the data that are available about the performance of the new stanford Y2E2 Energy and Environment building. We taught the class because one of us (Maile) had done extensive modeling and energy analysis of the building and we thought the process would be of value to students, that we could successfully teach students to do some rudimentary prediction and some real analysis, and his work could use the elaboration and validation provided from the careful attention of some students.

Course objectives

Initial objectives were for students to:

- Investigate specific methods to use in creating a Building Information Model (BIM) to enable energy analysis programs to predict energy performance of medium sized commercial buildings.
- Apply several commercial tools that predict building energy use and investigate use, strengths and limits of those energy modeling software tools.
- Analyze measured building performance and attempt to relate predicted and measured performance: look for the extent of any deviation between measured and predicted performance since, for a few buildings on which measured and predicted energy performance data exist, the predicted energy has a systematic optimistic bias in comparison with actual measured energy use.
- Make recommendations to an owner about methods to model the building, methods to do energy analysis, methods to collect actual energy performance data, and methods to interpret predicted and measured performance.

Related studies

Dramatic statutory requirements for energy performance now include the US EISA 2007 law, which stipulates that, by 2010, that the US GSA must use 55% less energy than average and by 2030 all new facilities must achieve net zero energy occupancy. US Executive Order 13423 requires reduction in facility energy use per square foot by 30 percent by the end of FY 2015, relative to 2003 baseline, i.e., metered annual energy consumption ~55 KBTU/GSF. A California 2006 law requires reduction in greenhouse gas emissions to 1990 levels by 2020. These statutory requirements suggest need for dramatic improvement in sustainable development practices.

There is every indication that current statutes only begin to anticipate emerging objectives. For example, **Figure 1** shown in [MacKay] leads reasonably to the extraordinary prediction that, if societies take it seriously, will lead to an emerging demand for all buildings in the world to have low embodied energy and operate as Zero energy buildings [ZEB] by 2050. In 2006, the United Arab Emirates used about 33 per capita tons of CO_2/year/person; the US about 19, and the UK about 10.

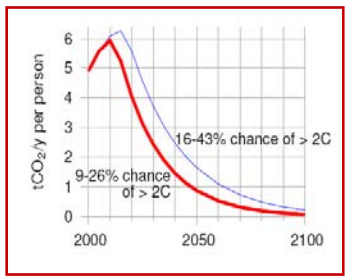

Figure 1: Predicted impact of global warming: if the global community sets a goal to limit probability of global warming > 2°C to the range of 9 – 26%, then there will be an emerging demand for all buildings in the world to have low embodied energy and operate

There is emerging evidence that the AEC industry needs fundamentally new methods to respond to these requirements for efficiency, effectiveness and performance. For example, on those rare projects for which there are available energy use objectives, predicted and measured values, the measured use systematically and dramatically exceeds objectives, and predicted values also systematically exceed measured energy in practice. For example, in 2001, a small community opened in Malmo, Sweden, as a model of sustainability [Persson]. Many design features for sustainability included visual attractiveness, careful building siting, solar collectors, insulation, noise mitigation, attention to indoor air quality and attention to lighting. The energy design objective for the project was 105 kWh/m^2 per year. The project includes twenty buildings, designed by different architectural teams and built by different contractors for different kinds of residential and commercial use. Of the twenty buildings, every one has an observed energy use that exceeds expected. Estimated energy use was in the range from 32 to 107 kWh/m^2 per year, while observed was in the range 74 to 356 kWh/m^2 per year. The least discrepancy was about 1.4 times the predicted of 95 kWh/m^2 per year, and the greatest discrepancy was 3.4 times the predicted of 104 kWh/m^2 per year. Careful investigation showed a lower base load but actual heat use significantly higher than expected. Reasons for the high heat load include thermal bridges and air leaks across the building skin that were mitigated only when the entire skin system was prefabricated, which was not the normal case.

The highly publicized Lewis Center at Oberlin College similarly has measured energy use in the range of 120 – 200 kWh/year and a prediction by the design team of about 64kWh/year [Scofield]. An American Physical Society report [Richter et al.] claims "Whatever their efficiency, these 121 LEED buildings consume more total energy per square foot (either site or primary) than the average for the entire commercial building stock." In its first year, the Energy and Environment building at Stanford had predicted energy savings between predicted and baseline of 41% [Kunz et al]. In this building, actual exceeded the initial prediction and design objective by about 65% and the revised ("calibrated" based on actual occupancy use) objective by a little less than 5%. The data suggest that, even when good people try hard, energy performance comes nowhere near objective, and the objectives need to become much more stringent.

The LEED system has received common, if not yet broad, attention for new building. A prescriptive set of recommendations that has minimal attention to energy, there are few analyses of the actual performance of LEED buildings. The American Physical Society report [Richter] on the energy future claims "Whatever their efficiency, these 121 LEED buildings consume more total energy per square foot (either site or primary) than the average for the entire commercial building stock." It continues "It should be noted that energy efficiency is but one of many criteria for LEED building certification and credits for energy efficiency are awarded based on design simulations, not measured building energy performance. There has been very little work on validating whether projections of performance correspond to actual building performance; that is an area requiring further research."

Findings

Overall building energy use

Figure 2 shows the total energy consumption, including electricity, which is measured directly by meters, and heating and cooling, which is computed from the flow rate and differential (entrance vs. return) temperatures of steam and chilled water. The figure has five columns:

1. initial design predictions (Design Old model) for the new building, which was the original building objective,
2. predicted energy use for a baseline university building (Baseline Old model),
3. revised predictions based on actual occupancy and base energy load (Calibrated Design New Model),
4. predicted energy use for a baseline university building using actual occupancy and base energy load (Baseline Old model), and
5. measured energy use for the for the new building using actual occupancy and base energy load (Actual Operation New model)

The university expected the energy savings between columns one and two (41%). Using assumptions about occupancy and base load after a year of use, the designer made a revised "calibrated" prediction of performance of the new building with its operational features (column three) and the baseline university building with the same calibrated assumptions (column four), and comparison shows effectively the same energy saving as before. The actual exceeds the initial prediction and design objective by about 65% and the revised (calibrated) objective by a little less than 5%.

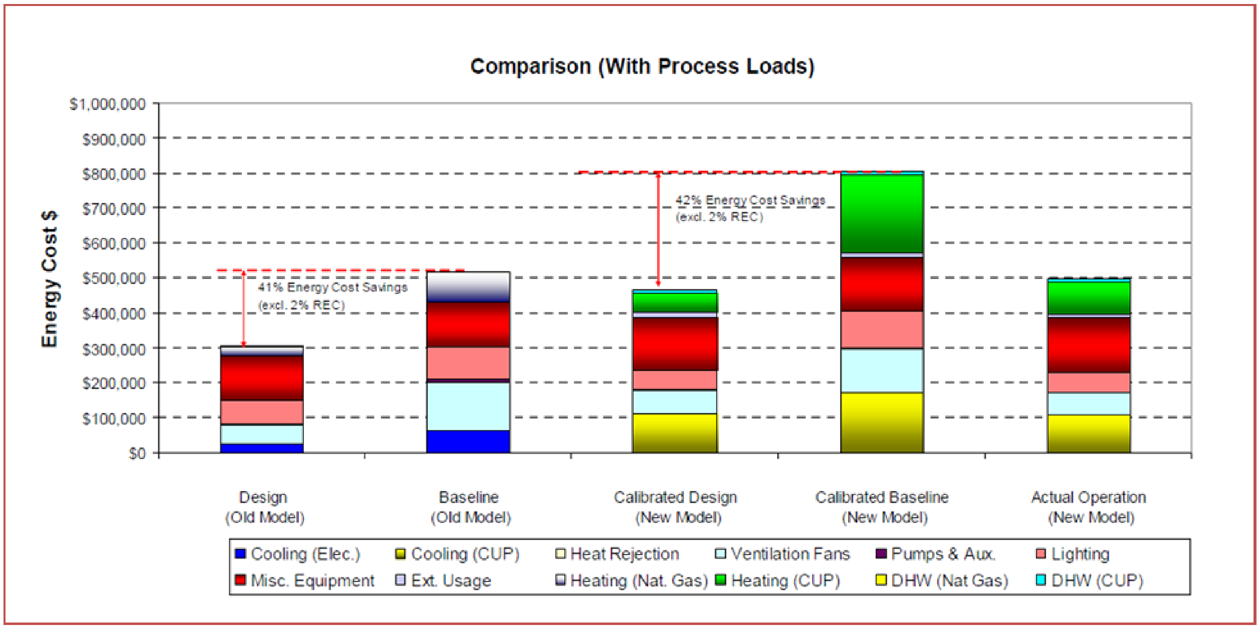

Figure 2: Initial predicted energy use for Y2E2 and a baseline university building with the same occupancy and equipment loads (columns 1 and 2), revised predictions for the building and baseline based on post-occupancy observed occupancy and base load assumptions (columns three and four), and measured use (column five)

Building component and system performance

Cooling water pipes from the central plant have valves in the building to control the flow rate to a space based on an occupancy schedule and sensed local space temperature. Figure 3 below shows that a representative valve opens and closes with the hour of the day and that sensed flow appears to track the valve position appropriately.

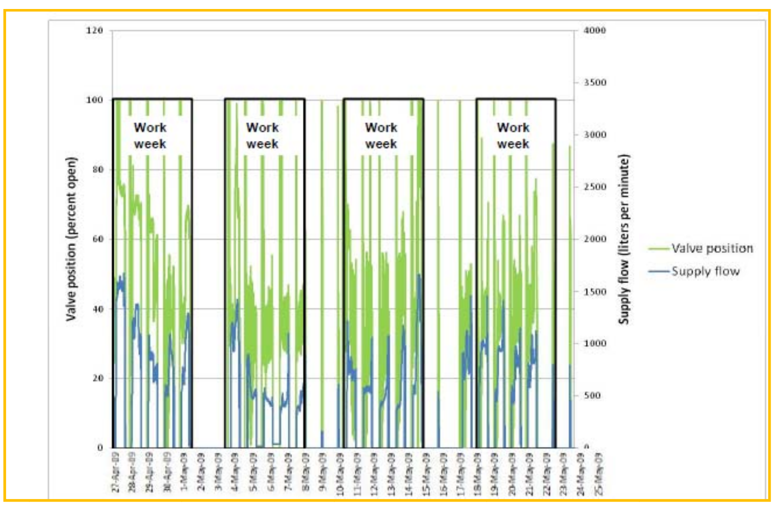

Figure 3: For this example, valve position affects supply flow appropriately

Figure 4 shows the measured rotational speed of the two pumps in the main hot water loop. The pumps cycle on and off every two weeks, which was the design intent, and that the operating speed exceeds the design limit of 25 Hz.

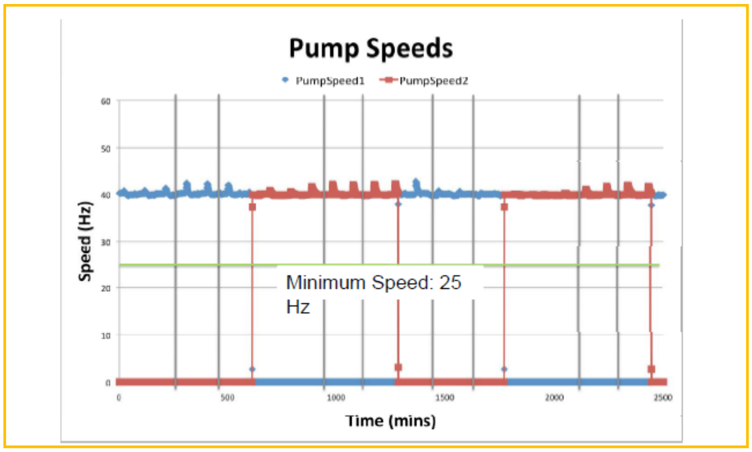

Figure 4: Pump speed operates in an appropriate range and varies per design intent

Figure 5 below shows the difference in main hot water supply and return hot water temperatures (red) and outside temperature (green) for one month of operation, which correlate appropriately given the system design intent.

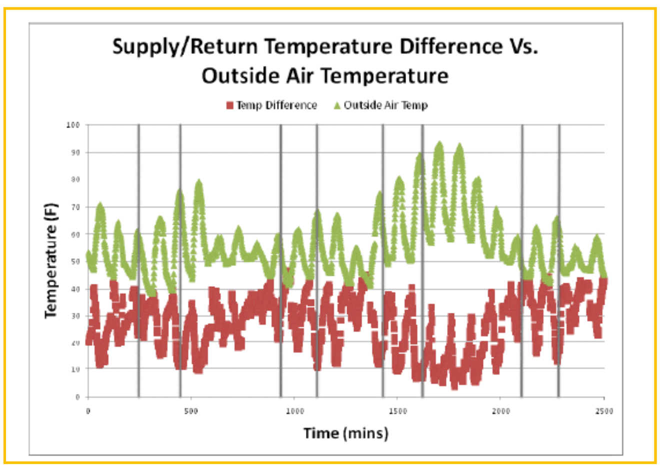

Figure 5: for one month of operation, the difference in main hot water supply and return hot water temperatures (red) and outside temperature (green) correlate appropriately given the system design intent.

Figure 6 below shows that, for one sensed control valve and its associated chilled water return line, the valve opens (A and B). In a period with elevated outside temperature, the chilled water return flow rate increased (not shown), which leads to increased bur appropriate variation in return temperature (C). Light vertical lines indicate daytime occupancy.

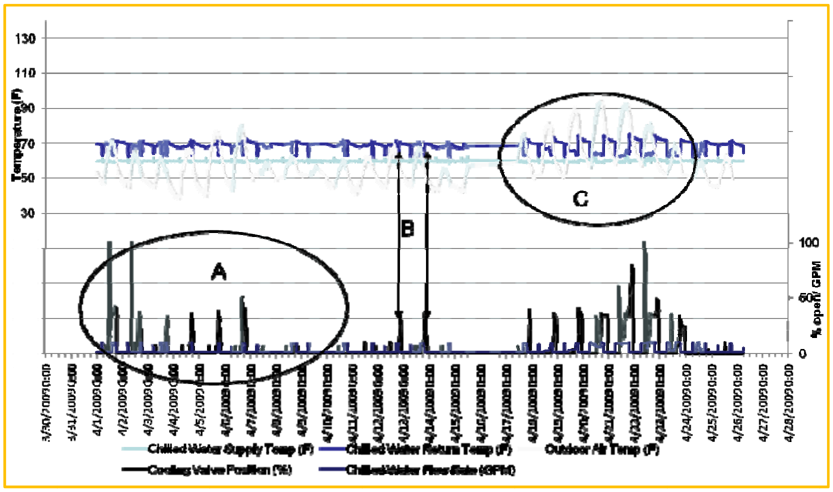

Figure 6: For the sensed control valve, its position (A and B), lower line, appropriately affects the chilled water return temperature

Sensor calibration problems:

- Hot water flow rate stays constant even though valve position changes
- Radiant slab valve position only 0 or 100% open (should change in 10, 5 or 1 % increments): see Figure 7.
- Current draw in representative offices shows integer values only
- Sum of electrical submeters << total electricity consumption
- In some cases there is incorrect labeling of sensors in the building management computer.
- Active beam hot water supply and return water temperature are reverse and values are inconsistent with hot water system level temperatures
- Chilled water valve position does not fully correlate with chilled water flow. The valve position is from a different office, suggesting that there is an incorrect label of a data point in the building management computer.

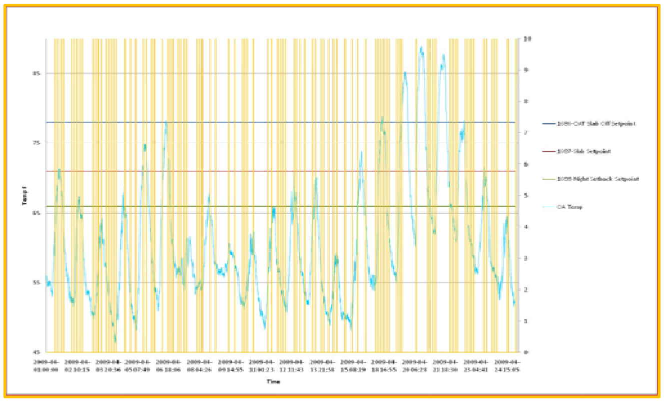

Figure 7: The building has radiant slabs for heating and cooling. The outside air (OA) temperature varied in the ranges from 46 – 90^{o}F. The slab feed line position (vertical lines) was either open or closed, which is different than the operational intent that it should change in 10, 5 or 1% increments.

The students' analyses of data charts such as those shown in this report enabled them to identify many additional problems, some of which are shown in figures below.

Data conversion/scaling problems:

- Temperature values out of range (e.g., 725 °F)
- Pressure values out of range (e.g., 600 psi)
- Minimum flow rate is 1 GPM
- Missing data points

Setpoint problems

- Hot water loop temperature seems to be around 150 °F, which is much different than the design intent specified in the "Sequence of operations" that calls for 180 °F: see Figure 8
- Cycling problems in some valves , e.g., heating coil valve cycles open and closed rapidly: see Figure 9
- Heat recovery bypass valve opens and closes rapidly during transitional periods

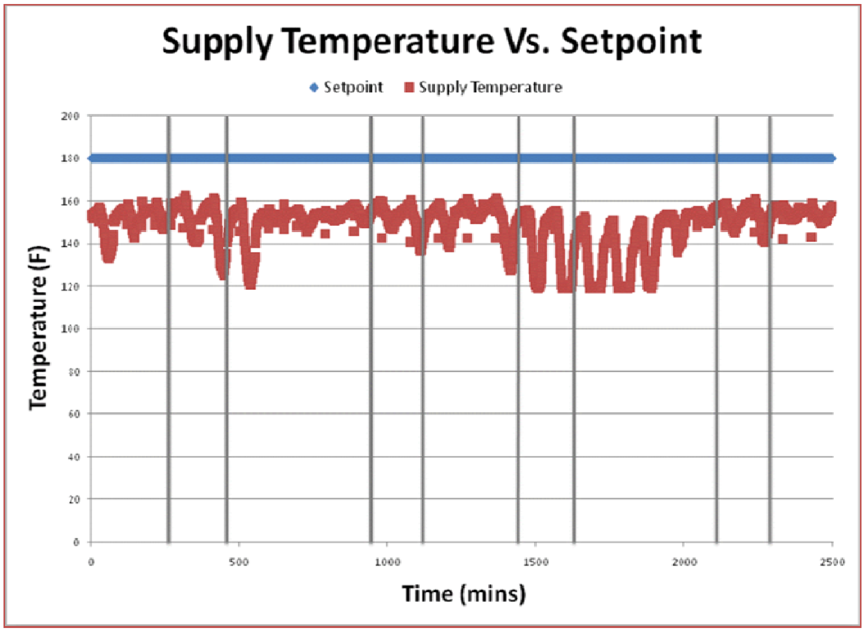

Figure 8: Hot water loop supply temperature varies from 120 to 160°F, although the design intent is that it should vary from 180°F.

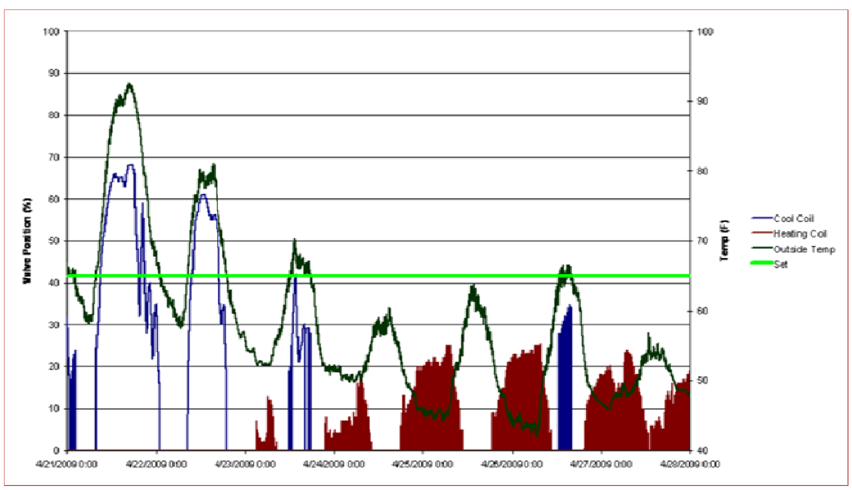

Figure 9: The heating coil cycles rapidly between 0 and about 20% open, which is not part of the design intent and causes unnecessary wear on the component.

System behavior problems

- Night purge on the 1st and 2nd floor seems to be on a regular schedule rather than dependent on outside and inside temperatures: see Figure 10.
- Night purge on 3rd floor seems random and does not follow control strategy: see Figure 11.
- Radiant slab control valve position does not show step behavior as outlined in sequence of operations

- Heat recovery cooling mode does not coincide with coil cooling mode at all times
- Measured (heat plant) close to code specified ASHRAE standard but greatly in excess of the design objective: see Figure 11.

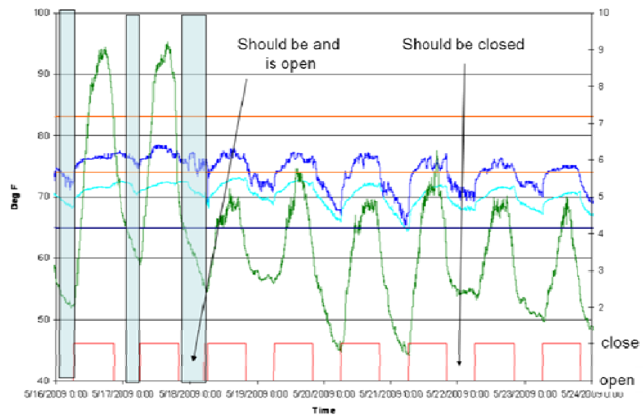

Figure 10: The building has a central atrium, which has operable windows to allow night purge of hot air when outside air temperature is cooler. The lower cycling red line indicates purge window position, which cycles with a calendar schedule and not in appropriate response to outside air temperature (green line that varies from 43 – 95°F.

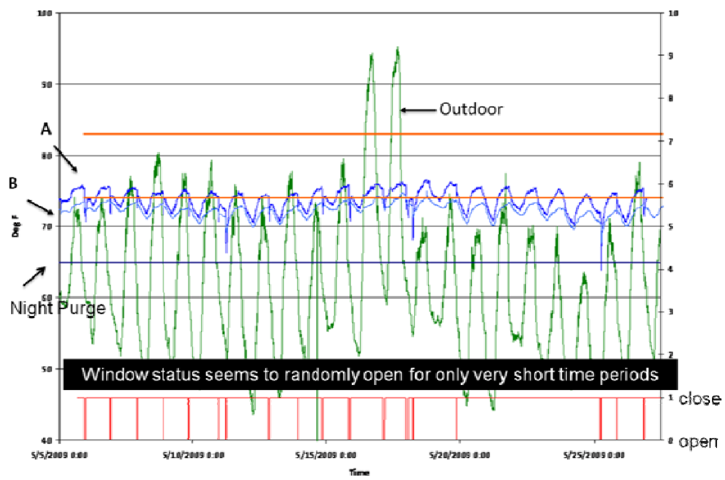

Figure 11: The third floor operable atrium windows seem to be open most of the time, closing for brief periods, shown by the lower cycling red line that represents window position. The green line that varies from 43 – 95°F represents outside air temperature.

Missing measurement points

In spite of the large numbers of kinds of sensors in the building and instances of those sensor types, the class found that many kinds of sensors would have been valuable to aid interpretation of the energy system performance if they had been available, including:

- Occupancy to allow identifying when heating or cooling energy was needed or unnecessary given the current use of the space by one or more occupants

- Electricity submeters by floor *and* per AHU to account for both the horizontal (floor) and vertical (AHU) divisions of the building.
- Radiant slab hot water flow rate, which is not now metered
- Tempered hot and cold water flow rates
- Manual window positions, to allow comparison of building operation with current (or inadvertent) preferences of occupants
- Main hot and cold water temperature set points

Recommendations

General suggestions

- **Identify tasks to commission the building:** Verify performance of each HVAC component, sensor and subsystem for each space or room. Sense measured performance under varying operating conditions and fix identified problems
- **Identify business case for commissioning:** Some improvements will lead to better building and save money given alternative ways the owner can spend money; other improvements will be real but not have high enough value to justify the opportunity costs. Take this issue seriously because clearly detailed commissioning of a monitored building such as Y2E2 now has a prohibitive cost, almost no matter what the potential value, yet engineers always can and want to do more and financial officers always can and want to save immediate costs.
- **Choose commissioning objectives and an implementing strategy, plan, schedule, resources and budget:** Probably it will be easy to achieve much higher data integrity and make many fixes!
- **Increase the number of points sampled by computer to measure both cost and value of energy use:** For example, on future projects and possibly as retrofits, add sensors that record light, electricity, heating and cooling use both by space or square foot *and* per value measure such as occupant or equipment-use-hour.
- **Set public and explicit objectives:** Define, measure and publicly report *performance* for each space against objectives by space type, e.g., energy use, asset utilization: occupant-hours or equipment use-hours/room/week; Comfort including temperature, daylight, illumination level;
- **Enable occupant control and clearly indicate control status to occupants:** make measurements and controls available to room occupants to enable them to become part of the solution and not just a problem

Guidelines for running this and other buildings: Specify

- Designer 3D BIM guide and energy analysis assumptions for contractors
  - Model, predict and measure performance by room, given assumptions appropriate for university
  - Clarify and publicly articulate rationale for objectives, including safety, comfort, financial, good citizenship (e.g., low CO_2 emission)
  - Document location of measurement points (for sensor placement)

    - Size measurement system to record reliable data for normal component operating ranges
- Commissioning requirements for contractors
    - Independently assess accuracy of recorded sensor data
    - Active components (e.g., valves and windows) operate (e.g., open/close) per specification
    - Passive components (e.g., pipes) have flows and pressures per specification
- "Continuous commissioning" process for operators and occupants

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