Diving Deeper: Using Data to Potentiate Student Engagement in K-12 Behavior-Based Energy Conservation

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ABSTRACT

A Massachusetts school district has won national awards for sustainability and energy conservation and has one of the nation's most energy efficient high schools. Using start-up funding five years ago, the district hired an energy manager and tasked her with designing and implementing a behavior-based energy conservation program as a primary focus. District-wide electricity usage fell 13% in two years as behavior-based strategies were implemented. A powerful highlight of the program is the engagement of student Green Teams in spurring adoption of energy-conserving behaviors by adult staff and faculty.

The district is now underway with efforts to move beyond general outreach and education campaigns to more sophisticated data-supported behavioral interventions that continue to incorporate student engagement. The energy manager and student teams are working with electrical panel monitoring that provides real-time, circuit-level data to identify inefficient equipment performance. The high school student team was able to leverage this granular real-time data to successfully make the case for a system-wide shift to power down desktop computers each night.

Gates Elementary School is now working to further expand the potential of data-supported behavior-based conservation programs. In a significant shift from the standard top down approach of an energy consultant walk through assessment, students will observe temperature, light, relative humidity, and occupancy data collected by off-the-shelf home automation software. They will use this data, combined with circuit-level data from the electrical panel monitoring, to advocate for more efficient building operation as well as deeper engagement by building occupants in energy conservation. This paper will share the results and energy impact from these efforts.

Introduction

Published research indicates that schools can make significant reductions in electricity consumption by implementing behavior-based energy efficiency strategies that engage faculty, students, and staff as agents of change. The Acton-Boxborough Regional School District (ABRSD) used start-up funding in 2011 to hire an energy manager and tasked her with designing and implementing a behavior-based energy conservation program as a primary focus. ABRSD electricity usage fell 13% in two years as the behavior-based strategies were implemented. A powerful highlight of the program is the engagement of student Green Teams in spurring adoption of energy-conserving behaviors by adult staff and faculty.

Despite these successes, there was no clear pathway to pair local electric utility incentives with the savings generated by these behavior-based school initiatives. However, upon seeing the school district's success and recognizing the potential for demonstrable energy savings, Eversource, the local electric utility, agreed to explore the possibility of providing incentives through their energy efficiency programs. They asked the authors to develop and prove the efficacy of a behavior-based program model that could deliver predictable savings in a school and could be scaled cost effectively and deployed in a large number of schools.

The program model that we brought forward builds on a foundation of occupant engagement and active student participation, and enhances it with data-driven monitoring and reporting. With guidance from a behavioral program mentor, students and teachers design a school-specific program outreach plan. Data captured from energy use monitoring equipment installed in electrical panels and placed in classrooms both informs and confirms the impact of energy-related changes identified and implemented by students, faculty, and staff. In addition, the energy use monitoring can confirm that a school has achieved savings targets, information that is critical for any program that seeks utility incentives in exchange for energy savings.

Gates Elementary School

In early 2015, Eversource and the authors identified an elementary school to test the proposed school behavior program: Gates Elementary School in Acton, Massachusetts. Program considerations for the building selection focused on minimizing potential extraneous effects such as planned equipment or schedule changes. In addition, the program required support from the school principal as well as a faculty member serving as the Green Team advisor, and support from facilities management.

From a program validation perspective, Eversource preferred to identify multiple schools with similar construction, number of students, and energy use. As this wasn't possible, Eversource requested a full year of energy monitoring to document baseline energy consumption before the program began.

Building Description

Gates Elementary School was constructed in 1967. There are approximately 500 students in grades K – 6. Slab on grade, brick construction, flat roof, and single pane windows. Heating is forced hot water with two new high efficiency gas condensing boilers. Heating distribution includes classroom unit ventilators and air handlers for larger spaces. Lighting is primarily fluorescent ceiling fixtures. Computer use includes desktops for the central administration office and the computer lab and low-power Chromebooks in each classroom.

Energy use and potential energy savings

Table 1 summarizes the energy use for Gates and target energy savings from actions that students, faculty, and staff could make as part of the proposed program. The target savings are estimates that the authors developed for Eversource's consideration to provide a framework for potential system benefit investments that the program could support.

Table 1. Fiscal Year 2015 energy use

	12 month Electricity (kWh)	12 month Natural Gas (Therms)
Annual energy (use)	240,120	35,940
Target savings (%)	10%	5%
Target savings (use)	24,012	1,797
Est. energy price ($/unit)	$0.20	$1.00
Target savings ($)	$4,802	$1,797
EUI (before)	15.2	66.7
EUI (after)	13.7	63.3
Target EUI savings	10%	5%

Program Implementation

The authors began the program in March 2015 by installing energy monitoring equipment, with a plan to keep it in place for two years. Green Team planning began in December 2015, and outreach to the Gates community was initiated in March 2016.

Circuit-level monitoring

Our efforts needed to achieve two goals: 1) Energy savings in the school and 2) a validation of our program model. Electrical circuit-level monitoring was key to both.

Monitoring was installed on every electrical circuit in the school. While this comprehensive approach to monitoring would be prohibitively expensive for future program implementations, Eversource recognized that it was necessary to obtain the level of detail needed for their evaluation of the program, that it would enable them to tie student efforts to specific reductions in energy use, and they agreed to support it.

An electrical subcontractor installed an energy monitoring system manufactured by PowerHouse Dynamics called SiteSage. The system includes four major components:

1) 20, 50, and 150 amp current transducers (CTs) installed on individual or electrical circuits
2) CT connection and wireless communication devices installed in the electrical panels that collect, store, and distribute information from the CTs every minute
3) Wireless communication devices installed near but outside the electric panels that collect and distribute information for the internal electrical panel communication devices to the Internet
4) A cloud-based service data service that collects data from the external communication devices and archives and summarizes data collected by the CTs

The electrical subpanels at Gates (and other elementary schools that we have monitored) fall into three major end use categories: HVAC, non-lighting, and lighting electrical loads. Table 2 includes energy use for these groups that we monitored during a sample week in March 2015. HVAC-related circuits include heating circulation pumps, exhaust fans, air handler units, and unit ventilators. HVAC equipment is the major source of electricity use in the building. Non-lighting loads include kitchen appliances and classroom and common-area plug loads. Lighting is primarily indoor fluorescent ceiling light fixtures. Outdoor parking lot lighting is recorded on a separate electrical account and is not included in Table 2.

Table 2. Gates electricity use per major category (March 16-22, 2015)

Category	Electricity (kWh)	Percent of Total Electricity Use (%)
HVAC	4,083	52%
Non-Lighting	2,041	26%
Lighting	1,478	19%
Unknown	230	3%
Total	7,832	100%

Classroom temperature, light, and plug load monitoring

Connecting students, faculty, and staff with classroom-level energy use data was recognized as a critical component of the program, but the authors needed to find a cost-effective alternative to full-building energy monitoring. Previous energy conservation engagement programs at ABRSD had used Kill-a-Watt outlet meters as a stand-alone device to help identify appliances to target for powering down. This information was helpful in educating occupants, but what was missing was ongoing, detailed information on lighting and plug load consumption at specific locations that could be used to provide meaningful feedback over time and help spur high levels of engagement in powering down. We tested a few sample home automation sensors and found that they offered the potential to give the students a mobile monitoring kit that they could deploy.

The school district funded the purchase of 3 kits, one for Gates Elementary, one for the middle school, and one for the high school. Each kit included: a communication hub, 8 multisensors (light, temperature, relative humidity, and occupancy), and 16 electrical outlet dimmers that recorded instantaneous watt levels and accumulated kWh. The multisensors recorded data every 8 minutes and the outlet dimmers recorded data at change of state. A cloud-based interface allowed the authors to pair each sensor with the communications hub and to archive data for a couple days. In addition, the school district signed up with a software service that archives the sensor data longer than two days and provides data analytic services for a nominal fee.

Green Team engagement

Key to the success of the behavior-based energy program is a spirited and engaged Green Team. The team currently includes 37 children in 6th grade supported by a faculty advisor and the school district's energy manager.

The first task assigned to the Green Team was to learn about and deploy the classroom monitoring equipment. The students met this with great enthusiasm. Turning lights off remotely using the electric outlet dimmers was particularly exciting for the kids. The Green Team spent four weeks between New Year's and the school's February break moving the monitoring equipment between clusters of classrooms to assess light levels, temperatures, and outlet energy consumption throughout the school. The authors downloaded and organized the data for future Green Team presentations and outreach.

Facilities Management engagement

An important element in the behavior program included actively engaging facilities management staff in the effort. Previous behavioral initiatives at the middle school and high school worked with the custodial staff to tightly manage hallway lighting, but working with facilities staff on building HVAC operation was more challenging. Potential reasons for less effective communication with facility operations included their concern about receiving less-informed, third party input on relatively complex HVAC systems and concern about potentially making changes to building management system settings that might compromise school building operation expectations or risk potential equipment failure.

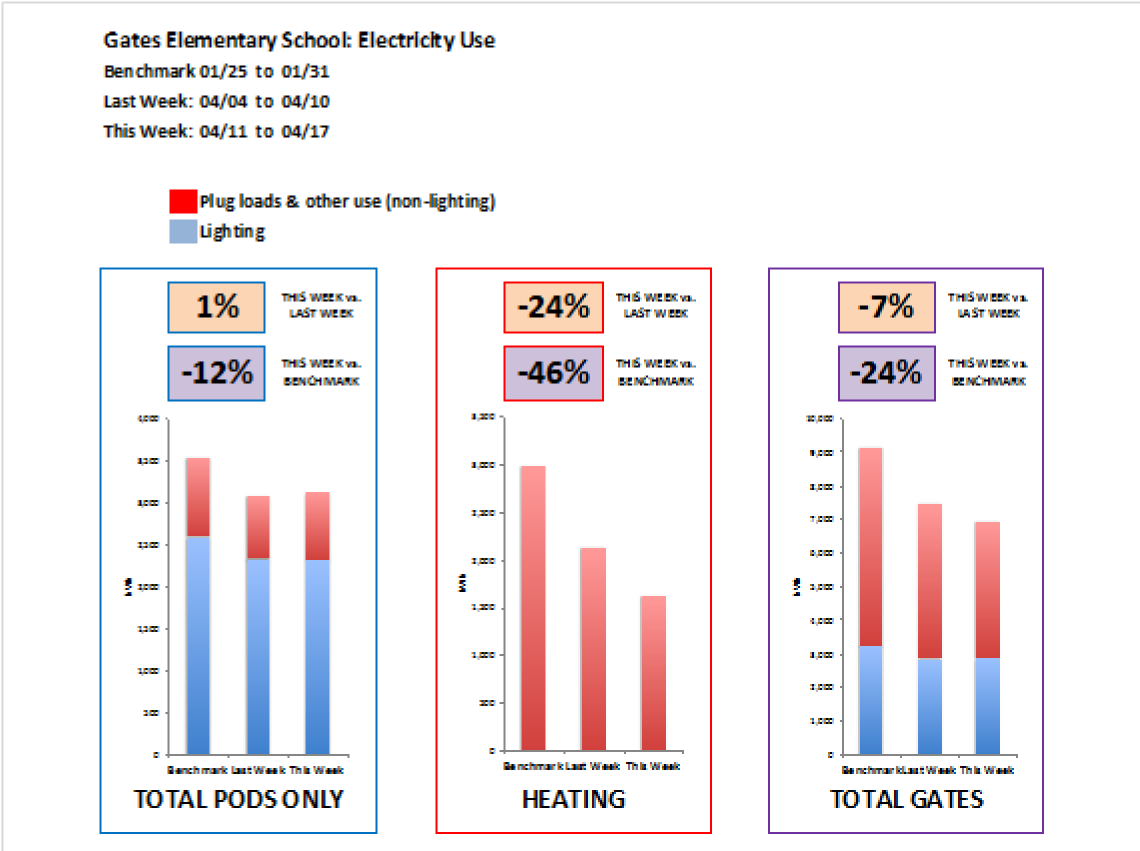
Monitoring data collected by the students in the classrooms and data collected by boiler room circuit-level monitoring allowed the authors to create custom reports for facilities staff that mitigated these concerns by allowing the staff themselves to identify potential HVAC-related energy savings opportunities. The building operators used this documentation as a guide for either adjusting existing equipment or identifying future equipment upgrades.

Data reports

The authors developed program reports to translate the enormous amounts of data we collected into actionable information. Our goal was to help identify and support strategies for engaging students and staff. The reports that we developed included energy competition reports, temperature and light maps, and HVAC equipment charts. Because future school programs would be unlikely to afford the comprehensive monitoring we had put in place on all electrical panels, and because Eversource had stipulated that all of our efforts needed to be scalable and reproducible in order for them to consider the model for incentive reimbursement, we needed to think carefully about how to share electrical panel monitoring data with program participants. We decided that a cost-effective option for future schools would be to install monitoring on just two panels – the main switchboard panel, which would show electricity use detailed at the sub-panel level, and the boiler room electrical panel, which would show electricity use detailed to the circuit level. To mimic this strategy at Gates Elementary School, we limited the reports we shared with students and staff to a presentation of electricity use by sub-panel and electricity use from the boiler room panel.

Energy reports – Using the data that showed electricity use by sub-panel, we were able to provide weekly updated reports that highlight the level of electricity use (both lighting and non-lighting) for each classroom cluster (called "pods" at Gates) in the building. In addition, the reports indicated the change in consumption (by percentage) compared to the previous week as well as compared to a pre-established baseline, which we developed based on a week of energy use that we measured early in the project. Figure 1 is a sample report that was sent out to the Gates community via email by the Green Team advisor and also posted in the main lobby. The electricity data has not been adjusted for weather or daylight hours. Some savings, in particular the heating savings, can be attributed to seasonal temperature changes.

Figure 1. Sample report charts distributed to Gates community

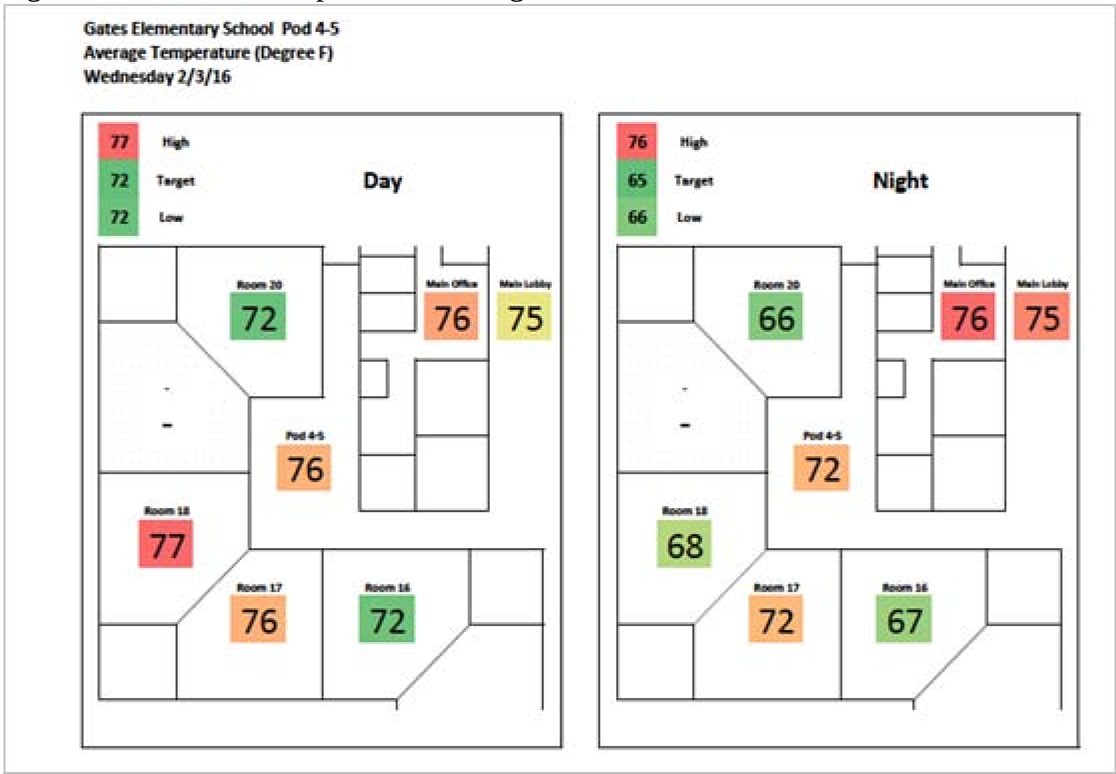


Temperature and Light maps – We found that the classroom monitoring data was most useful when we provided it on individual maps of the pods. Figure 2 includes both day and night temperature readings. Red boxes indicate rooms that have temperatures higher than the target temperature setting, and green boxes indicate rooms that have temperatures at or below the target temperature.

Constant temperatures in the administration office turned out to be a thermostat programming issue that has since been corrected. Constant temperatures in the halls and main lobby turned out to be a heating pump outdoor reset and thermostat issue. The heating pumps were circulating hot water through the building distribution piping 24/7, fans in the wall-mount cabinet heaters were running 24/7, and the thermostats did not have a temperature setback feature. This meant that the corridor heating was running 24/7. Facilities staff has reduced the heating pump outdoor temperature sensor to 40 Degree F at night[1] and is discussing replacing the existing thermostats with programmable setback thermostats.

[1] The heating temperature setting was set higher previously. The heating pumps are set now to remain on when the outdoor temperature is 40 Degree F or below and turn off when the outdoor temperature is above 40 Degree F.

Figure 2. Classroom temperature readings taken in Pod 4-5



Boiler Room reports – We developed two boiler room reports for facilities management staff. The reports focused on major equipment connected to the main boiler room electrical panel. The first report provides the total kWh per day when class is in session. The second report provides the total kWh per day when class is not in session.

Figures 3 and 4 are class-in-session weekly reports for two different weeks. Figure 3 shows electricity use before any changes were made. Figure 4 shows electricity use after changes were made based on the initial report.

Facilities staff made two major changes based on this report. First they turned off an electric space heater located in a small outbuilding. Staff had been using the heater to keep caulking and paint warm and to keep the room warm enough for the old fluorescent lights to turn on more quickly. Second as mentioned above, facilities staff turned down the heating pump outdoor reset temperature control from 55 Degree F to 40 Degree F during unoccupied hours. Previously, as seen in figure 3, heating pumps 1 (40 kWh per day) and 3 (33 kWh per day) remained on through the nights and weekends even if the average outdoor temperature rose as high as 55 Degree F. As seen in figure 4, the heating pumps run significantly less now and consume less electricity.

On a smaller energy savings scale, facilities staff noticed that the air compressor and air dryer use about 30 kWh per week. These two pieces of equipment serve a few remaining pneumatic controls that were not removed as part of an upgrade to DDC controls. The school is going to investigate if it can convert the last remaining pneumatic control equipment to DDC and turn the compressor and air dryer off.

Figure 3. Daily heating circuit electricity use (before)

Gates Elementary School | **Heating Circuit Electricity Use (kWh)** | **Before**

School In Session (9:00 AM - 3:30 PM)

Circuit	Monday 2/22/16	Tuesday 2/23/16	Wednesday 2/24/16	Thursday 2/25/16	Friday 2/26/16	Saturday 2/27/16	Sunday 2/28/16	Total
Outside lights	0	0	0	0	0	0	0	0
Outside lights{1}	0	0	0	0	0	0	0	0
Exhaust fan Cafeteria	2	1	2	2	2	0	2	10
Heat Unit - Cafeteria{1}	6	6	6	6	6	0	6	36
Heat Unit - Cafeteria	7	7	7	7	7	0	7	43
Unit Heater - Boiler Room	0	0	0	0	0	0	0	3
Oil Pump	0	0	0	0	0	0	0	1
Heat pump 1	40	40	40	40	40	40	40	279
Heat Pump 2	0	0	0	0	0	0	0	1
Heat Pump 3	33	33	33	33	33	33	33	232
Boiler 1	2	4	4	0	3	0	0	14
Boiler 2	5	6	6	3	6	4	4	33
Air Compressor	3	3	3	3	3	3	3	21
Powers Air Dryer	1	1	1	1	1	1	1	9
Incinerator	33	33	33	33	33	33	33	232
Total	133	136	135	130	136	115	129	915
Average Temperature	36	31	34	55	33	30	36	36

Figure 4. Daily heating circuit electricity use (after)

Gates Elementary School | **Heating Circuit Electricity Use (kWh)** | **After**

School in Session (9:00 AM - 3:30 PM)

Circuit	Monday 4/11/16	Tuesday 4/12/16	Wednesday 4/13/16	Thursday 4/14/16	Friday 4/15/16	Saturday 4/16/16	Sunday 4/17/16	Total
Outside lights	0	0	0	0	0	0	0	0
Outside lights{1}	0	0	0	0	0	0	0	0
Exhaust fan Cafeteria	2	1	2	1	2	0	0	8
Heat Unit - Cafeteria{1}	6	6	6	6	6	0	1	31
Heat Unit - Cafeteria	7	7	7	7	7	0	1	36
Unit Heater - Boiler Room	0	0	0	0	0	0	0	3
Oil Pump	0	0	0	0	0	0	0	1
Heat pump 1	34	40	27	23	22	21	15	182
Heat Pump 2	0	0	0	0	0	0	0	1
Heat Pump 3	28	33	23	19	18	17	12	151
Boiler 1	1	0	1	0	3	2	1	8
Boiler 2	4	4	3	3	0	0	0	14
Air Compressor	3	3	3	3	3	3	0	17
Powers Air Dryer	1	1	1	1	1	1	1	9
Incinerator	0	0	0	0	0	0	0	0
Total	87	95	73	64	63	45	33	460
Average Temperature	49	51	43	45	47	48	48	48

Results and Recommendations

The program can be judged from both an educational and energy reduction perspective. The program has significant educational benefits as a learning tool for students to expand their awareness of sustainable energy issues, peer communication, and advocacy. However, the focus of this report is on the energy reduction impact of the program. We provide the following discussion of the equipment we used, energy savings that we documented, and additional energy savings that could be achieved.

Monitoring equipment effectiveness

Reviewing data from the baseline electrical panel monitoring, we identified the equivalent of slightly more than 29,000 kWh per year, or about 12% of the total annual electricity use, that the program participants could potentially turn off when school was not in session. Examples included classroom and common area lights that remained on, heating circulation pumps and other heating equipment running constantly 24/7, and a space heater running 24/7 constantly to keep supplies warm in a repurposed outbuilding. Student, faculty, and staff actions and investigations may identify additional savings opportunities.

Reviewing data from the baseline room monitoring equipment, we identified numerous opportunities to reduce out-of-session heating system operation. Several rooms have higher-than-target room temperatures, and a few rooms maintain the same temperature constantly 24/7. Preliminary weather-adjusted thermal energy savings are about 9%.

Student, Faculty, Staff actions

Student and faculty actions – After returning from February break (February 15-19), Green Team students focused their efforts on creating an effective school-wide outreach campaign, asking the Gates community to turn off unneeded lighting and reduce plug load. Green Team members worked as "energy detectives," checking on classrooms to assess whether lights were off in unoccupied spaces. Thank-you notes were delivered when lights were successfully powered down, and "oops" notes were delivered if lights were found left on in unoccupied spaces. The students created posters and switch plate prompts, researched and presented energy savings tips during morning announcements, and created a video documenting the deployment of the energy sensors. A new bulletin board was set up in the main lobby with energy data posted to provide feedback on how much energy was being saved. Green Team student members were empowered to change hallway lighting to reduce it to the target setting if they found fixtures overlit.

Metering of the circuits serving the classroom pods reveals a significant reduction in electricity use (ranging from 6% to 16%) compared to the baseline period before outreach began. Elevated awareness about energy conservation was confirmed as well through a pre- and post-observational survey conducted by the Green Team. Before the start of the outreach campaign, Green Team members tallied 13 out of 24 unoccupied classrooms with equipment powered up (lights and/or projector); the count dropped to 4 out of 24 on their follow-up survey.

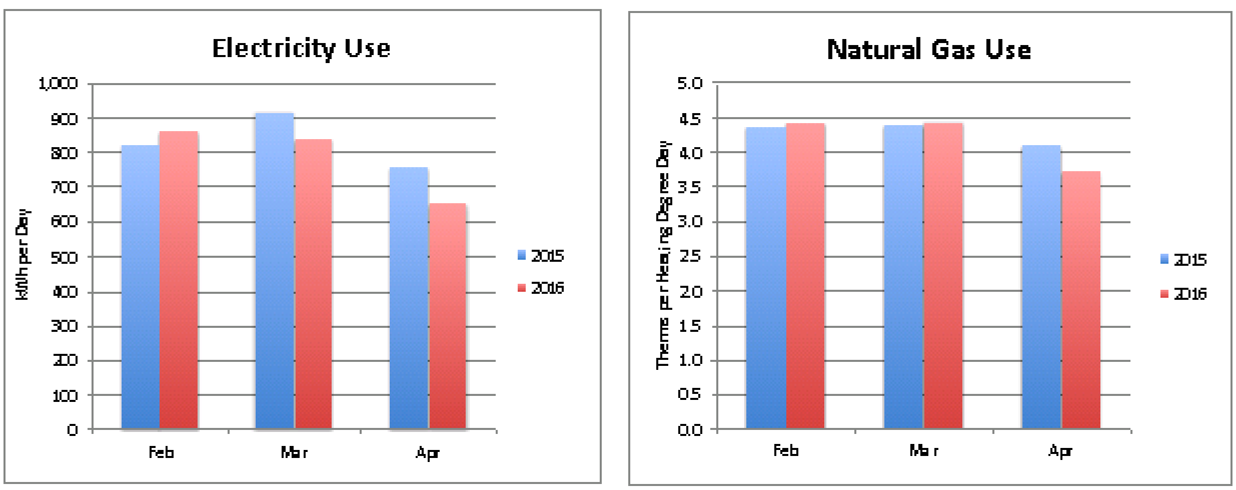
Green Team outreach efforts culminated in an all-school meeting on March 31 where students presented results documenting each pod's energy savings efforts and awards for their school-wide energy savings poster contest. Going forward, the Green Team plans to continue sharing updated reports about energy use with the school community to promote awareness.

Staff actions – The school district's facilities director scheduled a meeting at Gates on March 28 to discuss energy data findings with Gates custodial staff and licensed facilities staff. Room temperature reports and heating circuit electricity use reports were reviewed, and staff developed an action plan to address issues identified. Specific proposed actions included turning off the space heater in the incinerator building and relocating material that might freeze into the school, setting the unoccupied outdoor reset for pump operation down from 55 to 40 Degree F except during peak cold weather, confirming thermostat programming for the air handlers, and installing programmable thermostats (already in stock) to turn off the corridor heaters running 24/7 at night.

Energy savings – Figure 5 includes two graphs that illustrate the impact of the student, teacher, and staff actions on the school's energy use intensity. The first graph includes energy use intensity in terms of kWh per day for electricity. Electricity savings start to show up in March and continued through April. Electricity use per day in April 2016 was 14% below the electricity use per day in April 2015.

The second graph includes energy use intensity in terms of therms per heating degree-day for natural gas. Natural gas savings start to show up in April. Natural gas use per heating degree-day in April 2016 was 9% below the natural gas use per heating degree-day in April 2015.

Figure 5. Electricity and natural gas energy savings



Cost effectiveness – It is premature based on just this pilot project to assume that data-driven behavioral programs are cost effective in K-12 schools. Our pilot project budget included installing monitoring equipment on every single circuit in the school and additional program and analytical technical support. However, the potential to include targeted monitoring data and room and major equipment performance reports is very compelling.

The students, teachers, and staff at Gates appear poised to exceed our estimated savings target of about 24,000 kWh and 1,800 therms per year or about $6,600 per year. Program managers can use these target savings estimates to help determine a range of potential investments they can make in future data-driven behavioral programs in similar schools.

Conclusion

Data-driven behavioral programs in K-12 schools potentially offer a cost-effective bridge for system benefit programs to support energy education and behavior programs in elementary schools. The data help inform program participants about potential energy efficiency actions that they can take, measure the impact of these actions, and spur additional savings actions. In addition the data offer clear documentation for system benefit program managers to confirm that energy savings actions met projected energy savings targets. As an additional benefit, students, faculty, and staff can continue to use the monitoring equipment to monitor savings persistence and identify additional opportunities for energy savings investments.

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