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Authors
Fernandes, S
Granderson, J
Singla, R
et al.

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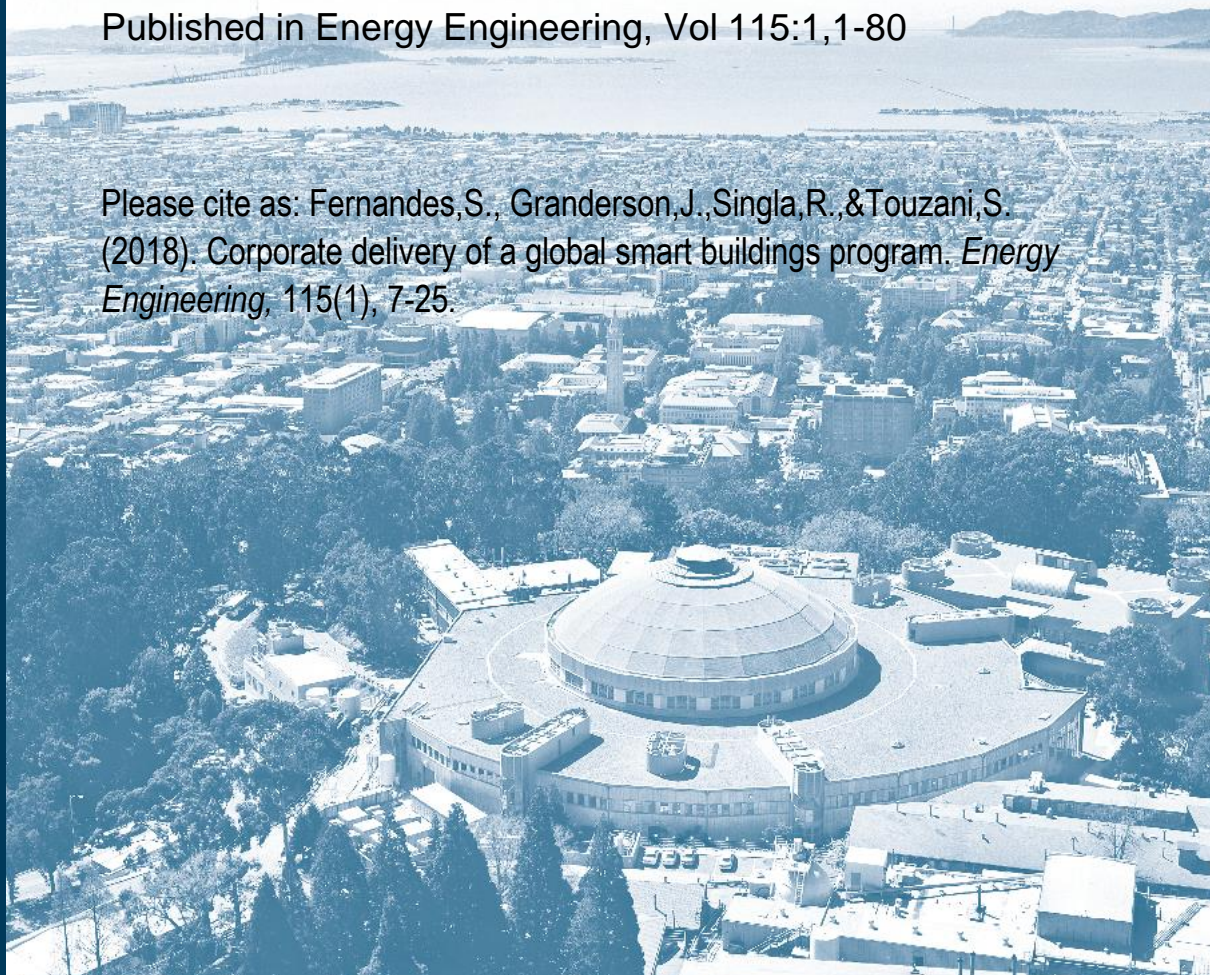
Corporate Delivery of a Global Smart Buildings Program

Samuel Fernandes, Jessica Granderson, Rupam Singla, Samir Touzani

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Samuel Fernandes, Jessica Granderson, Rupam Singla, Samir Touzani
Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720, USA

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[1] Corresponding Author: sgfernandes@lbl.gov; 1 Cyclotron Rd., Berkeley CA, 94720; (510) 486-4048.

Abstract

Buildings account for about 40 percent of the total energy consumption in the U.S. and emit approximately one third of greenhouse gas emissions. But they also offer tremendous potential for achieving significant greenhouse gas reductions with the right savings strategies. With an increasing amount of data from buildings and advanced computational and analytical abilities, buildings can be made "smart" to optimize energy consumption and occupant comfort. Smart buildings are often characterized as having a high degree of data and system integration, connectivity and control, as well as the advanced use of data analytics. These "smarts" can enable up to 10-20% savings in a building, and help ensure that they persist over time.

In 2009, Microsoft Corporation launched the Energy-Smart Buildings (ESB) program with a vision to improve building operations services, security and accessibility in services, and new tenant applications and services that improve productivity and optimize energy use. The ESB program focused on fault diagnostics, advanced analytics and new organizational processes and practices to support their operational integration. In addition to the ESB program, Microsoft undertook capital improvement projects that made effective use of a utility incentive program and lab consolidations over the same duration. The ESB program began with a pilot at Microsoft's Puget Sound campus that identified significant savings of up to 6-10% in the 13 pilot buildings. The success of the pilot led to a global deployment of the program. Between 2009 and 2015, there was a 23.7% reduction in annual electricity consumption (kWh) at the Puget Sound campus with 18.5% of that due to the ESB and lab consolidations.

This paper provides the results of research conducted to assess the best-practice strategies that Microsoft implemented to achieve these savings, including the fault diagnostic routines that are the foundation of the ESB program and organizational change management practices. It also presents the process that was adopted to scale the ESB program globally. We conclude with recommendations for how these successes can be generalized and replicated by other corporate enterprises.

1. Introduction

Smart meters and other sensors and metering devices are increasingly being used in buildings, generating a wealth of data. Analytics can be applied to this data, providing new insights into a building's performance, and opportunities for efficiency improvements. Energy Management and Information System (EMIS) technologies can be used to leverage this increasing availability of data to improve the operational efficiency of buildings, comprising one element in making the building smart. EMIS span a broad family of technologies including energy information systems (EIS), building automation systems, fault detection and diagnostics and monthly energy analysis tools. These tools have enabled whole-building energy savings of up to 10-20% with rapid paybacks, often in fewer than three years (Granderson 2011, 2016).

Using these insights and with the appropriate control strategies, buildings can be made "smart" and energy consumption minimized, while maximizing performance and occupant satisfaction. A "smart building" integrates major building systems on a common network and shares information and functionality between systems to improve energy efficiency, operational effectiveness and occupant satisfaction (Ehrlich 2009). These smart buildings are often characterized as having a high degree of data and system integration, connectivity and control, as well as the advanced use of data analytics.

In spite of their value, there remain barriers to the adoption of smart buildings, including lack of awareness of the benefits, upfront costs required for the investment, data privacy and security concerns and technological barriers such as incompatible platforms (Rogers et. al 2013, Elmualim et. al 2010). The technology sector offers a compelling focus area to understand trends and opportunities for smart commercial buildings - Mills et. al 2015 recently highlighted smart buildings efforts in major information technology corporate enterprises. In this paper, the smart buildings successes of Microsoft are detailed.

Corporations are increasingly working to develop strategies across their organizations and campuses for corporate sustainability. While there are different tools and methods to address corporate sustainability, there is often lack of clarity of how these tools and methods address various aspects of operations and processes, management and strategy, organizational systems, procurement etc.(Lozano 2012). This paper describes how Microsoft developed and implemented a tool to incorporate sustainability in its operations.

Microsoft launched the Energy-Smart Buildings program (ESB) in 2009 with a vision to improve building operations services, security and accessibility in services, and new tenant applications and services that improve productivity and optimize building energy

consumption. ESB was a part of Microsoft's overall sustainability strategy. The pillars of the ESB program were:

1) Fault detection and diagnostics (FDD): timely and targeted interventions in cases of faulty or under-performing equipment.
2) Advanced analytics and energy visualization: tracking and optimization of building energy consumption and performance over time.
3) Organizational change management process: Implementing organizational structures to support the implementation of the FDD and advanced analytics. This included collaborative models to support the global deployment of the program.

The ESB program began with a pilot in 13 buildings at the company's 118-building Puget Sound campus (Kofmehl et. al 2011). During the pilot Microsoft experimented with three different analytics and data-driven energy management approaches to determine a solution that would best satisfy its needs. Running an extensive pilot enabled Microsoft to become familiar with the technological and operational aspects of smart buildings prior to a full rollout.

This paper describes findings from research conducted through interviews, site visits, and energy consumption data analysis, obtained through collaboration with the Microsoft Real Estate and Facilities (RE&F) group. We document the energy and cost savings impact of the ESB program and the process adopted for global deployment. The paper details the fault diagnostics that were leveraged to generate savings and the processes and solutions that were used to cost-effectively integrate data across a diversity of building systems to enable advanced analytics and energy visualization. It also presents the process that was adopted to scale the ESB program globally and concludes with recommendations for how these successes can be generalized and replicated by other corporate enterprises.

2. Methodology

2.1 Drivers and launch of the ESB program

Microsoft has over 250 facilities across the world, with energy use reaching approximately 4 million kilowatt-hours per day (Mills 2015). Microsoft's Puget Sound Campus in Washington State, comprises 54% of global energy consumption of the corporation, and is the largest corporate campus in the United States. The Puget Sound Campus has 118 buildings with annual utility costs of approximately $60 million (Warnik 2013). Microsoft's goal is to cut its own emission footprint, reduce operational expenses and enable the information technology (IT) industry to develop smart building solutions.

With this goal in mind, Microsoft's Real Estate and Facilities (RE&F) organization launched the ESB program, with a view to apply a data-driven software-based approach to achieve energy savings and address the environmental impact of its building

portfolio. The specific objective of the ESB program was to increase employee productivity, reduce operating costs and optimize building energy consumption.

2.2 Details of the ESB pilot project

The 13 buildings included in the pilot project featured a variety of building management systems from different vendors. To provide a consolidated view of granular energy use across all of the buildings and generate actionable data to improve maintenance and efficiency, an analytical layer was deployed above the existing building management systems in these buildings. These analytical tools enabled energy use to be analyzed and managed at a campus level as opposed to a building level. In addition to applying a number of Microsoft's own products, the RE&F team decided to work closely with vendors during the pilot to test different solutions and approaches. A request for proposals (RFP) was issued by the RE&F team and solutions from three different vendors were selected for trial. These different solutions were tested at an Energy Innovation Lab at Microsoft that comprised of a small team and facility within RE&F that were responsible for vetting solutions before implementation in the pilot building sites.

One of the biggest impacts of the pilot project was the ability to identify a technology solution that could identify building faults and inefficiencies in real time by analyzing data streams extracted from the building systems. Prior to this, Microsoft was using a retro-commissioning process that 'touched' each building every five years. Fault detection and diagnostics (FDD) allowed a new way to proactively identify and prioritize operational problems as they arose, rather than on a 5-year cycle. The ESB pilot created a consolidated repository of information that comprised an energy dashboard as well as analytics. The visualization component of the solution allowed real time views of faults, allowing the engineers to digest a large number of problems and target those that were critical and had higher savings potential.

2.3 Puget Sound ESB rollout and global scale up

Following the successful pilot, ESB was expanded to other buildings on the Puget Sound campus between 2013-2016, with the majority being completed within a two-year period. Ultimately, 116 buildings were integrated into the ESB program; buildings that were eliminated from the program were those that were leased spaces in which the Landlord controlled use and access to the building automation systems.

During the Puget Sound rollout, a four-step operational process was established to guide ESB implementation:

> 1. *Assess*: The Microsoft team assessed whether a particular site was a viable candidate for ESB deployment. Key criteria for the assessment was whether the team had access to the building automation system controls.

> 2. *Deploy:* This was a six-step process that involved planning, site readiness, onboarding, tuning, transitioning and then steady-state operation.

3. Operate: In this step, any repairs or corrections needed were implemented.

4. Support: In this final step, users of the ESB technologies were trained to track savings and continue the delivery of ESB at their site.

The Puget Sound campus wide rollout was extraordinarily effective, resulting in significant operational efficiency gains (see Section 3), and deep energy and utility cost savings. Having demonstrated a scalable solution campus-wide, Microsoft began a global deployment of the ESB program. Coordinated from a central operations center at the Puget Sound campus, the global deployment began by targeting the campuses in Northern California, Shanghai, Beijing, Dublin and Hyderabad.

A dedicated team used lessons learned from the pilot and Puget Sound rollout to define four different models that could be used for the global scale up, depending on the operational structure and skill sets at each global campus.

Figure 1 depicts the delivery model that integrated the Puget Sound central operations center with support team members at the remote campus. The "integrator" was a third party operator that assisted with coordination between the central operations center and the support teams, while "Tier 1" represents the teams at various buildings where ESB was going to be deployed. To facilitate coordination and communication between central operations center and the Tier 1 teams, three different collaborative models were used, shown in Figures 2-4.

In the one-on-one collaboration model, the mechanical engineer at the central operations center developed a direct relationship with the engineer at the site. In the small teams model, the mechanical engineer at the central operations center collaborated with the technicians and 'chiefs' at the sites. 'Chiefs' are facility personnel at the buildings. The 'small teams' were comprised of the chiefs and technicians at the sites. In the distributed collaboration model, in addition to the mechanical engineering team at the central operations center a dedicated technician was present. At the site, there were leads assigned to specific tasks generated from the ESB system.
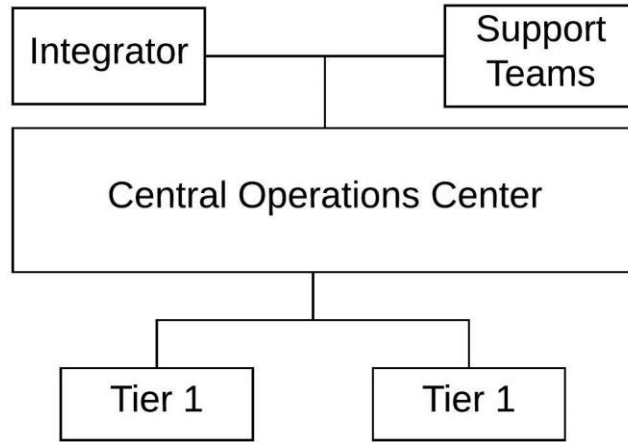
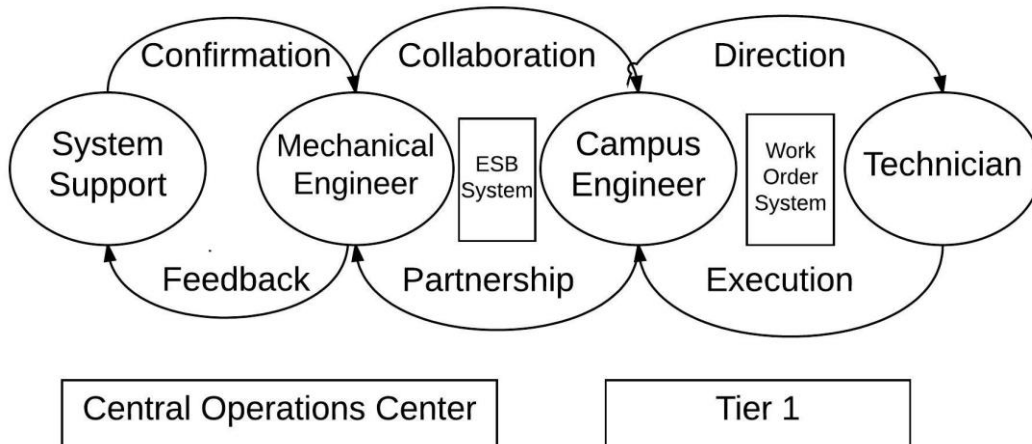**Figure 1. Integrator model for ESB deployment**
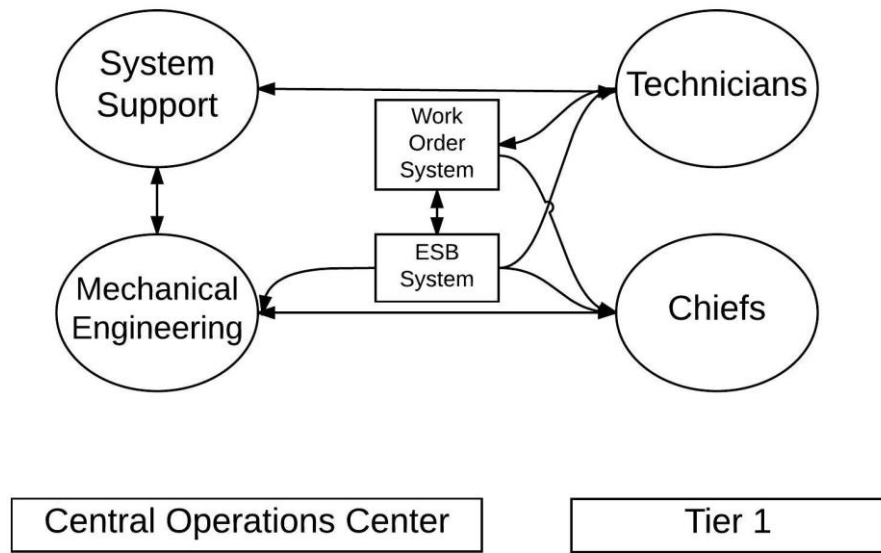

Figure 2. Collaboration model 1: one-on-one

Figure 3. Collaboration model 2: small teams
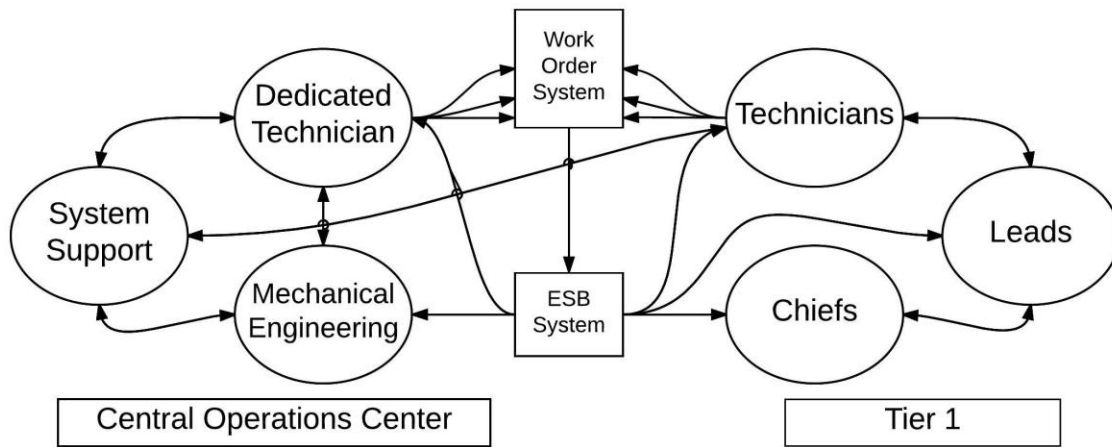
Figure 4. Collaboration model 3: distributed

3. ESB savings analysis

In an effort to estimate the energy savings associated with the ESB program, the authors conducted an on-site visit and interviews with the Microsoft RE&F team, and performed an analysis of campus and building level electricity consumption data. The site visit included meetings with the engineering team, data science team, and energy management and operations team. The data sets used in this analysis are summarized in Table 1.

Table 1: Data provided by Microsoft for the purpose of the analysis

Data set	Information
Square footage of all buildings	Building address and square feet information at the Puget Sound campus.
ESB fault catalog	Contains example of fault algorithm syntax and a list of faults.
Capital projects funded through utility incentive program	List of projects that were funded through the local utility incentive program. Information included financial and claimed project savings information.
Lab consolidation	List of labs that were consolidated, their floor area, date the consolidation occurred, buildings the labs were located in and new space use type.
Electricity consumption[*]	Monthly electricity consumption by meter number.
Meter list	List of buildings and electricity meter numbers.

*Gas data was not within the scope of this analysis.

Total campus energy savings from 2009 through 2015 were attributable to three primary energy management activities - consolidation of computer labs, capital projects, and ESB retro-commissioning and fault resolution activities. The capital projects were undertaken through the local utility incentive program. In order to quantify the effect of the ESB program, total campus savings over the period of analysis was quantified. From this overall savings number, savings due to the capital projects as reported through the utility program, were subtracted. The remaining savings were those due to the operational ESB program and lab consolidation measures. To further isolate the ESB savings, we attempted to quantify savings due to the laboratory consolidation activities; however as described in Section 3.2, conclusive results were not obtainable from the available data.

3.1 Total electricity savings analysis
Figure 5 shows the reduction in monthly kWh over the duration of the program and Figure 6 shows the annual kWh consumption at the Puget Sound Campus.
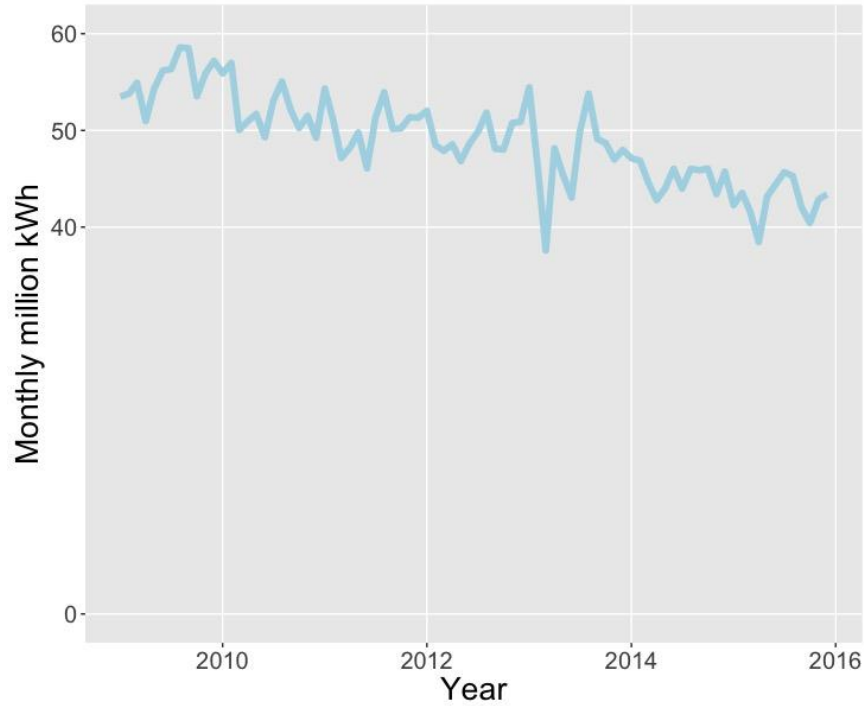
Figure 5: Sum of monthly kWh consumption of 90 buildings at Puget Sound campus
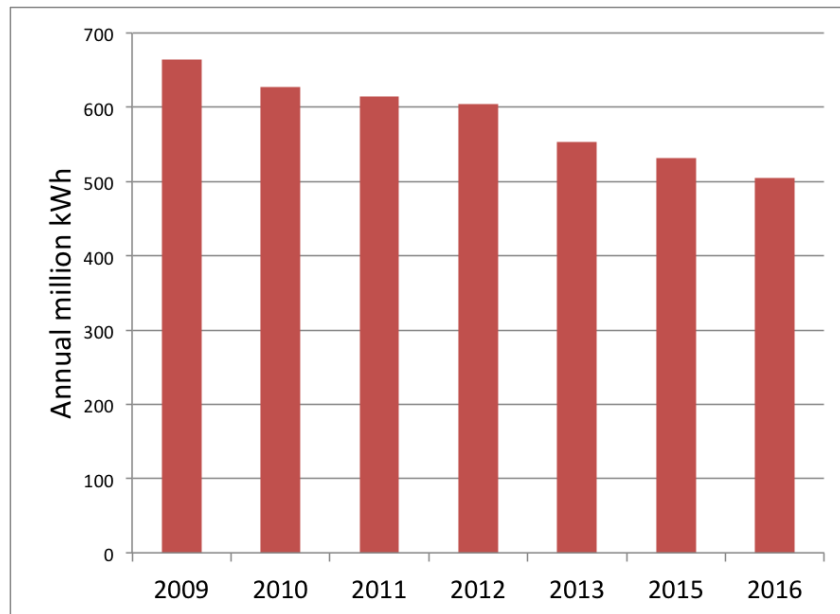
Figure 6: Annual kWh consumption at Puget Sound campus

3.2 Savings from capital projects and laboratory consolidations

Concurrent with the ESB program, energy savings were achieved through capital projects supported through the local utility's incentive programs. These savings were obtained from the engineering calculations conducted for the reporting required for the utility program. Figure 8 shows the kWh savings that were attributed to capital projects at the Puget Sound Campus for each year from 2011 through 2015. Capital projects

undertaken through the local utility program included, for example, a garage lighting retrofit, chiller plant control revisions, installation of variable speed drives, chiller replacements.
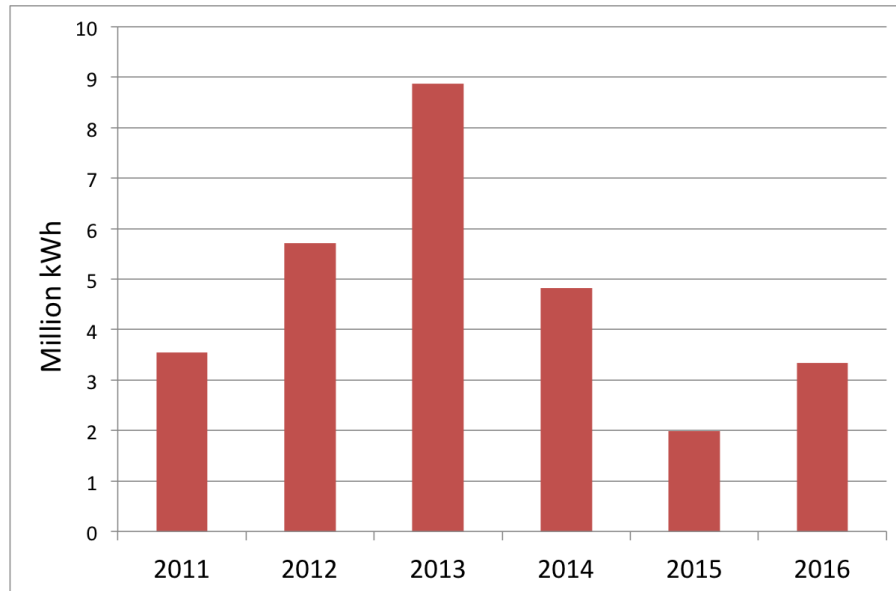

Figure 7: Annual electricity savings due to capital projects at the Puget Sound campus

In addition to capital projects, a number of the energy intensive developer laboratory spaces were consolidated to improve efficiency. In the consolidation, the floor area dedicated to labs was reduced and converted to less energy intensive spaces such as conference rooms and offices. To attempt to quantify the savings attributable to this consolidation we analyzed building energy use before and after the consolidations to determine whether there was a discernable change associated with the reduction in laboratory floor area.

Of the 44 buildings that underwent consolidation (comprising 4,333,612 sf), there was sufficient data for the analysis at only 9 (comprising 2,398,379 sf). In 35 of the buildings, data for electricity use or square footage or implementation date was missing from the data set. For each of the 9 buildings with a complete data set, the percent change in normalized energy use (kWh/sf) one year before the consolidation, and one year after the consolidation was calculated. This percent change was then regressed against the percentage of laboratory floor area in the building that was consolidated. Figure 9 contains a plot with the results of this analysis. As indicated in the plot, a strong relationship between the change in energy use and the consolidated floor area was not observed in the data, i.e., the R^2 value was quite low, at 0.22. Had there been a larger set of data available, i.e., n>9, the analysis may have revealed a more discernable energy impact
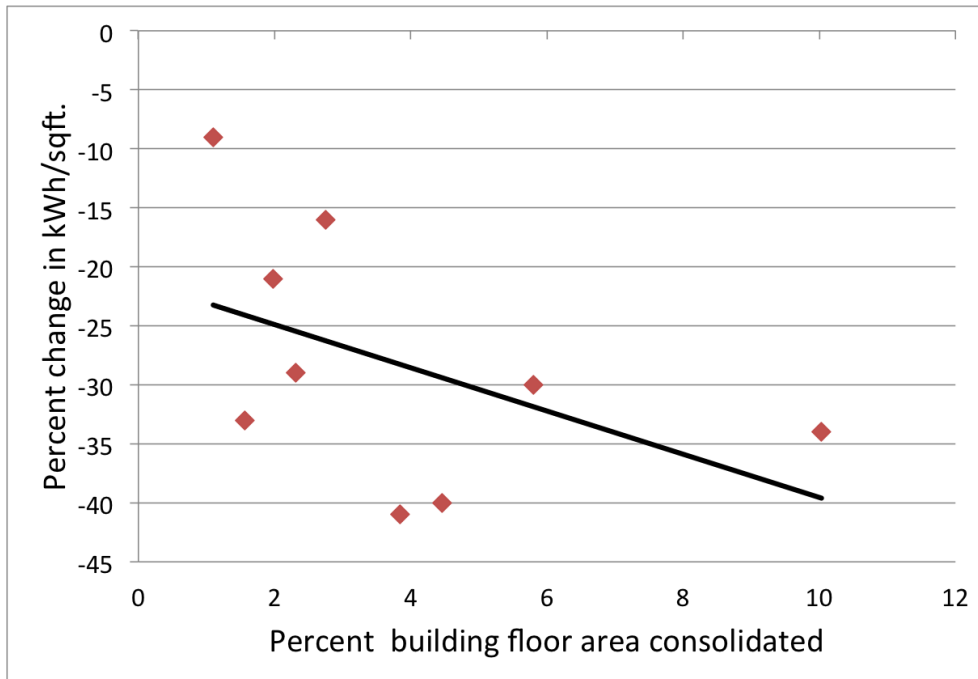
Figure 8: Percent change in kWh/sqft. in buildings with consolidated lab space vs. percent of the building floor area that was consolidated

3.3 Savings from the ESB program and lab consolidation

The savings from the operational efficiency measures in the ESB program and lab consolidation were calculated based on the total campus energy savings, and the savings from the capital improvement projects:

Total campus savings from 2009-2015 = 22.7 million kWh/yr

      Total capital project savings from 2011-2015 = 4.9 million kWh/yr

      Total ESB and lab consolidation savings from 2009-2015 = 17.8 million kWh/yr

      Percent campus savings from 2009-2015 = 23.7%

      Percent campus savings from ESB and lab consolidation = 18.5%

Although it was not possible to isolate the energy savings due to lab consolidation, the majority of the operational savings are likely attributable to the ESB program. This is because: a) the fraction of campus floor area in which lab consolidation occurred was relatively small (0.2%); b) analysis of the subset of 9 buildings (63.1% of the total consolidated floor area) for which consolidation data were available did not reveal a significant whole building energy before and after consolidation.

Finally, we note that these savings are based solely on analysis of the campus electricity data. The ESB program scope included gas-consuming systems and end uses as well, and therefore generated additional savings in excess of those reported in this analysis.

4. Fault detection and diagnostics: Core of the ESB program

Automated fault detection and diagnostics (AFDD) is a method of identifying and isolating problems in the operation of building equipment. Faults can be due to broken or malfunctioning equipment, non-optimal control sequences, and also maintenance issues. There are AFDD tools on the commercial market that range from handheld devices used to take measurements and assess specific pieces of equipment to software tools installed as an overlay to a building automation system (BAS).

For the ESB program, Microsoft designed a rule-based FDD system, wrote a library of rules, and implemented them in a software platform that integrates trend log data from the BAS. Rule-based FDD systems rely upon logical comparisons to relate operational parameters to one another, based on underlying engineering knowledge of how the systems should operate. For example, in a relatively simple case, a rule may specify that when the system is in a given operational mode, the value of one parameter should be greater than another, within a certain tolerance range. Successful implementation of rule-based systems therefore requires attention to the tuning of rules and thresholds to prevent excessive false negative or false positive results.

The ESB fault library spans over 200 core rules and cover almost all airside and waterside HVAC equipment on campus, both unitary and built-up, from chillers and boilers through Air-Handling Units (AHUs) and Variable Air Volume (VAVs), Fan Coil Units (FCUs), water heaters, Air Conditioners (ACs) and heat pumps. Some rules are general and apply to any piece of equipment of a given type; others represent permutations of core faults that were customized to apply to specific items or configurations of equipment. In the tuning process, further additional permutations were identified and the library was expanded further, resulting in an extensive library of over 6000 total rules. For each fault, potential causes and fixes were also defined.

To illustrate the scope of the FDD rule set, Figure 10 presents the number of systems covered, the number of distinct faults, and the number of rule expressions for each of the 37 buildings in the East Campus portion of the Puget Sound campus. The number of rule expressions is higher than the number of distinct faults because one particular fault may have a number of variations, which could be the same fault in different pieces of equipment, or the same fault with different values for tuning parameters, or may even look at entirely different BAS points for the same fault, all of which could result in different rule expressions.
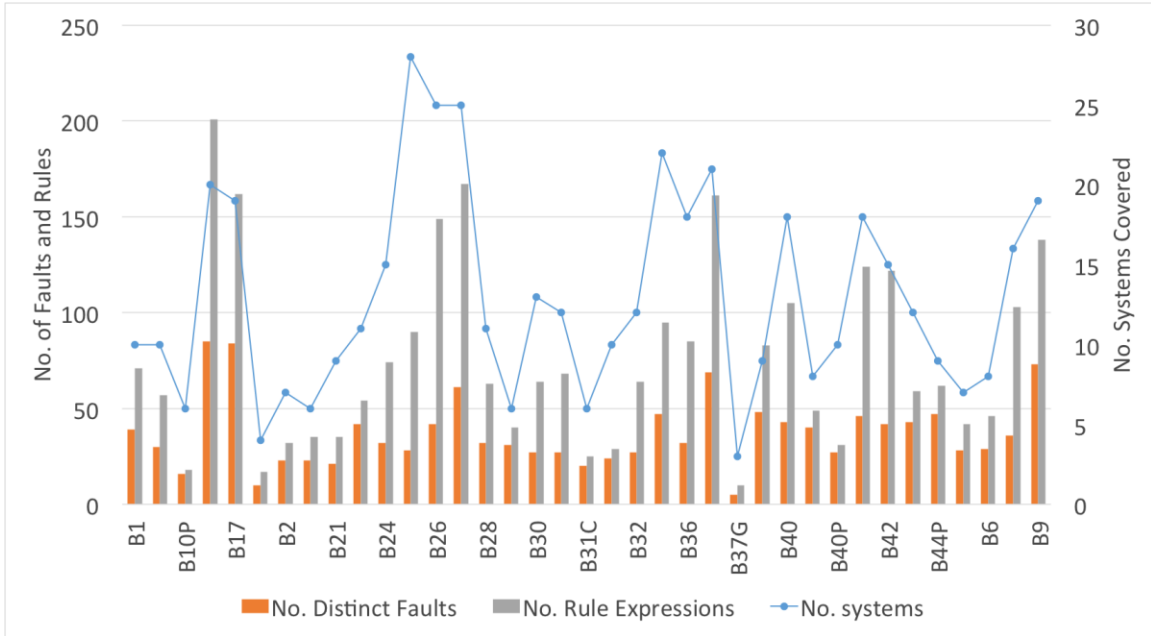
Figure 9: Number of systems covered, distinct faults, and rule expressions for the 37 buildings within the East Campus

For a more concrete example of how the FDD system was implemented, and the extent of this implementation, the treatment of a specific building (Building 41, one of the 118 total buildings served in the campus-wide ESB program) is described in the following. Table 2 lists each system and the number of faults and rules that were employed. Note that different configurations of the same basic equipment are listed separately, as the faults are tailored to the specific pieces of equipment. For example, separate entries are included for the AHU locker room, AHU Office, and AHU Private Branch Exchange (PBX). Table 3 gives examples of 5 different faults in Building 41. For each fault, the system, the fault, and the rule description is given. The 'failed DAT (discharge air temperature) sensor fault' is listed as a VAV box fault, but the same fault could also be listed for AHUs and for FCUs. Additionally, the limits on DAT sensor that trigger the fault (<0F or >120F), and the length of time for the fault before it triggers (>45 minutes) could all be tailored for specific installations.

Table 2. Number of rules in Building 41, by system type

System	No. Distinct Faults	No. Rule Expressions
AHU Locker Room	9	9
AHU Office	21	21
AHU PBX	13	13
Chilled Water Pump (CHP)	1	1
Chilled Water Plant (CHW)	9	9
Exhaust fan (EF)	1	1
Fan Coil Unit (FCU)	11	16
Garage Exhaust Fan (GEF)	1	1
Garage Supply Fan (GSF)	1	1
LAB FCU 2054	6	6
LAB FCU 2419	6	6
LAB Single VAV (SVAV)	4	4
LAB VAV	4	4
SF	2	2
SVAV with FCU	6	6
SVAV With Heating	8	8
SVAV Without Heating	6	6
VSVAV	10	10
Total	**46**	**124**

Table 3. Examples of faults and rule descriptions from Building 41

System	Fault	Rule description
AHU	OA Damper Stuck Closed Fault	If the supply fan status is on, and if the outside air damper is more than 95% open, and if the mixed air temperature is more than 6F greater than the outside air temperature, all for longer than 60 minutes, then activate the fault.
AHU	Unnecessary Mechanical Cooling Fault	If the chilled water coil valve position is > 5%, and if the outside air temperature is less than the discharge air temperature minus 3F, both for longer than 30 minutes, then activate the fault.
CHW Plant	CHW High DP Setpoint Fault	If the chilled water loop differential pressure setpoint is greater than 10" for longer than 30 minutes, then activate the fault.
FCU	CCV Leaking Fault	If the fan is enabled, and if the coil control valve position is less than 5% open, and if the room air temperature is higher than the discharge air temperature plus 3F, all for longer than 30 minutes, then activate the fault.
VAV	Failed DAT Sensor Fault	If the discharge air temperature is >120F or <0F for longer than 45 minutes, then activate the fault.

5. Conclusion

In this paper we have discussed the deployment of the energy smart buildings program at Microsoft, from its inception and launch of the pilot program to the deployment across multiple buildings and campuses. Analysis of the annual electricity consumption of the buildings at the Puget Sound Campus shows a 23.7% reduction in annual electricity use over the duration of the program. The reduction in campus energy use over the time period of the ESB program was due to a combination of factors including lab consolidations, capital projects and the ESB. The total ESB and lab consolidation savings were 17.8 million kWh/yr and accounted for 18.5% of those savings. Savings due to the lab consolidations were relatively small compared to those due to the ESB program.

To assist in testing new technology concepts for the ESB program, Microsoft established an Energy Innovation Lab at their Redmond Campus. This lab is a small facility where early stage ideas for energy efficiency in commercial buildings are rapidly tested for feasibility. The Energy Innovation Lab is managed by core staff from the RE&F team and were instrumental in testing fault rules, hardware integration, and related solutions for ESB. The operational process to Assess, Deploy, Operate and Support that was developed by Microsoft to deploy the program could be used by other organizations looking to develop and deploy a similar program. In addition to this operational process, Microsoft developed a change management model that leveraged the use of an 'integrator' and a central operations team that worked with teams at each of the buildings where deployment was planned. The integrators were critical in ensuring that the program was centrally supported and gradually introduced to participating buildings. The individual building managers relied upon this central support for more

information about the program and savings information was tracked and reported centrally. By launching and implementing the ESB program, Microsoft successfully implemented an important component of their corporate sustainability strategy that addressed both the organizational change management and technology implementation.

The remarkable efficiency improvements that were achieved in Microsoft's ESB program are rooted in a rule-based FDD system. This system was designed, implemented and tuned by Microsoft, and integrated with a commercial software tool. The ESB fault library spans over 200 core rules and covers nearly all airside and waterside HVAC equipment on campus, both unitary and built-up, from chillers and boilers through AHUs and VAVs, FCUs, water heaters, ACs and heat pumps. The ESB program represented the transition from periodic retro commissioning on a 5-year cycle, to continuous identification and resolution of efficiency and performance issues; the savings that resulted are an impressive indicator of the effectiveness of this approach when implemented according to best practice. The robust change management structure that engaged key stakeholders across the organization's campuses were critical to the global deployment process.

To conclude, Microsoft has demonstrated an industry-leading approach to dramatically improving the efficiency and performance of their buildings over a 7-year time period. Critical components of their success that can be replicated by others endeavoring to launch similar efforts include:
- Using pilots as a lower-risk opportunity to vet solutions before rollout and scale up
- Iterating to refine fault detection procedures, and grow a library over time
- Iterating with operational staff to refine graphical user interfaces for maximum effectiveness
- Implementing a prioritization scheme and standard operating procedure to manage volume and ensure resolution
- Investing human resources to sustain a dedicated, empowered implementation team
- Ensuring that in-house and contracted staff have the skills necessary to integrate data across diverse systems, architect a viable networking communications and data storage system, and conduct end-to-end system troubleshooting
- Coupling technology innovation with organizational change management processes

The lessons from this successful program can be replicated by other large corporations that aim to develop energy savings programs.

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