Coordinating Fault Detection, Alarm Management, and Energy Efficiency in a Large Corporate Campus

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ABSTRACT

Microsoft sought to reduce energy use on its Puget Sound campus by enhancing analysis of energy consumption and building system optimization. The pilot project focused on 13 diverse buildings, representing 2.6 million square feet and equipped with various building management systems. An analytical layer above the existing building management systems was deployed to provide a consolidated view of granular energy use across all of the buildings and generate actionable data to improve maintenance and efficiency. This higher-level software focuses on: 1) fault detection and diagnosis; 2) alarm management; and 3) energy management analytics. Applying these tools to the entire Microsoft campus allows energy use to be analyzed and managed at the campus level as opposed to the individual building level.

The ability to analyze data streams to identify building faults and inefficiencies in near real-time proved to be one of the most important benefits of the technology. Management systems in existing buildings generate hundreds of alarms per day, ranging from critical problems to informational messages. The software quantifies energy losses from each identified fault in terms of dollars per year and potential saved energy (kWh), automatically receives the alarm priority from each system and aggregates the alarms for reporting. This integrated energy management system allows Microsoft to improve building system performance and minimize building base load and consumption. Early results show that complete implementation of the system has the potential to reduce energy consumption by 6-10% on the Puget Sound campus at costs that meet Microsoft's internal standards for ROI.

Introduction

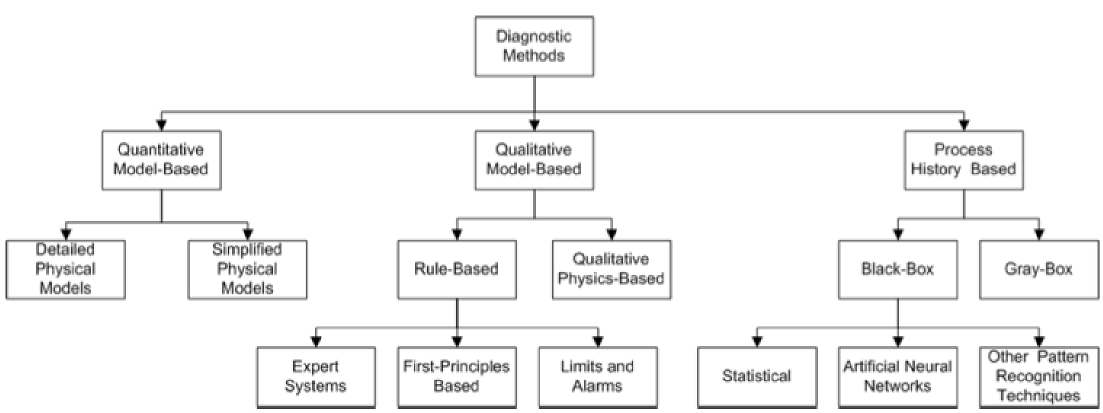
A diverse array of commercial buildings makes up a large share of the building sector in the U.S., consuming almost 20% of primary energy and costing about $100 billion in energy costs every year (Accenture 2011). Within these commercial buildings, it is estimated that poorly maintained, degraded, and improperly controlled equipment wastes an estimated 15% to 30% of the energy used (Katipamula and Brambley 2005a). Recognizing an opportunity for significant cost savings, Microsoft sought to reduce energy consumption on its 118-building Puget Sound campus in Redmond, WA through greatly enhanced buildings system optimization and analysis of energy consumption. Dubbed a "Smart Building" solution, the initial phase of the program included 13 buildings representing 2.6 million square feet of floor space. A business intelligence layer above the existing building management systems was installed in these buildings to provide a consolidated view of granular energy and performance data. Microsoft's approach consists of three integrated strategies: 1) fault detection and diagnosis; 2) alarm management; and 3) energy management analytics. Identifying building faults and inefficiencies in near real-time using data streams from buildings systems allows for improved efficiency, reduced maintenance costs and higher productivity of building managers. Based on the success of the pilot phase, Microsoft is in the process of expanding its Smart Building program to the entire Puget Sound campus.

FDD Methods and Applications

A core part of the Smart Building strategy is advanced fault detection and diagnostics (FDD). FDD has been (and continues to be) an active part of engineering systems in the aerospace, process controls, automotive, manufacturing, nuclear, and national defense fields for many years, but applications for HVAC and other building systems have lagged behind. The literature has traditionally focused on FDD methods, rather than implementation, decision processes and tools. However, Kircher et al. implemented an energy information management system in an office building at Lawrence Berkeley National Lab (Kircher et al. 2010). The information monitoring and diagnosis system consisted of high-quality sensors, data acquisition software and hardware, and the data visualization software included a web-based remote access system that, together, identified control problems and equipment faults (Piette, Kinney, and Haves 2001). This paper aims to present Microsoft's general experience implementing FDD in a pilot project and not to provide a detailed description of the algorithms used.

In general, the process of fault detection and diagnosis consists of two steps. In the first step, disparate building system data collections are automated and integrated by connecting to devices, control modules, or servers (converting protocols if needed). Once collected, the data are transported to a storage repository, at which point the centralized data source can be searched to identify abnormal conditions. In the second step, algorithms are created to diagnose the underlying causes of any abnormal conditions that are found. When faults are identified, it is useful to prioritize them in terms of severity and determine if and how they should be corrected. A review of the survey literature reveals that most past research focuses on methods for FDD. These methods can be either qualitative or quantitative and use varying degrees of a priori knowledge of the underlying physics of a particular process. In the extreme cases, FDD methods are either entirely based on fundamental physical relationships or completely driven by empirical data. Katipamula and Brambley (2005a) provide a useful classification of different FDD methods that can be seen in Figure 1.

Figure 1: Classification of FDD methods



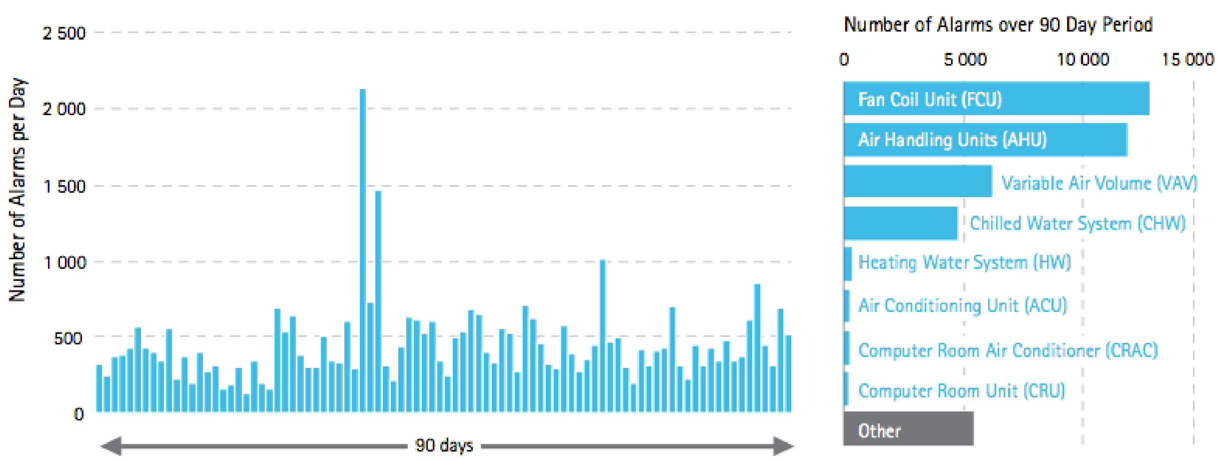
Source: Katipamula and Brambley (2005a)

Much of the literature on FDD in buildings focuses on developing the methods identified above, however there are also studies that address implementation. Specific applications of detecting faults in buildings dates back to at least 1985 (Usoro, Schick, and Negahdaripour 1985) and covers a wide variety of building systems, including refrigerators, air conditioners, heat pumps, chillers and air-handling units (Pakanen and Sundquist 2003; Katipamula and Brambley 2005b). Research in this area has focused on faults associated with single devices and have been conducted in a laboratory or a single test building. In contrast, Microsoft has expanded the FDD approach to tens of buildings and thousands of devices.

Alarm management

On a typical day, Microsoft's current building management systems generate hundreds of alarms, which flood control and building technicians' email inboxes with automated notifications. The importance of these alarms ranges from major issues, such as a power outage, to insignificant messages, such as a notification that a self-test has started. Figure 2 shows sample statistics of Microsoft's building alarms over a 90-day period. A key challenge is to recognize the importance of a given alarm, as well as correlations between messages from related events. Interpreting these requires deep knowledge of the building infrastructure and occupancy. Errors can lead to issues being missed and inadequate prioritization of interventions.

Figure 2 – Alarm Volume at Microsoft



Source: Accenture (2011)

Existing literature on advanced methods for alarm management is thin and spread across several disciplines. The issue has gained some attention in telecommunications networks because operators of those networks are also subject to large volumes of alarms, which can result in important messages being misinterpreted or overlooked completely. In this context, alarm correlation refers to a generic process that automates a variety of different network management tasks. These tasks include compressing multiple occurrences of an alarm into a single alarm, substituting a specified number of a particular alarm with a new alarm, inhibiting low-priority alarms in the presence of higher-priority alarms, and substituting a set of alarms following a pattern with a new alarm (Jakobson and Weissman 1993). Other areas where alarm management is an important issue include industries/processes with large consequences for failure, such as nuclear power plants, commercial aviation, and space systems (Woods 1995; Mumaw et al. 2000).

Energy Management

In addition to advanced FDD and alarm management, Microsoft has a broader goal of managing its energy consumption more holistically. To this end, the Smart Building solution incorporates energy analytics and associated dashboards that will be used by building managers, executives, and Microsoft employees to improve energy efficiency. Data types commonly processed by energy analytics include energy consumption data; building characteristics; building system data, such as heating, ventilation, and air-conditioning (HVAC) and lighting data; weather data; energy price signals; and energy demand-response event information (Motegi et al. 2003). Advanced analytics have been commercially available for over a decade and generally are defined as products that combine software, data acquisition hardware, and communication systems to collect, analyze and display building energy information (Granderson 2009). Common features of products that are currently on the market include sub-metering, demand response notification, load profiles, benchmarking, rate analysis, forecasting, diagnostics and automated control (Motegi et al. 2003).

Methodology

Rollout of the Smart Building solution at Microsoft's Puget Sound campus is ongoing, with a goal of bringing more than 100 buildings online by April 2013. The timeline for the project is shown in Table 1. To manage the implementation of the Smart Building solution, a project team was created to address high-level strategic decisions and a system team was tasked with solving the technical challenges associated with the solution.

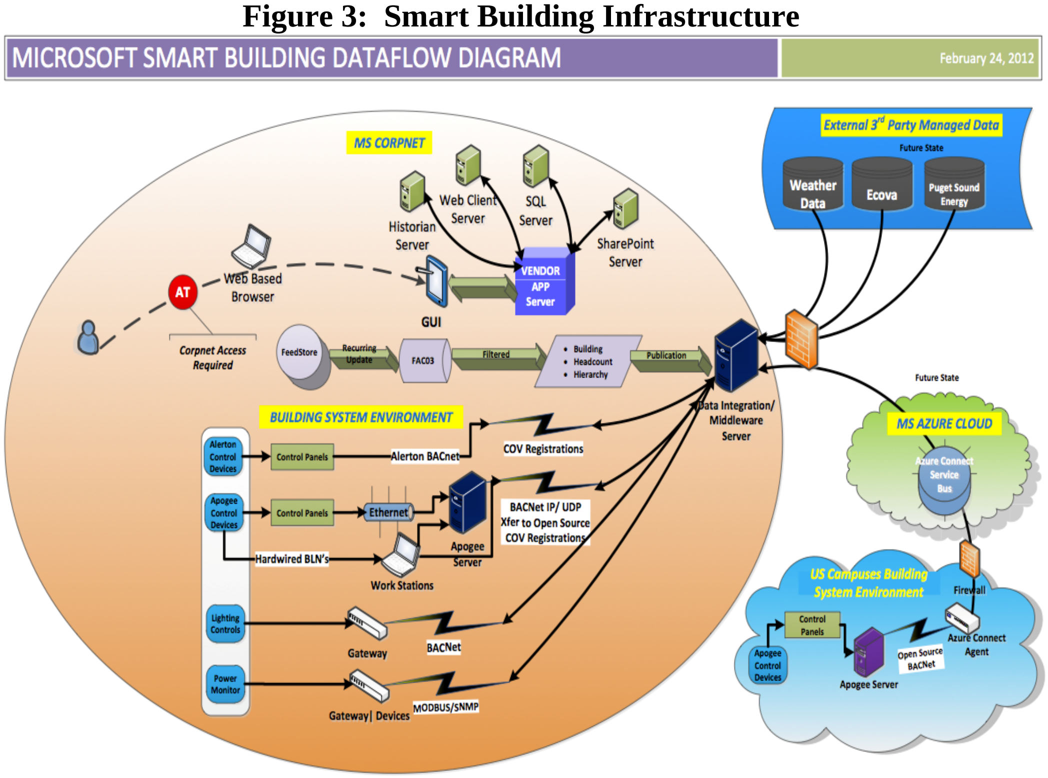
Table 1: Timeline of Smart Building Activities

Date Range	Activity	Description
June – September 2009	Visioning	Worked with multiple stakeholders to document vision, goals, and preliminary scope.
October 2009 – March 31, 2010	Consultant Engagement for Building and Technology Assessment	• Key Components of the Engagement o Assess sampling of buildings on the Puget Sound Campus (eight buildings) o Building system readiness to integrate ▪ Meters installed at appropriate levels to provide actionable data o Technology Recommendation ▪ Proposed system architecture ▪ Gaps/Issues/Risks ▪ Recommendation on Buy vs. Build a technology solution o Develop an assessment methodology to identify potential buildings that are candidates to integrate with the Smart Building solution o Document business requirements
April – October 2010	Request for Proposal (RFP) Process for Pilot Project	• Issued RFP for Pilot Project • Selected Three (3) Vendors • Contract Negotiations with each Vendor, 1 year terms • Microsoft IT procured servers

Date Range	Activity	Description
October 2010 – September 2011	Pilot Project	• Implement each vendor solution divided into two phases • Evaluate and Score each Solution • Solution Selected • Planning Sessions • Multiple support teams engaged
October 2011 – March 2012	System Upgrades	• Implement upgrades and change requests align to Microsoft requirements
March 2012 – April 2013	Adding Buildings (On-Boarding)	• Begin the process of adding buildings to the Smart Buildings solution • Goal of 100+ buildings for Puget Sound

Applying an energy management system incorporating FDD and alarm management on the Puget Sound campus presents significant challenges in terms of both scale and heterogeneity. Whereas previous research projects have focused on individual pieces of equipment, simulations or single-building demonstrations, Microsoft is implementing its solution on a large, diverse corporate campus consisting of 118 individual buildings with nearly 15 million square feet of office space. Within those buildings are 30,000 pieces of mechanical equipment that contribute to the base building load of 200 million kWh/year of electricity and generate 500 million data points from sensors each day. Further compounding the problem is the fact that although each building is managed by its own building management system (BMS), there are 7 different BMSs used to manage the equipment. These disparate systems combined with the sheer volume of information that needs to be organized make even seemingly simple tasks such as aggregating data across buildings complex and nontrivial.

Figure 3: Smart Building Infrastructure



Source: Microsoft

The typical flow of data on the Puget Sound campus is: control devices generate data values that communicate with a building system workstation (building network trunks), gateway device, control modular or panel, or server (see Figure 3). If necessary, the workstations, gateways, or servers convert closed-source protocol to open-source protocol. The Smart Building solution only collects data that has changed since the previous call. For HVAC systems, data is collected at 15-minute intervals. Power monitoring data is collected every 2 minutes.

The initial algorithms for fault detection were created by a third-party vendor, who provided a solution that outperformed solutions from other vendors during the pilot project that ran from October 2010 – September 2011. Microsoft has since enhanced the third-party solution by contributing to the configuration of the FDD algorithms and adding additional fault rules. The current iteration of the tool is designed to identify and display over 80 faults that occur in several different pieces of equipment, including the central plant, variable air volume systems (VAVs), air handler units (AHU), fan coil units (FCU) and makeup air units (MAU). A list of these faults is presented in Table 2 in the appendix.

Microsoft periodically retro-commissions their buildings, which allowed their team to develop manual processes to identify and quantify optimization opportunities. The development of customized fault detection algorithms for Microsoft was largely an automation of those manual processes, which range from simple setpoints and schedule checks to trend analysis for pattern recognition. The algorithms fundamentally seek to answer the question of "Is this piece of equipment behaving as it should in the current situation?" If the answer is "no", then subsequent checks can be triggered to further process the flagging of faults into a prioritized list of actionable data. This type of detailed fault analysis to generate actionable data requires algorithms tuned to specific systems, equipment, and configurations making configurability of a Smart Building solution a key requirement for successful implementation.

Current Results and Expected Future Benefits

Sample output from the FDD algorithms is presented in Figure 4. The primary benefit of the Smart Building solution is its positive impact on the productivity of building managers and engineers. Microsoft will retro-commission roughly 20% of campus buildings each year. Even at this rate of inspection, only large pieces of equipment are checked because it is too costly and labor intensive to hunt for problems with smaller equipment. By using FDD to conduct maintenance in real-time and prioritize faults based on estimated savings, building managers are able to identify more problems, strategically target the critical ones and make informed decisions about how to allocate their time and resources. During the pilot project, one systems control operator described an example of this benefit with regards to VAVs – "At Bravern 1 [a 13-floor office building that was part of the pilot] there are about 400 VAVs. Of those, approximately 156 currently have primary air damper faults that look to be legitimate. This is a newer building, so there is a good possibility that they may have been incorrectly adjusted during installation or we have widespread mechanical failures. These faults do not generate any alarms, and any overcooling would be compensated for by the heaters in units that have heat, so it is likely that these would have gone unnoticed for a long time (Whitson 2012)." With approximately 35,000 VAVs, 800 air handlers, and thousands of other types of equipment across the campus, the potential benefits of more timely and comprehensive maintenance are likely to be significant.

The Smart Building solution could generate future cost and energy savings for Microsoft in other ways. In one pilot building, technicians identified high minimum primary (cold) setpoints, which caused a significant number of VAV boxes to inefficiently operate in heating and cooling modes simultaneously. Since the customer space temperature is acceptable to occupants, this VAV issue had gone unnoticed by building operators. Another potential source of savings arises from the difficulty in detecting buildings operating outside of normal occupied hours. The Smart Building solution allows daily reviews (rather than a periodic review) because building operators can view all buildings and systems generating faults. A final example of the potential benefits involves setpoints. Heating and cooling setpoints outside of design guidelines also become easy and quick to view in the Smart Building solution without running extensive reports. Tests conducted on the pilot buildings validated this capability.

Due to the increase in maintenance productivity that is expected from the Smart Building solution, Microsoft is planning on moving from a retro-commissioning maintenance model to a continuous-commissioning model. In the continuous-commissioning model, Microsoft expects that interventions equivalent to a full 5-year retro-commissioning cycle for the entire campus would be able to be accomplished in just one year. Annual energy cost savings from continuous commissioning enabled by automated fault detection alone may thus exceed US$1 million on the Puget Sound campus (Accenture 2011). This fundamental shift in maintenance strategy represents the primary mechanism for cost savings from the Smart Buildings solution.

Figure 4: Sample FDD Output

Building	Bldg. Cluster	Equipment	Fault and Diagnosis	Priority	Estimated Savings*
Bldg 58	Cluster E	AHU - 012	Leaking chilled water value	High	$11,291
Bldg 58	Cluster E	AHU - 003	Damper position fault	High	$4,782
Bldg 53	Cluster E	VAV - 022	Over cooling	High	$2,235
Bldg 58	Cluster E	CHI - 002	Changes to set points	Medium	$895
...	...	...	...	...	...
Bldg 54	Cluster E	VAV - 006	Air temperature sensor failure	Low	-

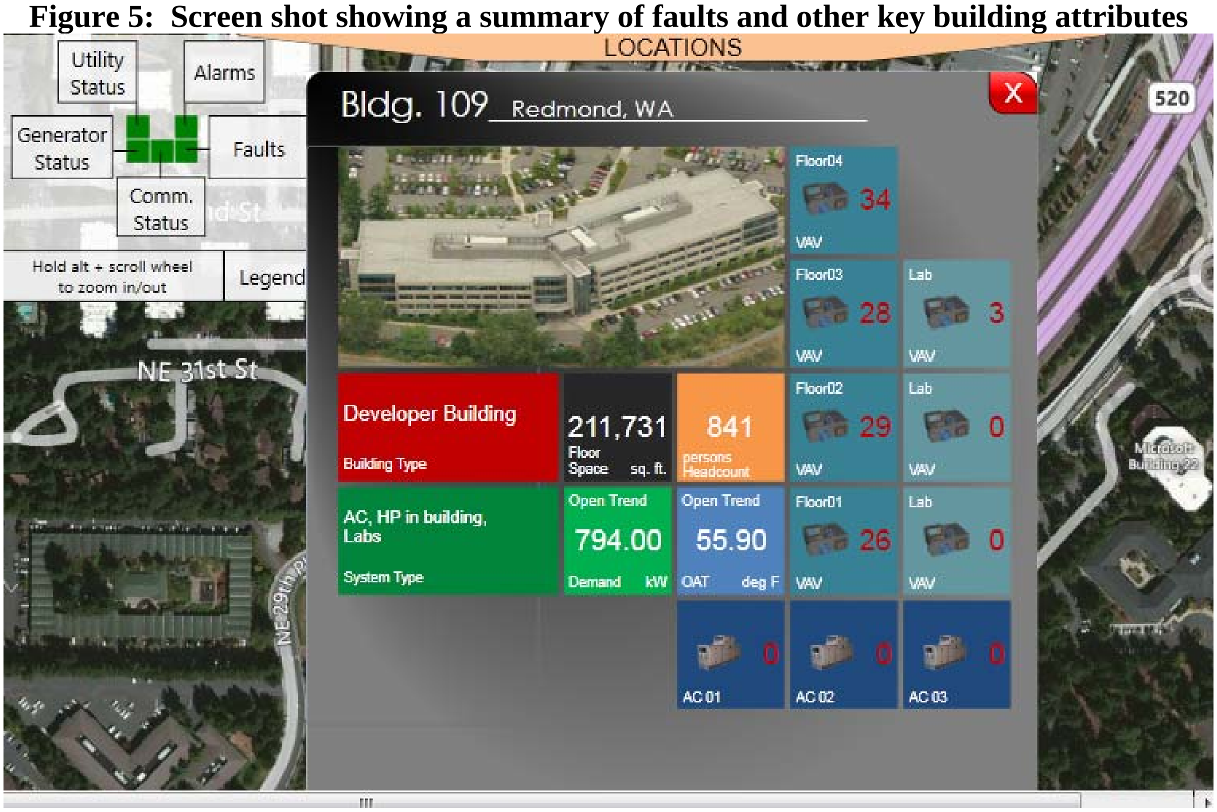
* Estimated savings potential, expressed an annual cost of wasted energy if not fixed.
Source: Microsoft

Initial calculations by Microsoft suggest that the Smart Building solution will meet the internal ROI standard for the company and reduce energy consumption by 6-10% when implemented across the entire Puget Sound campus. This savings estimate is based on the compression of the retro-commissioning cycle and past experience of energy savings when buildings are retro-commissioned. Since retro-commissioning focuses on larger equipment (chiller plants, and air handler units), centralized access and visibility to smaller equipment (VAVs, Fan coils, etc.) creates saving opportunities such as the VAV example presented above. Microsoft has created a three-step process taking 15-day start-to-finish to add building(s) to the system.

Dashboards

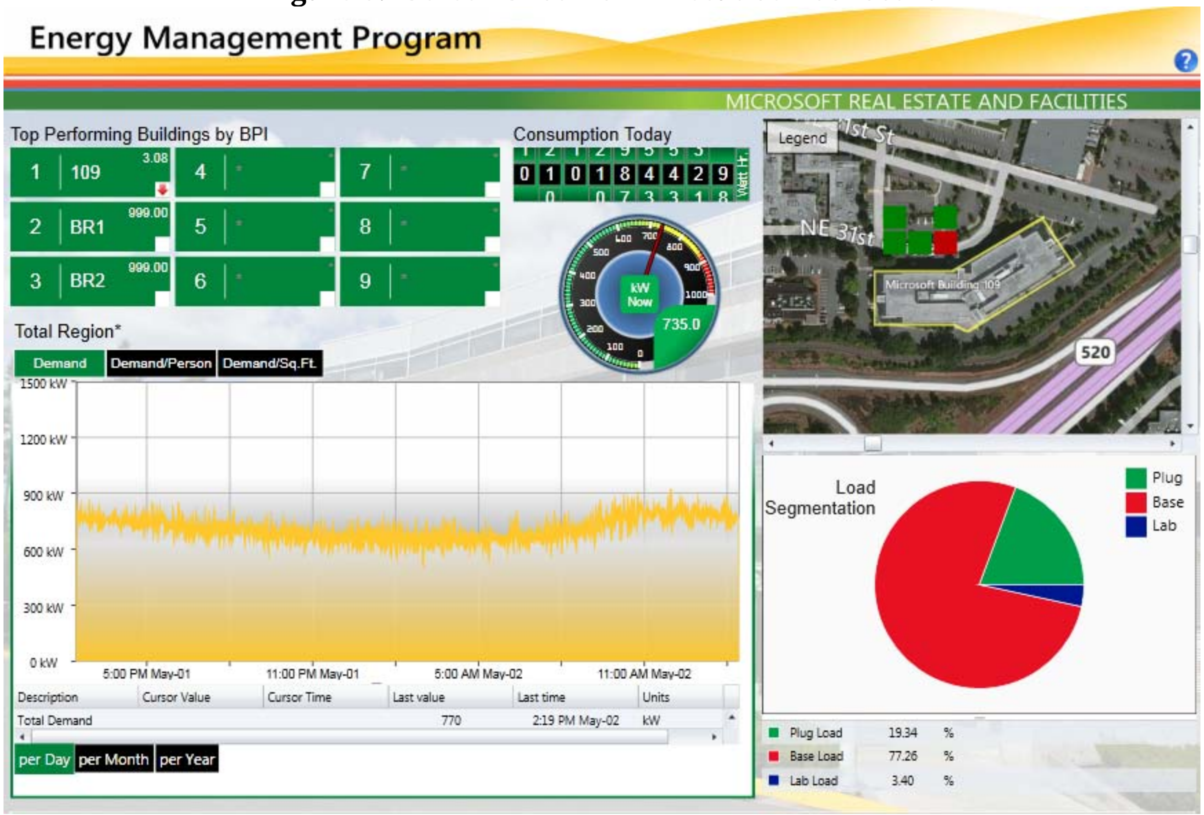
Another important feature of Microsoft's Smart Building solution is the energy management analytics and associated dashboards that organize and present information on building energy performance to users of the system. These dashboards serve as the interface between energy consumption data and Microsoft building managers, engineers and other technicians on campus. They are designed to display key information on building attributes and performance, including the current faults identified by the FDD algorithms (see Figure 5). The California Independent Service Operator (ISO) and many university campuses, including UC-Davis, UC-Berkeley and UC-San Diego (Agarwal, Weng, and Gupta 2009), currently use similar energy dashboards to share energy consumption information. Microsoft aims to raise employee awareness, influence behavior and be a data source to support corporate energy saving initiatives by displaying building consumption data. One current idea is to introduce a competitive element to the dashboard that shows the ten best- and worst-performing buildings at any given time By pairing this information with incentives, Microsoft hopes that control technicians will compete to operate their buildings most efficiently.

Figure 5: Screen shot showing a summary of faults and other key building attributes



Source: Microsoft

Figure 6: Screen Shot from Executive Dashboard



Source: Microsoft

Conclusion

Microsoft is improving the energy performance of the buildings on its Puget Sound campus by utilizing a combined approach of fault detection diagnostics, alarm management and energy management analytics. A pilot project involving 13 diverse buildings significantly improved the productivity of control technicians and allowed them to identify and prioritize building faults and inefficiencies in near real-time. Managing energy consumption on a large corporate campus has been challenging due to the amount of data that must be processed and problems associated with exchanging information between building management systems that are incompatible both within and between existing buildings. Microsoft estimates that the solution will reduce energy consumption on the Puget Sound campus by 6-10% when fully implemented, with the primary savings due to a switch from a 5-year retro-commissioning maintenance schedule to a continuous-commissioning approach.

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Appendix

Table 2: List of faults addressed by Microsoft Smart Buildings solution

	Rule #	Fault	Central Plant	Rule #	Fault	AHU	Rule #	Fault	Miscellaneous	Rule #	Fault
ıead			Pumps				1	OA Damper stuck closed	FCU	1	Occupied Setpoint
	1	Flow		1	Dist. Pump operation		2	OA Damper stuck open		2	Unoccupied Setpoint
	2	Damper 1		2	Bldg Pump operation		3	Single OAD		3	Dirty Filter
	3	Damper 2		3	Prod. Pump operation		4	w/Separate Minimum OAD	FCU - CHW		
	4	Pressure		4	CDW Pump operation		5	Duct Static reset		4	CCV Leaking
ral				5	CHW Over pumping		6	Supply air temp reset		5	Overcooling
	5	Underheating		6	CHW DP Setpoint		7	Primary	FCU - DX		
	6	Overheating		7	CHW Pumping Minimum		8	Alternate		6	Overcooling
	7	Sim. Heat/Cool		8	CDW Pumping Minimum		9	Unoccupied fan operation		7	Overheating
			Cooling Tower				10	Off hours operation		8	Sim. Heat/Cool
	8	Occupied Setpoint		1	CDW Setpoint		11	Minimum Fan Speed	FCU - VFD		
	9	Unoccupied Setpoint		2	CT Staging		12	Dirty Filter		9	Fan Speed
	10	Off hours operation		3	CT Fan	AHU - No MAT			Exhaust Fan		
				4	Pan Heater		13	OA Damper stuck closed		1	Off hours operation
	11	Fan Speed		5	Fan Operation		14	OA/RA Damper Adjustment		2	Unoccupied fan operation
	12	Constant Mode	CDW Filter				15	Economizer Optimization	MAU		
				1	Filter Pump Operation	AHU - CHW				1	Off hours operation
	13	Flow	Chiller				16	CCV Leaking/Low Cooling		2	Unoccupied fan operation
	14	Damper 1		1	CHW Setpoint		17	w/MAT		3	HCV Leaking
	15	Damper 2		2	Chiller Operation		18	No MAT		4	Dirty Filter
	16	Pressure		3	Low cooling	AHU - DX				5	Overheating
				4	Chiller staging			Low Cooling	General		
			Bypass Valves				19	w/MAT		1	Stuck/Failed Sensor
				1	CHW Bypass		20	No MAT		2	Loop Tuning
				2	CT Bypass	AHU - Heating				3	Device Cycling
			Boiler					Sim. Heat/Cool			
				1	HW Dist. Pump operation		21	w/hot water			
				2	HW DP Setpoint		22	w/gas			
				3	HW ST Setpoint		23	w/electric			
							24	HCV Leaking			