Transforming the Practices of Building Operation and Maintenance Professionals: A Washington State Pilot Program

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ABSTRACT

Retro-commissioning studies place the potential energy savings from improved operation and maintenance (O&M) of commercial buildings between 5% and 30%. A pilot program has been initiated in the state of Washington focused on capturing a significant portion of this potential through transformation of building O&M professionals' practices. The program consists of three parts: 1) re-tuning large commercial buildings, 2) installation of wireless smart monitoring and diagnostic systems (SMDS) on packaged heating, ventilation and air-conditioning (HVAC) units for small commercial buildings to guide servicing of these units, and 3) increasing the energy focus of O&M subject matter for education of both current practitioners and new students considering or pursuing careers in this field. The 3-year program began in October 2006, with most of the first year devoted to initiating the large-building effort. Mid-year (2007), the small-building HVAC effort was started; the educational curricula effort began in 2008.

This paper describes the program and its components, and provides interim results. Over 8 million square feet of building space is directly involved in the re-tuning effort and much more should be impacted following completion of the project. The paper also characterizes the participating organizations and buildings and provides information on the re-tuning process, information on the SMDS, descriptions of the methodologies used to measure impacts, impressions of participants, and a discussion of barriers encountered in implementation.

Background

Commercial buildings in Washington State consume about 34% of the state's entire electric energy, at a cost of about $1.9 billion per year[1]. Since 2001, there has been an average annual increase of about 4% in electricity consumption and 9% in the cost of electricity. The commercial building sector has been the fastest growing electricity-consuming sector in Washington State. Primarily fueled by the economic growth of the last 10 years, commercial floor space has increased state-wide.

Operations and maintenance of the HVAC systems in commercial buildings is often neglected. It is common to find economizers on air-conditioners and heat pumps that do not modulate dampers and two-by-fours propping outdoor air dampers open (Stouppe and Lau 1989; Breuker and Braun 1998a; Lunneberg 1999; Ardehali and Smith 2002; Ardehali et. al. 2003; Katipamula et al. 2003a; Jacobs 2003), leaking valves, simultaneous heating and cooling caused by malfunctioning valves, excessive use of reheat resulting from low supply air set point, and air-conditioning systems that are improperly charged and operating with dirty filters and heat exchangers (Houghton 1997). Sometimes, building systems run 24-hours-per-day despite

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[1] http://www.eia.doe.gov/cneaf/electricity/st_profiles/washington.pdf

several hours of non-occupancy. These are some of the conditions that cause substantial energy waste. Although there are no reliable nationwide data on energy impacts associated with inefficient operations, there is a general consensus that between 10% and 30% of the energy is being wasted (PECI 1997; Ardehali and Smith 2002; Claridge et al. 1994; Claridge et al. 1996; Mills et al. 2004).

In addition, many commercial buildings lack a control infrastructure adequate for monitoring building systems' performance well. For example, less than 10% of the commercial buildings in the U.S. have central energy management and control systems[2] (EMCSs) (EIA 2006). The rest of the commercial building stock may have distributed controls, such as unitary stand-alone controllers and time clocks, but such distributed controls are frequently not tied to central monitoring to provide a useful way for monitoring performance and detecting improper operations. As a result, system performance degrades, leading to substantial energy waste.

A pilot project has been initiated in the State of Washington focused on capturing a significant portion of this savings potential through transformation of the practices of building O&M professionals. This project intends to change the way HVAC systems in large and small commercial buildings are operated, serviced and maintained by targeting high-impact energy efficiency measures that can be delivered immediately, at low- or no-cost. Because HVAC contributes approximately 38% of the electricity consumption in commercial buildings (Taylor 1989), a significant portion of the electricity can be saved by targeting high-impact HVAC energy efficiency measures. The Office of the Washington State Attorney General provided funding for the project, using funds from a settlement concerning alleged illegal manipulation of electricity prices during the West Coast energy crisis of 2000-2001.

The project consists of three parts, each focused on transforming the practices of practitioners operating and maintaining building systems:

- **Re-tuning large commercial buildings**. Companies providing HVAC servicing are being trained to provide HVAC and controls re-tuning services. While providing the training, HVAC systems in selected large commercial buildings are being "tuned" for efficient operation.
- **Deployment of wireless smart monitoring and diagnostic systems in small commercial buildings**. Packaged HVAC units in small buildings typically lack condition monitoring and supervisory controls. The project is deploying 150 wireless sensing condition monitoring and diagnostic systems. HVAC service providers are being trained to install this SMDS and use its results to guide maintenance.
- **Outreach and training**. To ensure the lasting impact of this project on commercial sector electricity customers in the State of Washington, outreach and training is being provided to increase the energy focus of O&M subject matter for education of both current practitioners and new students considering careers in this field. In addition, the authors plan to work with select trade schools and community colleges to develop curriculum based on the experience gained in the project to create a pipeline of better qualified technicians to the field.

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[2] Several different terms identify an energy management and control system (EMCS), including building automation system (BAS), building control system, building management system (BMS), and energy management system (EMS).

Re-Tuning Large Commercial Buildings

Many large[3] commercial buildings today use sophisticated EMCSs to manage a wide range of building systems. Although the capabilities of the EMCSs seem to have increased over the last 2 decades, the capabilities of these systems are not fully utilized, and many buildings are not properly commissioned, operated or maintained. Lack of proper commissioning, the inability of the building operators to understand the complex controls, and lack of proper maintenance leads to inefficient operations and reduced equipment lifetimes. Tuning building systems controls using EMCSs helps ensure maximum building energy efficiency and the comfort of building occupants. A poorly tuned system can sometimes maintain comfortable conditions, but at a high energy cost to overcome unrecognized inefficiencies.

Periodic re-tuning of building controls and HVAC systems is likely to enhance building operations and improve building efficiency. *Re-tuning, as used in this project, is a systematic, semi-automated process of detecting, diagnosing and correcting operational problems with building systems and their controls*. The process can significantly increase energy efficiency at low or no cost – and the impact is immediate. Unlike the traditional retro-commissioning approach, which has a broader scope, re-tuning primarily targets HVAC systems and their controls. In addition, re-tuning uses monitored data to assess building operations even before conducting a building walk through. Monitoring-based commissioning is not new; several researchers have used such an approach (Brown and Anderson 2006; Brown et al. 2006). However, most of the early monitoring-based approaches installed permanent meters and energy information systems before commissioning the buildings. In contrast, our re-tuning approach leverages existing EMCSs to trend data.

The approach used for the large commercial building re-tuning service is as follows:

1. Eight service providers who service large commercial buildings in Washington State were recruited to participate in the project.
2. At least two engineers or technicians from each service provider organization were trained on how to apply the re-tuning methodology (see next section). The training consisted of two parts, 1 day of classroom training[4], followed by in-field training for 2 to 4 days. The service providers were reimbursed for attending both the classroom and the field training.
3. After completion of the training, the service providers are required to re-tune five or more buildings on their own. The service providers are also required to provide a list of: 1) the problems identified, 2) corrective actions implemented, and 3) corrective measures that need additional work or resources to complete. Each service provider was reimbursed for its time to re-tune the buildings.
4. After the service providers complete the re-tuning of their buildings, Battelle project staff visits the re-tuned sites for spot inspections to evaluate how well the service providers have learned and applied the re-tuning process.
5. After 12 months of electricity consumption data are collected following re-tuning, Battelle project staff will estimate the impact of the program on the electricity

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[3] For this project, a large commercial building is defined as a building with 100,000 sf or more of conditioned space and having an EMCS.

[4] See http://buildingefficiency.labworks.org/lg_bldg_training.stm for more details.

consumption using monthly data. The savings will be estimated by the difference between the weather normalized electricity consumptions for the 12 months before and after re-tuning. Savings estimated using monthly billing data should reveal savings if they are greater than about 5% of total electricity use.

The goals of service provider training are to 1) educate them that the buildings can be tuned to save electricity, 2) teach the proper techniques and skills to perform re-tuning, and 3) prepare the service providers to potentially offer re-tuning as a service. Demonstrating to the service providers that they can save money on electricity for their customers will help ensure that the service providers will continue to re-tune HVAC systems on other buildings that they service, leading to a more efficient commercial building stock.

Re-Tuning Methodology

An early version of the re-tuning methodology was initially developed during the electricity crisis of 2000–2001 for the Federal Energy Management Program (FEMP). These procedures were adopted by FEMP and rolled out as part of the U.S. Department of Energy (DOE) ALERT (Assessment of Load- and Energy-Reduction Techniques) Program for federal facilities. These procedures were further refined and formalized for use in this current project. The re-tuning method consists of six primary steps: 1) initial collection of relevant building information, 2) pre-re-tuning phase, 3) building walk through, 4) re-tuning phase, 5) post-tuning phase and 6) savings analysis. Procedures for executing each of these primary steps are summarized in the sections that follow.

Initial collection of relevant building information. The first step in re-tuning a building is to gather sufficient building information to enable set up of trend logs in the EMCS in the pre-re-tuning phase. This requires determining the overall design and type of mechanical systems in the building, the approximate number of each major piece of equipment (e.g., air handlers) and the number of zones. This information provides the basis to identify which trend logs need to be set up to collect data useful for understanding the current operations of the building and identifying probable operational issues even before visiting the site[5].

Pre-re-tuning phase. The pre-re-tuning phase involves setting up the trend logs, collecting trend data for at least 1 week (preferably 2 weeks) for key points in the mechanical system and analyzing the data to learn more about current building operations. This analysis helps identify operational errors, such as equipment running unnecessarily during unoccupied hours. Before starting collection of trend data, the technician prepares a monitoring plan, which is based on the building information gathered in the previous step. To help the service providers, Battelle developed monitoring templates and also suggested a list of points to trend for common HVAC systems. The plan identifies trend logs that need to be set up in the EMCS and how the trend data will be analyzed. For each trend log (i.e., sensor or control point), the plan specifies the duration of the logging period (number of days) and the measurement period (time interval

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[5] If the service provider already regularly visits the building and is familiar with the EMCS, this serves to streamline the process of setting up trend logs.

between logged values). The monitoring plan depends on the specific HVAC systems in the building[6].

After the plan is complete, the technician implements the plan, first by creating the trend logs in the EMCS. After sufficient data are collected (as specified by the logging periods in the plan), the technician analyzes the data, using a semi-automated spreadsheet analysis tool and analysis guidelines provided to the technicians, to gain insight into current operations and to detect problems with the building systems and their controls. The spreadsheet, provided by the Battelle project team, reads trend log files from EMCSs and automatically produces a set of plots that the re-tuning technicians are taught to use for detecting operational issues.

Building walk through. The purpose of the walk through is to develop a reasonable insight into the building condition, the overall building design, and the HVAC system design. It is also used to collect basic data about the building systems and confirm initial findings from analysis of the trend data in the previous step. This understanding is then used in the next phase to guide re-tuning of the building. Examples of the information collected includes: types of heating systems, types of cooling systems, presence or absence of air-side economizers, type of EMCS, electricity consumption patterns, etc. The walk through consists of seven primary steps: 1) review of mechanical and electrical prints, 2) walking the outside of the building, 3) walking the inside of the building, 4) walking across the roof, 5) walking through the air handlers, 6) walking through the plant area and 7) reviewing the control system and its front end.

Re-tuning phase. Based on the building walk through and the analysis of trend logs, the technicians prepare a plan for re-tuning the building. Use of the building control system is a central focus of the re-tuning process, and the re-tuning plan identifies specifically how the EMCS is exercised to detect and diagnose performance problems and other faults not identified from trend data. The control system is also used to confirm faults and operational issues identified during the trend analysis and building walk through. The specifics for use of the EMCS depend on the types of systems in each building and the capabilities of the EMCS. The technician uses this plan to guide re-tuning of the building. Some of the key factors that are verified, ensured, optimized, or adjusted during re-tuning include: discharge air set points; discharge static pressure set points; heating and cooling control loops; all aspects of economizer controls; weekly and daily schedules for equipment; time limits for manual overrides for space conditioning; optimal start codes for heating and cooling systems; proper use of dead bands for space temperature set points; annual cooling plant shut down; if warranted, proper sequencing of chillers, cooling towers, and pumps; variable frequency drive-driven cooling equipment configured properly and working correctly; chilled-water pumps configured to avoid over-pressurization; annual heating plant shut down; if warranted, heating system components properly sequencing; hot-water pumps configured to avoid over-pressurization; proper set back and damper closing for terminal boxes serving spaces not requiring ventilation during unoccupied times; when ventilation is required 24/7 in some spaces of the building; proper operation of occupancy sensors controlling lighting in offices and conference rooms; proper lighting control in hallways and common spaces during unoccupied times; and outdoor lighting

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[6] A sample plan for a building with variable-air-volume air-handling units with a central plant with chillers and boilers can be found at http://buildingefficiency.labworks.org/media/large_building_trending_requirements_for_retuning.pdf.

turned off when not required. Findings are recorded on log sheets as systems are inspected and re-tuned. Templates have been developed for this purpose.

As part of re-tuning, the technician corrects problems that are detected that can be corrected immediately (e.g., changing set points, changing schedules, and making minor control sequence changes). The technician also records a list of problems that could not be corrected that require repairs or replacement of equipment or decisions by higher-level building management or the owner.

Post-re-tuning phase. In this phase, three reports are prepared, two of which the service provider delivers to the building owner or client.

Upon completing re-tuning of a building, the service provider sends copies of the re-tuning log sheets to Battelle project staff and retains the originals. These sheets include observations made, the results of measurements, and actions taken to remedy problems identified. They also include a list of improvement opportunities identified during the re-tuning process that could not be implemented during the re-tuning visit but that the owner or building manager should consider implementing in the future. Some of these may require incurring additional cost to complete. The service provider will also use this information to complete a template, to prepare a *post-re-tuning report* on the building. This report summarizes the overall process, the problems identified, the problems corrected including how they were corrected, and the list of potential additional actions recommended. The service provider provides this report to the building owner/client with a copy sent to Battelle project staff.

The project staff also performs quality assurance (QA) evaluations of the work done at each building. The project staff visits the building (accompanied by the service provider) to spot check the condition of the building systems and the controls and the quality of work that was done to correct problems found during re-tuning. The QA information is used by Battelle to generate a report for each building on the quality of the re-tuning completed. The report includes suggestions on how to improve re-tuning deficiencies found during the QA evaluation. This report is delivered to the service provider. The Battelle project staff will prepare a final report for each building approximately 13 to 14 months after the completion of re-tuning. This final report, in addition to including the earlier findings, will provide estimates of the energy savings resulting from re-tuning.

Savings analysis. The electric energy savings and the cost-effectiveness of the proposed solutions implemented are key for widespread acceptance of the re-tuning process. In addition, the effectiveness of the service providers in providing re-tuning is also important to ensure that the actions taken will correct problems and the benefits from this program continue beyond the initial demonstration. Battelle project staff will determine electric energy savings impacts based on utility data (monthly kWh, weather data, and other important) data and the savings will be related to the reported problems and solutions implemented. Based on the electric energy savings of the selected candidate buildings, the project staff will project the cost-effectiveness that is likely achievable in a multi-year HVAC tuning program for other large buildings. Another important measure of success is the effectiveness of the service providers and instructors. The authors will develop metrics to evaluate the technicians' training through surveys. Additional metrics include the number of companies and technicians using the methods and installing the new technology after participating in the program, but because there is no post-program follow up, this will only be assessed by surveying the participating service providers regarding their intentions for the future

Deploying Smart Monitoring and Diagnostics Systems (SMDS) in Small Commercial Buildings

A significant portion of the electricity cost for a small[7] commercial building is attributable to HVAC systems and lighting. Small commercial buildings typically have several vapor-compression air-conditioning systems on the roof to meet the heating and cooling needs; these units are generally referred to as packaged roof-top units. During commissioning and tuning, packaged roof-top systems are often found with inoperable dampers, dirty or clogged filters and coils, incorrect refrigerant charges, failing compressors, failed fans, missing enclosure panels, incorrectly implemented controls, and other problems. These units are often run until a catastrophic failure occurs. Upon complete failure, a service company repairs or replaces the unit—unnecessarily expensive options. Minor adjustments to controls or schedules and minor timely maintenance can lower energy bills and prevent catastrophic failures.

Currently, very little monitoring of systems is performed in commercial buildings, especially small commercial buildings, which constitute over 95% of commercial buildings and over 50% of the total commercial floor space in the U.S. (EIA 2006). EMCSs are not generally deployed in small commercial buildings because of the high first cost. Without an infrastructure for proper control and continuous monitoring, however, problems cannot be detected, reported and corrected. Many of the problems plaguing small commercial buildings will continue to exist, unless low-cost solutions are developed and deployed.

Pacific Northwest National Laboratory[8] (PNNL), working with the U.S. Department of Energy (DOE) and NorthWrite Inc., has developed a low-cost SMDS. This technology includes both hardware and software applications that automatically detect and diagnose improper operations (Katipamula et al. 2003a,b; Katipamula and Brambley 2004a, b, c; Brambley and Katipamula 2004; Brambley et al. 2004a, b). The approach used in transforming the servicing of small commercial buildings through deployment of SMDS is as follows:

1. Six service providers who service packaged HVAC units in commercial buildings in Washington State were recruited.
2. The service providers are trained on installation of the SMDS (see next section for details on the technology). Each service provider will install SMDSs on 10 or more roof-top units. A total of 152 units will be deployed in Washington State.
3. The service providers are required to service the roof-top unit before installation of the SMDS (to eliminate any refrigerant-side faults and improve the general operating condition of the unit). The service providers are also required to monitor the website on which monitoring and diagnostic results will be posted to see if any faults develop or efficiency of the unit degrades over the course of the project term (12 months). If significant faults or efficiency degradation is detected, the service providers must make reasonable attempts to repair the compromised units. Service providers will be paid by

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[7] A small commercial building is defined in this project as a building with less than 50,000 sf, served by packaged roof-top HVAC units.

[8] Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC05-76RL01830.

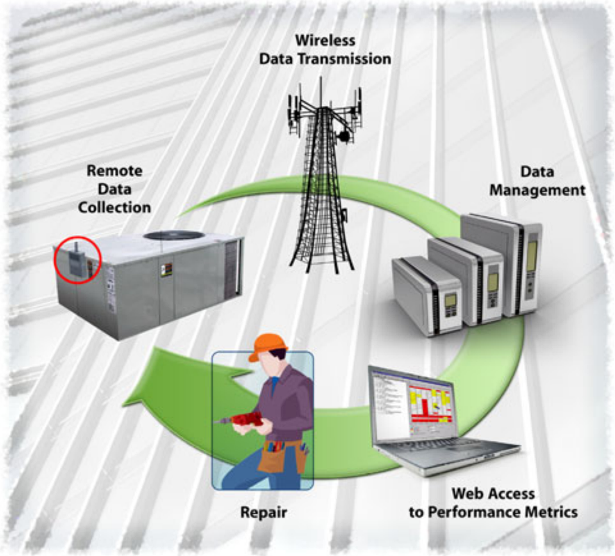
the program to install the SMDS units and a small fee for reviewing SMDS reports weekly. The program will not reimburse them for servicing the HVAC units based on the SMDS finding; service will be covered by an existing maintenance contract or paid by the customer.

The intent of providing training to service providers is to: 1) educate them that cost-effective solutions for continuous monitoring and diagnostics can save electricity, 2) teach them how to provide the service, and 3) show that this service can be provided for a fee or as a way to provide customers a higher level of service than provided by competitors. Demonstrating to the service providers that they can provide monitoring, control and diagnostics services as a practical part of their businesses will help ensure that the service providers continue to offer this service beyond this project. The project will measure the following: 1) the number and kinds of faults and performance degradation found by the SMDS, 2) service actions taken by the service providers in response to the SMDS reports, and 3) the energy savings resulting from the service actions taken by the service providers.

Smart Monitoring and Diagnostic System

The SMDS is a data collection, diagnostic processing and communications hardware mounted in a small enclosure installed on the side of each packaged air conditioner or heat pump and provides continuous remote monitoring and diagnostics for the unit. The SMDS works by constantly collecting data from sensors installed on the equipment to measure its performance and detect and diagnose problems with its operation. The unit then sends the results wirelessly, directly from each packaged unit to an application service providers' network operations center, where the data are stored securely and information on the condition of each packaged unit is made available on the world wide web. A computer, a web browser and an Internet connection are used to access the diagnostic results. The SMDS process is shown in Figure 1.

Figure 1. Schematic of the SMDS Process



Functionally, packaged roof-top units can be divided into two primary systems: 1) air side and 2) refrigerant side. The air-side system consists of the indoor (supply) fan, the air side of the indoor coil, and the ventilation damper system (including its use for air-side economizing), while the refrigerant-side components include the compressor, the refrigerant side of indoor and outdoor heat exchangers, the outdoor fan, the expansion valve, and the reversing valve (for heat pumps). The SMDS only provides air-side diagnostics and monitoring of overall unit efficiency (not refrigerant-side diagnostics).[9]

For temperature-based economizers or no economizer, the SMDS requires the following sensors: 1) outdoor-air dry-bulb temperature, 2) return-air dry-bulb temperature, 3) mixed-air dry-bulb temperature, 4) outdoor-air damper-position signal, 5) supply-fan status, and 6) heating/cooling mode. To identify whether the system is actually in heating or cooling mode, the status of the compressor (and the reversing valve for heat pumps) is used. With these measurements, economizer operations and ventilation requirements are monitored and evaluated to verify their correct performance and detect faults when they are present. For an enthalpy-based economizer, the outdoor-air and return-air relative humidity (or dew-point temperature) are required in addition to the six measurements used to monitor the performance of units with temperature-based economizer controls.

To monitor the efficiency of the roof-top unit, the SMDS uses, in addition to the measurements used for temperature-based economizing, the following: 1) supply-air temperature and humidity, 2) mixed-air humidity and 3) power consumption of the unit. The supply-air flow rate is assumed for calculation of the efficiency. Deviations between this assumed value of air-flow rate and the actual rate do not affect the detection of efficiency degradation, although they do affect the absolute magnitude of the efficiency. The faults that can be detected on the air-side can be grouped into four categories: 1) inadequate ventilation, 2) energy waste, 3) temperature sensor and other miscellaneous problems, including control problems, and 4) missing or out of range inputs. Refer to Katipamula et al. (2003b) for details on the diagnostic approach for detecting and diagnosing air-side faults. A detailed review of both air-side and refrigerant-side diagnostics is also presented in Katipamula and Brambley (2004a, b, c).

An embedded processor in the SMDS uses diagnostic logic to convert data from the suite of sensors installed with the SMDS to useful information. This information includes indicators of the unit's performance, alarms for faults detected, and diagnostic results useful for targeting maintenance and repair service.

Outreach and Training

The third part of the project focuses on ensuring lasting impact of this project on commercial-sector, electricity customers in the state of Washington. The outreach to businesses and education institutions will be accomplished by:

- Training HVAC service providers in methods and technologies tested and demonstrated in this project and in the general principles and practices of good energy management

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[9] Refrigerant-side diagnostics have been coded by the Battelle project team but are not deployed in the SMDS to limit its cost.

- Influencing the education of students who have or may choose career paths related to the HVAC servicing or building energy management fields through additions to curricula.
- Publicizing the results of the project to other HVAC service providers, who are not part of the training, and to customers to encourage widespread adoption of these energy-saving methods.

The first of these will focus on training businesses and personnel currently providing installation, servicing, and operation of building controls, HVAC and lighting systems. The second effort will focus on developing material and tools for training the next generation of business owners and HVAC technicians, by targeting those preparing to enter this field in the next few years. The training methods developed under this project will be transferred and curricula will be developed in collaboration with vocational education programs at the secondary school level and with selected trade schools and community colleges across the state to create a pipeline of qualified technicians in the future. The third outreach component will involve disseminating knowledge about the benefits of HVAC system re-tuning and condition-based maintenance to the business community, both providers and customers of HVAC services. The project staff in conjunction with state employees, service providers, and customers will write articles for trade and professional publications about the results of the project. A clear demonstration of cost savings will provide a powerful incentive for businesses to adopt the technologies demonstrated in the project.

Project Status

The project began in October 2006 and will continue through December 2009. A significant portion of the first year was dedicated to the development of the re-tuning training material[10] and conducting re-tuning training for service providers. The SMDS hardware was designed and software upgraded to match the hardware. The outreach activities started in the spring of 2008. Details on progress in each of the three focus areas are provided below.

Building Re-Tuning Progress

Selection of the committed energy service provider companies is the key to ensuring that re-tuning of controls and HVAC systems in commercial buildings is successful and continues beyond this project. The project staff contacted a number of organizations to identify and recruit service provider for the re-tuning task. Based on the recommendations of organizations such as the General Service Administration (GSA), the Washington General Administration and the Northwest Energy Efficiency Alliance and interviews of prospective service provides, the project recruited eight service providers throughout Washington State. All eight service providers were trained on the re-tuning approach and are currently using it on about 56 buildings covering over 10 million square feet. The selection of the buildings was made by the service providers based on the criteria set by the program (see Table 1). Battelle staff were not directly involved in recruiting private buildings or their owners. In the case of Federal- and State-owned buildings,

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[10] See presentation materials at http://buildingefficiency.labworks.org/lg_bldg_training.stm.

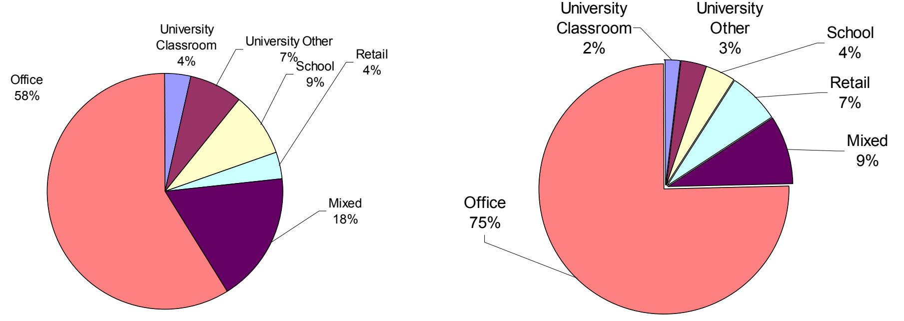
Battelle staff did work directly with the GSA and Washington State General Administration staff, respectively, to recruit and select buildings.

Figure 2 shows the distribution of buildings by type. Most buildings selected for re-tuning are office type (58% by number and 75% by area). Although not shown in the figure, most buildings selected are from the west side of the state (80%), compared to 20% from the east side of the Cascade Mountains.[11]

Table 1. Criteria for Selection of Buildings

Type of Building	Commercial
Size	>100,000 sf
Controls	Central building automation system (direct digital controls preferred)
HVAC	Central heating/cooling or large packaged systems (preferably with air-side economizers)
Other Consideration	Interest by building staff and management in saving money on energy use; in making buildings “green”; willingness to make appropriate changes to controls and replace low-cost equipment that is working improperly; allow project team to access monthly utility bills; and buildings with legacy controls (older than 10 years) will be given lower preference.

Figure 2. Distribution of Building Type by Number and Square Footage



Building Type by Percentage of Buildings (Total 56)

Building Type by Percentage of Floor Area (Total 10,247,387)

As of spring 2008, six classroom and eight field training sessions to train the eight service provider companies were held. Over 15 buildings have been re-tuned. As expected, a number of operational problems were found in every re-tuned building. Most of the operational problems could be corrected at no or low cost. A list of operational problems found in the 15 buildings re-tuned so far is shown in

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[11] The east and west sides of Washington are generally divided by the Cascade Mountains, with the west side most heavily populated along the Interstate 5 corridor.

Table 2. Only problems that were found in multiple buildings are listed. There are a number of additional problems specific to each building that are not listed in the table below.

Initial reaction of service providers. As noted earlier, the project recruited eight service providers for the re-tuning work. All service providers were eager to participate in the project and learn the re-tuning approach. However, some of the service providers had some reservations on the use of monitored trend data to detect operational problems. The primary concern was the time it would take and associated cost to set up the logs and review the logs manually. After experiencing the re-tuning training however, even the reluctant service providers saw value in the analysis of trend logs. As one service provider put it, "Now I don't have to convince the building owner about the problem, the graph from the trend data does that for me."

One of the objectives of the large commercial building task is to document the savings attributable to re-tuning of building controls and systems. While providing field training, authors found a number of "no-cost" and "low-cost" operational changes that could result in significant savings (>5% of the total consumption) in almost all buildings. Although many of the changes identified during the re-tuning were easy to implement with little cost, many of the changes took a long time for the service providers to actually implement. The main stumbling block appears to be the perception by building operations staff that they lacked clear authority to implement even minor operational changes. In many cases, the building operator takes directions from someone who is not present in the building on a day-to-day basis. Often all staff is not given clear authority to make operation changes to the building; authority to make decisions should be clearly communicated to the building O&M staff. Furthermore, there is some reluctance by building operational staff to make changes because they perceive that changes may lead to complaints. Complaints are perceived as already being at an acceptable level. The potential benefit of further decreasing complaints and costs is not perceived by some of the building staff as worth the risk because changes could increase the number of complaints in some cases.

The Battelle project staff is working with service providers, building operators, and building owners to find a way to expedite implementation of corrective actions in response to the re-tuning findings. Although there is some initial reluctance by building operators to make changes, the project has received excellent reviews from the participants of the training classes. For example, the GSA is considering requiring all building managers and service providers that service Federal buildings to take the re-tuning course. Two organizations have asked for additional training courses.

Table 2. List of Common Problems

Type	Problem	Cost	Number of Buildings
Controls	Systems running longer hours than needed	Low-cost	6
	Improper economizer operations	Low-cost	6
	Outdoor-air is not reset to zero during morning warm-up or cooling	Low-cost	5
	Optimal start/stop not working or not present	Low-cost	4
	Tight dead band (1°F), causing excessive cycling between heating and cooling modes	Low-cost	3
	Building unoccupied during summer months, but all systems running during that period	Low-cost	3
HVAC	No chilled water or hot water reset	Low-cost	6
	Leaky valves	Capital	3
	Static pressure too high	Low-cost	2
	Exhaust fans on 24 x 7	Low-cost	2
	No static pressure reset	Low-cost	2
Building	Un-insulated chilled/hot water pipes or missing attic insulation	Capital	4
	Missing door/window seals	Capital	3
	Faulty sensors	Capital	2
Lighting	Some areas over lit	Low-cost	4
	Lack of occupancy sensors in common areas	Capital	3

SMDS Progress

Just like for the re-tuning task, selection of committed energy service provider companies is the key to ensuring that SMDSs are successfully deployed in commercial buildings. Project staff contacted a number of organizations to identify and recruit service providers. Based on an organization's recommendations, six companies were recruited and a few more will be recruited before the deployment begins later this summer. As of early March 2008, four service providers are under contract and two more are in contract negotiations with Battelle. The four service providers are signed up to install SMDSs on 82 rooftop units.

In addition to recruiting service providers, the project has also selected NorthWrite to build the SMDS units and to host the web service for the project. This company[12] will offer the SMDS as a service to the service provider companies even after the completion of the project. NorthWrite has developed the web pages and the communication pathways to receive data and diagnostic codes from the SMDSs in the field. Two prototype units were deployed in March 2008 to test all features of the SMDS. Deployment of the rest of the 150 SMDS will start in June 2008.

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[12] www.northwrite.com

Conclusions

The paper summarized a three-part program underway in Washington State aimed at subsectors of the commercial buildings industry. The program components focus on: 1) re-tuning of equipment in large commercial buildings (>100,000 sf), 2) testing of a smart monitoring and diagnostic technology for packaged air conditioners and heat pumps on small commercial buildings (generally <50,000 sf), and 3) influencing the education and training of currently practicing and future HVAC technicians and building operators through outreach and curriculum development.

Only the first of these components, for large commercial buildings, has completed significant field deployment as of early spring 2008. Re-tuning of large buildings started early in the summer of 2007. Interim results of re-tuning 16 buildings reveal a few important observations:

1. A number of operational problems have been found in every building. The most common are 1) systems running at times when they are not needed, 2) poor economizer operation, and 3) no reset used for chilled water or hot water. Each of these problems was found in over one-third of the buildings re-tuned thus far.
2. The reception to re-tuning training has been enthusiastic. Leveraging EMCSs to detect operational issues and graphically diagnosing the causes of problems has proven to be valuable to program participants. Many very positive comments on the content of the course have been received from managers and technicians trained, and two organizations have asked for expanded offerings of the training.
3. Despite the positive response to the training classes, most buildings staff are reluctant to make changes to the systems in their buildings for fear that anything changed could lead to occupant dissatisfaction and complaints. This reaction is common even for changes that can be implemented at little or no cost and have a high probability of significant energy savings and improved control of comfort conditions. This has greatly limited the rate of implementation of corrective actions during initial re-tuning visits to buildings and required that most recommended actions be put on a list of actions deferred for future implementation. In several cases, this issue has been discussed with organization management as a potential problem in clear communication of expectations and authority to make changes to the operations staff and subcontractors. In most buildings, progress is continuing in the desired direction, although in many cases slowly. This is an important issue that must be addressed to achieve the maximum energy savings and improvement in building operations possible in existing buildings.

Re-tuning is planned for about 40 more large commercial buildings for a total of 56 buildings and over 10 million sf. Based on the buildings identified by service providers, these buildings will be distributed based on floor area as follows: 75% office buildings, 9% school and university buildings, 9% mixed use, and 7% retail.

Utility energy-use data collected for 12 months before and after the re-tuning visit will be used along with weather and other data to estimate normalized energy impacts of the program for the participating buildings. Results are not yet available. Based on past experience, the authors believe that savings greater than 5% of the total energy use will be detectable.

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