BATTELLE

SAVING ELECTRICITY IN THE STATE OF WASHINGTON: IMPROVING EFFICIENCY OF COMMERCIAL BUILDINGS

A Report on a Groundbreaking, State-Funded Energy Efficiency Project (2006-2018)

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Overview

Saving Electricity in the State of Washington: Improving Efficiency of Commercial Buildings

Legal settlements fund a visionary research effort that has produced influential and impactful results well beyond state borders

In the years following the energy crisis of 2000-2001, the State of Washington and six energy companies entered into settlements to resolve the state's claims that Washington consumers were injured during the crisis by the companies' roles in soaring energy prices. Then-Attorney General Christine Gregoire, in talking about settlements with two of the companies, said:

Christine Gregoire
(Photo courtesy Washington State Library)

"By manipulating energy prices, these companies created real financial hardships for businesses and consumers. We can't undo that damage, but we can find a fair way to use this money to help consumers and businesses."

The state recovered more than $40 million dollars, most of which was returned to business and residential consumers. A portion of the funds was set aside for energy education and training, low income energy assistance, residential weatherization and energy efficiency research.

In response to a state call for research projects, **Battelle**, operator of **Pacific Northwest National Laboratory** (PNNL) in Richland, WA, submitted a proposal in 2005 focused on improving energy efficiency of commercial buildings. The proposal recognized that these buildings consumed more than one-third of the state's electric energy and were the fastest growing electricity-consumption sector. Further, many of the buildings did not possess effective systems to control heating, cooling and other functions. Battelle's proposal outlined a strategy and methods for changing the way that heating, ventilation, and air conditioning (HVAC) systems in commercial buildings were operated, serviced, and maintained—ultimately to produce significant energy and cost savings. Importantly, Battelle's proposed high-impact energy efficiency measures could be delivered readily and inexpensively to buildings.

Battelle, based in Columbus, Ohio, has cultivated a presence in the Pacific Northwest for more than 50 years. In addition to managing Pacific Northwest National Laboratory in Richland, WA, Battelle established an office in Seattle and founded a marine sciences research facility at Sequim on the Olympic Peninsula. Battelle also has actively supported education, economic development and community activities across the state.

The multi-year effort was funded by the state and launched in 2006, and will be referred to as the "state project" in this report. Battelle's initial focus was on identifying participants—organizations and individuals—from across Washington, with an emphasis on two types of prospects: building management entities possessing structures in need of operational improvements, and HVAC service providers interested in learning and applying energy efficiency methodologies.

The state project concentrated on developing solutions in these primary thrusts:

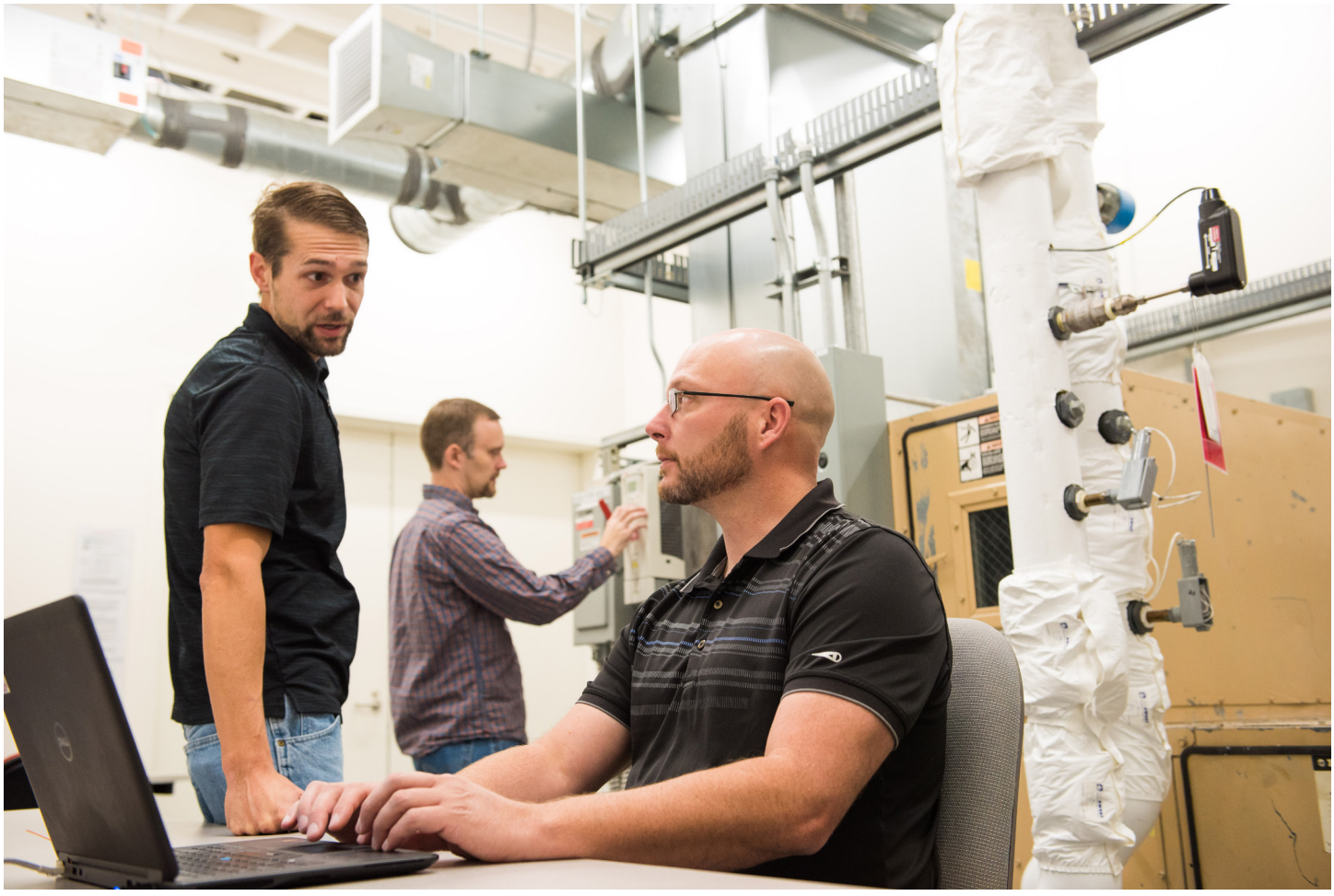
- **Large Commercial Buildings**. The emphasis was on "tuning" HVAC systems to achieve efficient operations. This task included deployment of system controls and mechanical maintenance strategies, as well as a training component designed to ensure that HVAC service providers would continue to deliver technical support

to the buildings—and to new customers—beyond the state project's lifetime.

- **Small Commercial Buildings**. Recognizing that HVAC systems in these structures typically lack sophisticated controls, this effort sought to deploy a low-cost wireless sensing, control, and condition monitoring technology in buildings and train HVAC service providers in installation and maintenance of this equipment.
- **Small Business and Education Outreach**. This component transferred to current and future technicians the skills needed to evaluate existing HVAC systems and to install upgrades. The task targeted technicians working in the industry for an immediate impact and worked to transfer training materials to technical schools across Washington to build a long-term resource of qualified technicians.

The state project leveraged multiple Battelle capabilities at PNNL, A **U.S. Department of Energy** (DOE) national laboratory, including existing methodologies that were developed, tested, and successfully applied under DOE's **Federal Energy Management Program** (FEMP) and further advanced by DOE as the Assessment of Load- and Energy-Reduction Techniques—ALERT—program. To execute the project, Battelle also drew upon work by DOE and private industry on smart grid technologies, and longstanding PNNL relationships with public and private energy entities, including DOE's offices of Energy Efficiency and Renewable Energy, Fossil Energy, and Policy. The relationships also included other federal agencies, like the Bonneville Power Administration, and state energy offices.

These extensive resources were underpinned by Battelle's experienced research and development team. The team possessed diverse expertise and decades of practical field



Battelle expertise at PNNL has been developed over many years and provided a strong foundation for the state project. Researchers at PNNL are nationally recognized for their work in the power grid, buildings, control systems, and more.

experience in HVAC systems and energy management and control systems. Additionally, the team's skillset contained capabilities for development of classroom materials, and also included seasoned instructors to conduct training in both academic and professional development environments.

In 2009, Battelle was asked by the state to extend the project to a second phase. In this part of the effort, Battelle partnered with selected Washington school districts, community colleges, and other educational institutes to improve the efficiency of their buildings. The state project sought to educate building operators, managers, and service providers on ways that buildings can easily be tuned to save electricity. The project also focused on a "train-the-trainer" approach designed to ensure that those instructed in proper tuning techniques and skills extend that knowledge to others. The second phase further included development of energy efficiency curriculum materials for primary and secondary schools that were provided to a number of districts. While this latter element was perhaps less impactful than others, it nonetheless forged new relationships and strengthened existing ones between school districts, Battelle, and PNNL, which is a key charge for PNNL as a DOE national laboratory.

Keep in Mind As You Read. . .

In addition to the state project results, this report chronicles subsequent federally-funded projects and activities that essentially were inspired by—and benefited from—the state project's groundbreaking work and outcomes in the field.

Also, in recent years, a new, more formal terminology has emerged to describe the tuning process for enhancing the operation of buildings. DOE has coined "Re-tuning™" to characterize the strategies and methods of detecting and fixing operational deficiencies to achieve enhanced efficiency in buildings. The term will be used throughout this report.

Accomplishments at a Glance

The following table provides a summary of key accomplishments of the project, which are described in more detail in the associated sections of this report.

Research Focus	Accomplishments
Large Commercial Buildings	**State Funding Outcomes**: • Six Steps of Re-tuning framework developed • Participating organizations and service providers identified and engaged; Re-tuning training sessions conducted • 26 buildings re-tuned statewide • Observation-driven Re-tuning methods developed • **Re-tuning website** developed and improved • 12 online training modules and web-based training program initiated; more than 5,000 users of web-based training since launch **Federal Funding Outcomes**: • Expansion and testing of methodologies nationwide; more than 75 buildings in multiple states have benefited • National Re-tuning advancements lead Seattle to adopt Tune-Up mandate for large nonresidential buildings • Software developed and deployed to automatically identify Re-tuning opportunities, via the DOE **Clean Energy and Transactive Campus** (CETC) project involving PNNL, Washington State University, and the University of Washington (work also partially supported by the **Washington Clean Energy Fund***) • General Services Administration (GSA) project introduces Re-tuning to federal buildings

Small Commercial Buildings	**State Funding Outcomes**: • Participating organizations and service providers identified and engaged • Improvements made to Smart Monitoring and Diagnostic System (SMDS), including development of a more targeted and less costly version that was based on participant feedback • Training delivered to service providers **Federal Funding Outcomes**: • Two advanced versions of SMDS tested in Puerto Rico, Maryland and New York • SMDS deployed in DOE Transactional Network Project to evaluate technology's performance-degradation detection methods • Potential future commercialization of SMDS algorithms
Education/Outreach	**State Funding Outcomes**: • Organized and conducted regular meetings to convey Re-tuning information to up to 25 state community college representatives who teach courses in the buildings sector • Voluntary integration of Re-tuning information in community college coursework • K-12 energy efficiency lesson plans and materials developed, conveyed to a limited number of school districts
Technology Developments	**State Funding Outcomes**: • Energy Charting and Metrics (ECAM) tool enhanced and adapted for state project use • Re-tuning algorithms integrated with OpenEIS tool **Federal Funding Outcomes**: • OpenEIS Re-tuning tool enhanced; VOLTTRON™ technology further developed for Re-tuning applications
Publications	5 journal articles; 3 conference papers; 4 formal reports; 1 book chapter; 22 presentations; 5 brochures/fliers; 9 other published products.

*The Washington Clean Energy Fund is a separate state funding mechanism that has supported, along with DOE, the multi-institute CETC project initiated in 2016 and led by PNNL. CETC has applied and helped advance some of the state project's Re-tuning concepts.

State Effort to Make Large Commercial Buildings More Efficient Catalyzes into National Re-tuning Approach

Early foundational work in Washington deploys new operational concepts more broadly and inspires groundbreaking DOE research and development that could change the role of buildings in the national energy system.

It started as a relatively modest effort in Washington State to improve the energy efficiency of large commercial buildings. Over time, the resulting methodologies have gained both national attention and federal funding for ongoing development, have established a new model for Re-tuning the operation of buildings to deliver energy and cost savings, and have been embraced by one large municipality for citywide implementation.

Re-tuning is the identification and correction of building operational problems that lead to energy waste. These problems might include heating and cooling systems that are running longer than necessary, or at times when the building is unoccupied. Re-tuning also can be used to coordinate and improve operation of lights, hot water heaters, and other functions.

Large commercial buildings are considered to be at least 100,000 square feet of conditioned space, but more often these structures are 250,000 square feet or greater. They require a substantial amount of energy to stay warm, cool, lighted and functional. Nationally, it's estimated these buildings consume on the order of 40 percent of the total electricity. And while most possess a building automation system (BAS) that manages operation of a range of equipment and devices—such as HVAC systems, hot water heaters, lights, and other functions—often the BAS capabilities are not commissioned, maximized, or maintained in a manner to achieve optimum energy efficiency. It's estimated as much as 30 percent of electric energy is wasted because of inefficient building operations—which subsequently also contributes to shorter operational lifespans for equipment and devices that must run for longer periods of time. While it indeed is possible for poorly performing building systems to meet functional needs and maintain occupant comfort expectations, the added wear and energy costs caused by sub-par performance may prove very high.

"Just like cars, buildings benefit from tune-ups. Significant energy savings are possible if all commercial building owners periodically look for and correct operational problems such as air-conditioning systems running too long."

Dr. Srinivas Katipamula, Battelle/PNNL

As part of the state project, Battelle outlined a building system Re-tuning plan to target low or no-cost improvements to large commercial buildings, which consume a significant portion of the state's electricity. The plan focused on leveraging a proven method that had been developed and tested by Battelle during and after the 2000-2001 energy crisis and resulted in the successful Re-tuning of 25 military and federal buildings on the West Coast. Funded by DOE-FEMP, the method effectively reduced electricity consumption in the participating buildings. The procedures were later adopted by FEMP and rolled out as the DOE ALERT program, in which Battelle became the lead training and implementation organization.

Battelle's plan involved transferring the knowledge and methods from the military project and other energy efficiency efforts to two types of entities. The first was property management, real estate and similar companies, which provided both a ready stock of large commercial buildings with BASs and in-house technicians to perform system tuning and maintenance. The second target audience was service firms—such as HVAC repair shops—that offer fee-for-service maintenance. Through the state project, these firms' employees could learn new skills and leverage the training to provide a beneficial and appealing new service to a range of building owners and operators.

Ideally, the state project's approaches would help generate a cadre of trained technicians, an increasing number of better-performing buildings across Washington, reduced energy consumption, and perhaps even economic development contributions.

Recruitment of Service Providers Begins

In 2006, after the State Attorney General's office concurred with Battelle's proposal and an approximate two-year implementation plan, Battelle developed training materials, including the Six Steps of Re-tuning framework (see related article on this page), and began seeking companies across the state to participate in Re-tuning courses.

Initial participants in the courses included:

Organization/Company & Location	Description of Company
McKinstry - Seattle	Provides consulting, construction, energy and facility services at multiple locations around the nation.
CBRE real estate services and investment - Seattle	Delivers a range of property management services nationally and globally.
Apollo Heating and Air Conditioning - Kennewick	Provides HVAC service in southeastern Washington.
Siemens - Seattle	Offers technical services to large commercial buildings.

As part of the state project, and to support building owners/operators and service technicians in their Re-tuning activities, Battelle staff adapted and enhanced the Energy Charting and Metrics (ECAM) tool, an add-on for Microsoft Excel®. ECAM enabled technicians to analyze building data and the trend logs from BASs.

Prior to the initiation of technician training, Battelle staff obtained and analyzed data for each building identified for Re-tuning, to gain a better understanding of existing performance and efficiency. Discerning the "personality" of a building can be crucial to developing the appropriate improvement strategies.

The training itself included one-day classroom sessions in which Battelle instructors provided basic Re-tuning tenets, followed by up to two days of practical work in the field. Once this phase was completed, the trainees conducted Re-tuning on their own. Battelle staff remained accessible to answer questions and help troubleshoot.

The training was well received by participants, and eventually 26 buildings were re-tuned during the project. It's likely that as technicians continued to apply their skills, additional buildings were tuned and benefited from system and control improvements, though the project did not capture these statistics.

A Step-By-Step Re-tuning Framework

During the early work of the state project, Battelle developed "Six Steps of Re-tuning," a framework that guides technicians in the assessment and enhancement of building performance. The steps are:

- Collect Initial Building Information
- Pre- Re-tune (collect and analyze data)
- Conduct Building Walk-Down (get to know the building)
- Re-tune Building (identify and correct operations problems)
- Conduct Post Re-tuning (report re-tuning findings)
- Perform Savings Analysis (determine and report impacts).

This approach reflects the Battelle-developed "data-driven" Re-tuning process that involves gathering data from building automation systems, followed by analysis and development of Re-tuning strategies. The icons shown here were used in lesson materials to help reinforce the process.

Classroom training, supported by field work, is a central focus of Re-tuning activities.

Observation-driven Re-tuning Developed

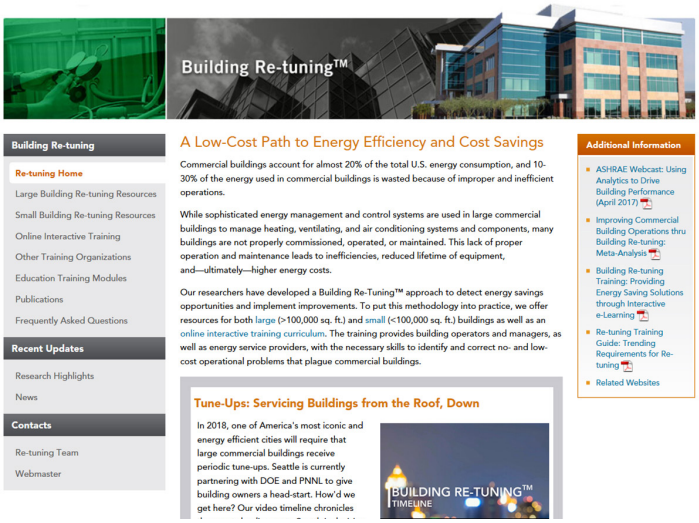
During the training phase for large commercial building Re-tuning, Battelle staff were periodically asked what could be done to improve performance in buildings that do not possess automation systems. Battelle subsequently developed "observation-driven" Re-tuning methods. Focused on smaller buildings without BASs, the observation-driven method is a prescriptive approach and included a set of basic steps to improve operation, such as adjusting programmable thermostats for better performance, and identification and repair of holes and penetrations in walls and window seals.

Observation-driven Re-tuning is now viewed as a viable and effective method for boosting efficiency and, in fact, this methodology was incorporated in later DOE-funded work. The approach also was adopted by the City of Seattle as a means for buildings of less than 100,000 square feet to comply with a citywide building tune-up ordinance launched in 2018.

Website Offers Information and Facilitates Training

As part of the state project, a Re-tuning website was established at **https://buildingretuning.pnnl.gov/** to provide ready public access to electronic training and various informational materials. Growing in scope over time and augmented with federal funding, the site now includes a wide range of information, including modules that cover the content of classroom training, and an instructor's manual. The manual helps guide lectures and discussions, and also provides information on how to conduct hands-on, in-the-field training. Since the initiation of the state project, building Re-tuning classroom instruction and field training have been provided to more than 300 operators, engineers, and energy managers from more than 30 organizations.

The state project also led to production of 12 online "training 101" modules that are available to service technicians or any individuals who want to understand more about HVAC economizers, which are central to efficient HVAC operations and save energy through the use of outside air to help cool a building's interior. The modules cover economizer fundamentals, control methods, troubleshooting, maintenance, and more.



The main page of the Building Re-tuning website.

Along with the modules, the state project developed an interactive web-based training program designed to provide the same type of information one would receive in classroom Re-tuning training. It was a solution for those who can't attend a live session, or who want to take a refresher. Congress later, and coincidentally, passed legislation requiring operators of federal buildings to participate in this type of training, and in many cases the operators have accessed the online training to fulfill part of those requirements. Over time, there have been nearly 5,000 registered users, many of whom represent the General Services Administration (GSA) program.

Years after its launch, the website continues to be maintained as a key resource for those seeking tools and materials to guide optimization of building performance.

Re-tuning Expands Nationwide

As the Re-tuning effort for large commercial buildings was executed in Washington State, the methods and results gained national visibility and broader endorsement. DOE, in partnership with Battelle/PNNL, pursued Re-tuning as a tool for addressing inefficiencies in building energy consumption across America and, in 2009, targeted American Recovery and Reinvestment Act (ARRA) funding to continue the research and advancement of Re-tuning strategies.

The ARRA-funded work, which was conducted by PNNL, operated under the same two basic principles as the state project: Recruit participants that own, manage, or operate multiple buildings, and train technicians to provide Re-tuning services. Initial participant organizations included the City of Boston, MA; the City of Denver, CO; and the City of Houston, TX; as well as private-sector firms such as CBRE; Jones Lang LaSalle; and Johnson Controls. Training components, for the most part, transitioned intact from the state project to the national effort. However, the curriculum was continually adapted and sharpened as PNNL learned more about the practical application of Re-tuning and received feedback from participants. Following training sessions in 2011, online surveys were conducted. Participants were asked a variety of questions about the quality and effectiveness of the training, and gave high marks. More than 80 percent agreed or strongly agreed that the technical level of the courses was appropriate, that they gained new knowledge, and they would use that knowledge in their day-to-day work.

Since the conclusion of ARRA work, DOE and other federal agencies have provided ongoing funding to advance Re-tuning strategies and methods. To date, approximately 75 buildings have benefitted.

New Tools Advance Automated Re-Tuning

The nationwide expansion of Re-tuning has benefitted from the development of two technologies that built upon and now far exceed the original ECAM tool's capabilities and bring improved automation to the process.

- **The Open Energy Information System**—"OpenEIS" derived from early Re-tuning development efforts in Washington State and ECAM, and was created by PNNL with support from Lawrence Berkeley National Laboratory (LBNL) and funding from DOE. This open-source data analysis and diagnostics platform provides standard methods for authoring, sharing, testing, using, and improving algorithms, or sets of computer codes that carry out specific actions to achieve enhanced building operations. Under OpenEIS, building operators manually gather operational data from the BAS, and then submit the data to the OpenEIS tool, which performs analysis via proven algorithms and diagnostics. Designed as a periodic check on building performance, the tool can identify a wide range of control and system issues that need to be adjusted to enhance operational efficiency. It's a particularly effective method for individual buildings, and provides useful information for building operators considering more expensive and intensive retro-commissioning of equipment and systems. Additional information on OpenEIS is available in the Re-tuning Technologies section of this document.
- **VOLTTRON™-based tool**—This latest advance deploys algorithms to detect, diagnose and, in some cases, self-correct operational problems.

The algorithms are incorporated into VOLTTRON, a distributed sensing and control software platform developed at PNNL, and integrated with a BAS, automatically gathering building operations data and providing a continuous monitoring capability that identifies performance issues. This tool cannot fix broken systems, but, for instance, it can autonomously correct issues such as incorrect heating and cooling schedules. The methodology was further developed and improved through the PNNL-led Clean Energy and Transactive Campus project, an effort jointly supported by Washington State's Clean Energy Fund and DOE. This tool is particularly effective for a group of buildings, such as a campus, due to its automated data-gathering capability.

Moving Forward

The national expansion of—and interest in—Re-tuning has led to advances in new knowledge, actual energy savings, and a better understanding of what this methodology could accomplish for the nation.

- In approximately 100 buildings involved in Re-tuning activities over the course of the state and national projects described in this report, almost all demonstrated significant potential to save energy (from 5 to 30 percent) by making simple changes to controls.
- The **Consortium for Building Energy Innovation** produced four detailed case studies in 2016. Re-tuning outcomes were documented for: A research building on the Georgia Institute of Technology campus in Atlanta; an office building and courthouse annex operated by the GSA in Washington, D.C.; and an office building in Dallas, Texas. Electricity savings ranged from about 10 percent to well over 20 percent for three of the four buildings.
- The study, "**Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction**," issued in 2017, concludes that taking basic steps to improve operational systems within offices, schools, and commercial structures could reduce U.S. energy consumption so dramatically that it would equate to 12 to 15 million Americans stopping their energy use altogether. The study was funded by DOE's Building Technologies Office and conducted by PNNL.

GSA Embraces CORe Concept in Buildings

The state program also influenced the development of Controls Optimization and Re-tuning, or CORe, a process requested by the GSA and developed by PNNL to improve the operation of federal facilities managed by the GSA. To date, PNNL has deployed CORe to tune many million square feet of these facilities, which range from small commercial buildings to skyscrapers. The Re-tuning has yielded tangible results—energy savings of more than 12 percent, on average, in facilities from which data was collected during subsequent PNNL site visits. In addition, PNNL provided Re-tuning training to building energy, management, and operations and maintenance staff, which included creation of long-term monitoring plans for buildings to make sure that Re-tuning progress is maintained.

Seattle Adopts Re-tuning Tenets

Inspired by Re-tuning successes, the City of Seattle municipal government has adopted a "**Tune-Up**" **mandate** for many large nonresidential buildings within the city (see related article on next page). PNNL provided technical support to the city during development of the mandate, and the OpenEIS tool was enhanced and updated to help facilitate the city-scale effort.

Study Finds Seattle Ordinance Will Cut Energy Use

PNNL, with funding from DOE, conducted a study that projects the potential energy savings from the Seattle Tune-Up ordinance. The study was a customization of a broader national study that simulated various Re-tuning-related measures implemented in buildings, and examined the ability of the measures to achieve energy efficiency and demand response (a technique that coordinates electricity use to balance power grid operation).

Along these lines, the study not only estimated impacts on building energy consumption, but lower peak electricity demand.

Seattle's climate was factored into the study, which looked at nine types of buildings from three perspectives: an efficient building with modern systems, a typical building, and an inefficient building. Potential energy savings were projected in all three categories; but taken as a whole, the study found that, on average, energy consumption could be reduced from four percent to 20 percent for electricity, and 20 to 65 percent for natural gas.

It Started in Washington State. . .

The key elements of the original large-building-focused effort in Washington State, launched in 2006, have experienced acceptance and expansion across the nation and now, with the Seattle mandate, essentially come full circle with large-scale implementation of Re-tuning in the Northwest's largest city.

The initial state project has delivered far-reaching, positive impact that will continue to influence energy efficiency methods in large commercial buildings nationwide.

Seattle Promotes Building Efficiency Through Tune-Up Program

The City of Seattle's Building Tune-Ups **Ordinance** aims for high-performance buildings with reduced emissions, lower utility bills for consumers, and more green jobs. Adopted in 2016, the new requirement went into effect January 1, 2018, with a gradual, rolling implementation. The rule applies to many large nonresidential buildings (50,000 gross square feet or greater) within the city.

Under the ordinance, affected owners and operators are required to tune building energy and water systems every five years. According to the City's **Office of Sustainability & Environment**, the requirement's goal is to optimize energy and water performance in buildings through low- or no-cost actions related to building operations and maintenance. Such actions can generate energy savings of 10-15 percent on average.

The Tune-Ups legislation is a key piece of Seattle's Climate Action Plan, the City's roadmap for achieving carbon neutrality.

Small Buildings: Genesis of a Low-Cost Smart Building Technology for Condition-Based Maintenance

A strategy to meet the unique operational needs of small buildings leads to the development of a promising tool that has been successfully tested in several U.S. locations and has yielded market-worthy algorithms.

In the state project, Battelle set out to establish a new paradigm in Washington for improving the energy efficiency, operation and lifetime of the systems that provide heating and cooling to small commercial buildings of 50,000 square feet or less. But what started as a limited deployment of a sensing and control technology in one state could, in the future, deliver much broader energy-efficiency impacts for small commercial buildings nationwide.

In Washington and across the U.S., HVAC systems represent a significant portion of electricity consumption and costs in small commercial buildings. These small structures typically possess several rooftop HVAC units that supply heating and cooling services. Often the units operate independently, without the coordination of a building automation system, and below peak efficiency. Additionally, when inspected after time in service, the units routinely exhibit a panoply of issues, including inoperable dampers, dirty or clogged filters and coils, incorrect refrigerant charges, failing compressors, incorrectly implemented controls, and more.

While the units may still operate sufficiently to meet basic service levels, they may be unable to address heating or cooling needs in severe weather, and/or may consume more energy than they should. These various issues ultimately could lead to a catastrophic, and perhaps unnecessary, failure, and replacement at significant cost. The ability to identify potential operational problems at the point when only minor adjustments to controls or schedules or minor repairs are required can prevent failures and, concurrently, reduce energy costs and extend the lifespan of rooftop units.

Under the state project, Battelle advanced a plan to implement a low-cost fault detection and diagnostics (FD&D) technology—the Smart Monitoring and Diagnostic System (SMDS)—with the purpose of detecting and diagnosing faults in a select number of small commercial buildings in the state. Contained in a small box affixed to each rooftop HVAC unit, the SMDS collects data from sensors monitoring and measuring a range of conditions, applies algorithms to detect and diagnose operational faults and efficiency degradation, and makes the resulting information available to building owners or operators via a cellular network connected to the Internet.

To create the version of the SMDS used for this project, Battelle leveraged and updated earlier work at PNNL under funding from DOE. Deployment of the SMDS devices was further enabled through Battelle-developed training for a select, recruited group of service providers in the state. The training was designed to help technicians not only learn about the SMDS capabilities, benefits, installation, and service techniques, but to show these individuals how they might apply the knowledge to provide the service in the future.

Feedback from service providers proved critical to the evolution of the SMDS. The initial multi-sensor configuration measured a variety of conditions, ranging from air temperatures and fan status, to overall power consumption of the RTU; but service providers, by and large, felt a need for fewer diagnostic details and more straightforward information that would enable them to quickly identify a fault, understand its potential cost, and determine whether a repairman needs to be dispatched. They also found the tested version of the SMDS hardware, with each unit costing up to $1,500, too expensive.

As is often the case with research and development, learning what works—and doesn't—provides the key information that refines and advances ideas to the next step and, ultimately, useful technologies. Outcomes from the state project were central in PNNL's efforts to secure additional DOE funding to further improve the SMDS. A more streamlined version resulted, involving use of fewer sensors and costing less than $600 per device.

Over time, DOE has continued to support development and deployment of the technology, which could become a key resource for increasing efficiency in buildings and reducing power consumption. In later work in 2014, two versions of SMDS were tested—an actual hardware package installed on rooftop units and an application that employs off-the-shelf components and Cloud-based data processing. Field tests were conducted on rooftop units in buildings in Puerto Rico, Maryland and New York. The testing successfully identified operational degradation and associated additional electricity costs, as well as performance faults.

The Cloud-based SMDS technology also was deployed in the DOE-funded Transactional Network Project, which involved seven rooftop units at LBNL in California and four units at Transformative Wave in Washington State, evaluating the technology's performance-degradation detection methodology.

The latest advancement of SMDS capabilities has been funded through DOE's Small Business Vouchers Pilot, a program in which PNNL is working with JouleSmart.

"We learned a lot in the state project. We leveraged the funding, and evolved the technology and outcomes to where they have a better chance of succeeding more broadly."

Dr. Michael Brambley, Battelle/PNNL

The joint effort supports the commercialization of a variety of algorithms designed to detect efficiency degradation, issues with properly calibrating economizers, and various operating problems associated with HVAC equipment.

The early work in the state project has helped to bring more federal funding to the region and lay the groundwork for SMDS's future emergence as a leading technology for making the nation's small commercial buildings more energy efficient.

Outreach to Educational Institutions Builds Awareness of Re-tuning Benefits

State community colleges and K-12 schools gain improved understanding of energy efficiency and contemporary methodologies.

One of the state project's objectives was to ensure that Re-tuning methods and outcomes be communicated beyond a relatively small group of participating technicians and building managers or owners. An education component was incorporated into the project, with a focus developing visibility and awareness, particularly with post-secondary institutions that likely would have vocational training programs and students seeking a career path in HVAC service or building energy management.

The project reached out to community colleges across the state, identified representatives pertinent to Re-tuning subject matter, such as instructors teaching building-focused courses, and began holding periodic meetings. Initially conducted at PNNL, the gathering rotated to various campuses. The resulting consortium, which involved as many as 25 individuals, proved very beneficial. While project leaders provided information and materials that could be used in classrooms, the community college representatives themselves found the networking aspect—talking to each other about what they were doing in buildings-related disciplines—highly productive. The meetings continued for several years and expanded knowledge of best practice methods for improving building operations and associated energy efficiency.

The project also sought to develop courses that could be instituted in secondary and post-secondary schools to enhance the training of next-generation building service technicians. This venture proved difficult, due to the multiple administrative steps that must be taken to incorporate new curricula at an educational institution. However, the community college representatives agreed to integrate into their courses pertinent state project-developed information and materials that naturally intersected with their existing lessons.

While development of actual courses proved challenging, the project experienced moderate success in increasing energy efficiency awareness in the kindergarten-12 student community. In the early years of the state project, and based on guidance from teachers and school district curriculum developers, energy efficiency lesson plans were developed that supported the Washington State Science Learning Standards and the Washington State Integrated Environmental and Sustainability Education Learning Standards.

In 2010, through the Battelle/DOE Academies Creating Teacher Scientists (ACTS) program, two teachers, from Richland, WA, and Wendell, ID, respectively, were engaged to assist in the development of lesson plans for grades kindergarten through eight. The plans were delivered to teachers to obtain constructive feedback on the content, but it also was hoped the information would be integrated into lessons, so as to convey energy efficiency tenets to students.

Further, Battelle trained teachers in a three-hour workshop titled, "Save Energy-Everyday-Everywhere for Grades 3-5," in November 2010, as one of the Content Series provided by the partnership between Leadership and Assistance for Science Education Reform (LASER), Educational Service District (ESD) 123, and Battelle's Pacific Northwest Division Science & Engineering Education program. The electronic training files were housed on a website that enabled teachers to communicate with each other and Battelle's energy scientists/engineers. Also, a "lending library" was established to provide schools access to various tools that could be used to expand upon written lesson materials.

Because of the limited funding and scope of the K-12 effort, it is difficult to discern its level of impact on students and teachers. However, the information and materials provided to teachers provided baseline information that likely was and could continue to be used for a variety of classroom lessons.

Outreach to a National Audience

Broader national Re-tuning visibility and interest presented additional outreach opportunities. Dr. Srinivas Katipamula, who played a leadership role for Battelle in the state project and also is a noted expert for his research at PNNL, was featured in a national webcast, "Take Control: Using Analytics to Drive Building Performance," on April 20, 2017. The three-hour event was sponsored by ASHRAE—the American Society of Heating, Refrigerating and Air-Conditioning Engineers. During the webcast, Dr. Katipamula and the other experts defined the importance of better building operations through improved controls and analytics, and how this approach can benefit the nation.

State Project Contributes Technologies to the Re-tuning Toolkit

Improvements and new tools continue to advance more efficient and effective methods in the effort to improve building performance and increase energy efficiency

Three key technology resources that enable Re-tuning have been developed or partly developed through state and DOE support.

ECAM—The Energy Charting and Metrics Tool is an add-on for Microsoft Excel® and was developed to facilitate analysis of data (energy and other) from buildings. ECAM, which was the initial technology used in the state project, makes extensive use of Excel pivot tables. ECAM capabilities were updated and enable:

- Creation of charts that assist Re-tuning
- Development of schedules and day-type information to time series data
- Filtering of diverse data types
- Normalization of data and creation of metrics based on consumption or equipment
- Development of various load profiles or scatter charts for data selected by the user
- New additions to the PNNL Re-tuning charts
- New modeling and verification for meter data.

To facilitate use of ECAM, the state project created a three-part webinar series. The webinars provide detailed installation assistance, demonstrate tool capabilities for analysis of metered electrical and end-use data, and familiarize the user with ECAM's methodology and functionality.

Open Energy Information System—"OpenEIS" was the next-generation tool used in the state project. It was created by PNNL with support from LBNL and funding from DOE, and is an open source analysis and diagnostics platform that analyzes building energy and operational data—at low cost or no cost—to identify improvement opportunities. The software allows users to merge data from multiple sources and obtain a uniform data set. Further, the platform provides standard methods for authoring, sharing, testing, using, and improving algorithms for operational building energy efficiency. To use OpenEIS, building operators gather operational data from a BAS, and then submit the data to OpenEIS, which applies proven algorithms and diagnostic capabilities to perform analysis. Although OpenEIS was initially developed for building systems, it can easily extend to analysis tools for other types of systems and devices where data is trended. The state project did not play a central role in development of OpenEIS, but facilitated integration of Re-tuning algorithms into the tool.

VOLTTRON™—This distributed sensing and control platform was developed as part of PNNL's Future Power Grid Initiative, a five-year effort focused on establishing capabilities in data management, simulation and visualization to help operators, planners and policymakers fully comprehend and use the 21st century grid. VOLTTRON has become a groundbreaking, nationally- and internationally-recognized technology that continues to grow in its applications for the grid, buildings, and buildings-grid integration. When integrated with a BAS, the technology and associated algorithms automatically gather building operations data and provide continuous monitoring that identifies performance issues and corrective actions. While VOLTTRON was not developed as part of the state project or for Re-tuning purposes generally, technical needs that were surfaced during the project, along with lessons learned, have helped influence and shape VOLTTRON as a more diverse and effective tool for Re-tuning applications.

A Building Re-tuning Timeline

This timeline conveys a fascinating evolution: In less than a decade, the state project moved from Re-tuning of multiple buildings in Washington State to inspiring national-level interest in the approach and its subsequent deployment. It's expected that Re-tuning will continue to grow and expand as a high-impact, energy-saving methodology.

2000
Electricity crisis spurs early building Re-tuning version

2006
Battelle coins six-step building Re-tuning process; develops training

2007-2009
Battelle pilots Re-tuning for large commercial buildings in Washington State

2010
General Services Administration initiates Re-tuning in its buildings

2011
PNNL/DOE release free online training, start nationwide train-the-trainer sessions

2012
DOE creates consortium to expand in-person Re-tuning training

2014
DOE funds PNNL and LBNL to develop OpenEIS platform

2015
PNNL analysis finds 5-30% in savings for commercial office buildings with automation systems

2015
Researchers at PNNL develop algorithms that automate identification of Re-tuning measures (AIRx)

2016
AIRx deployed on PNNL's campus, allowing continuous building system monitoring

2016
Seattle announces tune-up mandate for many buildings

More details about the Re-tuning timeline are available at:

https://buildingretuning.pnnl.gov/highlights/highlight.asp?id=2628

Publications

Advances from the state project and subsequent federally-funded activities have been documented and published in a wide range of journals and proceedings.

Journal Articles

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September 2018