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Introduction

Chairman Murkowski, Ranking Member Cantwell, and Members of the Committee, thank you for the opportunity to testify in today's hearing on efficiency in building management and control systems.

My name is Jud Virden and I am the Associate Laboratory Director for Energy and Environmental research at the Pacific Northwest National Laboratory (PNNL) in Washington State. PNNL is a U.S. Department of Energy (DOE) multi-program national laboratory stewarded by the Office of Science.

My comments today will focus on:

1. The importance of advanced building management and control technologies to the U.S. electric sector and economy.

2. PNNL's unique expertise and experience in improving building energy efficiency using building controls and pioneering research exploring the combination of advanced building controls and coordination of building energy assets with the electric grid.

3. Technology gaps and key future research and development (R&D) directions.

Importance of advanced building management and control systems—achieving energy efficiency and grid integration

In the United States there are approximately 125 million homes and more than five million commercial buildings. Nearly 75 percent of all U.S. electricity is consumed within these buildings. Electricity goes to functions such as air conditioning, heating and lighting, but increasingly buildings will also use electricity to charge electric vehicles and will generate and store electricity onsite with resources such as solar photovoltaic arrays and batteries.

The energy resource represented by these commercial and residential buildings is tremendous. PNNL recently completed an analysis for DOE's Building Technologies Office—within the Office of Energy Efficiency and Renewable Energy—which estimates that implementation of advanced building control technologies and related energy efficiency measures could reduce commercial building energy consumption by up to 29 percent. This study also showed that commercial and residential buildings could be operated in ways that would reduce peak electricity demand by 19 percent without disrupting the comfort of building occupants or key building functions, representing a resource that could be used to increase the reliability and resiliency of the electric grid at times of peak electricity demand. [Source: S. Katipamula "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction." May 2017.]

However, tapping that resource requires new technology that can automatically operate numerous devices. For example, energy consumption in commercial buildings is associated with space heating (25 percent), space cooling (9 percent), lighting (10 percent), refrigeration (10 percent), ventilation (10 percent) computers and office equipment (8 percent), cooking (7 percent), water heating (7 percent), and other uses (13 percent).

The key is control and optimization of each of these energy-consuming systems within every building, continuous control of multiple buildings, and automatic coordination of large numbers of buildings in response to signals from utilities asking to manage electricity consumption at various times of day throughout the year. This can be accomplished through new technology, and much of that new technology will be made possible by changes that have already revolutionized technology in other fields—low-cost sensing and measurement devices, information technology, and burgeoning connectivity of devices to communication networks and the Internet. In the vehicle industry, for example, the integration of new information technologies and unprecedented computing capabilities is revolutionizing the performance and automation of cars. We need to enable and accelerate this revolution for buildings.

The deployment of sensor and information technology in buildings and the grid—both highly complex systems—will generate large amounts of data. This massive data set must then be converted into useful information allowing us to measure, monitor, and control building energy use, grid operation, and the interaction between buildings and the grid in a secure environment. As such, ***the science and technology challenge for the foreseeable future is***:

> ***Developing novel approaches for integrating large amounts of data with new advances in analytics (such as machine learning), combined with high performance computing, and advanced control theories for extremely complex systems.***

PNNL experience—achieving energy efficiency and buildings-grid integration with advanced building control systems

Over the past 15 years, PNNL has been at the forefront of research focused on buildings, grid operation, and buildings-grid integration, supported by funding from DOE's Buildings Technologies Office, the Office of Electricity Delivery and Energy Reliability, the Office of Science, and other agencies. PNNL has teamed with other national labs—including the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Lawrence Berkeley National Laboratory—universities, and industry to demonstrate the art of the possible and translate it to practical applications. In the last 10 years, this research has led to 56 copyrights, 38 patents granted, and 68 technology licenses to U.S.-based companies. During the last year alone, PNNL had 219 publications featuring new research in these fields. Moreover, this research has resulted in significant new technologies, including:

- An agent-based distributed sensing and control software platform that enables collection of performance data from various building devices and systems, application of new diagnostic and control methods to optimize building performance, and a secure means of exchanging information between devices, between buildings, and between building and the grid;

- An incentive-based control methodology that combines concepts from economics and the field of control theory to optimize the operation of multiple buildings and coordinate their response to signals received from the electric grid; and

- A suite of software tools for simulation of advanced control approaches involving tens of thousands of buildings over very large geographical areas, integrating and synchronizing independent simulators of the various elements of grid operations (e.g., a feeder, a distribution system consisting of many feeders, and multiple distribution systems, as well as the many buildings connected to them).

Technologies—such as those described above—have enabled PNNL to develop and refine new control strategies and perform a variety of experiments involving building optimization and building-grid integration, including several pioneering field experiments, described below.

Building Energy Efficiency Optimization. *PNNL performed a roof top unit energy saving validation—integrating a PNNL open-source software platform for distributed control and sensing to optimize unit energy use.* Packaged air conditioners and heat pumps—also known as roof top units—are used for 60 percent of all cooled commercial buildings. They serve almost 70 percent of cooled commercial building floor space and represent 15 percent of U.S. commercial building energy consumption. Most roof top units operate with motors and fans that run at a constant speed. With support from DOE's Building Technologies Office, PNNL, Bonneville Power Administration, and Transformative Wave Technologies (located in Kent, Washington) teamed to show the energy savings that could be realized if constant speed fans were replaced with variable speed fans and linked to advanced control algorithms. After testing 66 roof top units on eight different buildings, set in eight different climate zones, the study showed an average 57 percent energy savings. [Source: W. Wang "Advanced Rooftop Control (ARC) Retrofit: Field-Test Results." July 2013.] This technology is particularly important as it addresses the small- and medium-sized commercial buildings that represent 60 percent of the existing building stock and 60 percent of commercial building energy consumption.

Buildings to Grid. *Olympic Peninsula Project—responsive building loads to improve grid reliability and resiliency*. One of PNNL's first experiments that evaluated the benefits of integrating responsive loads to improve grid reliability and resiliency took place in the Olympic Peninsula of Washington State. The primary issue was a 750 kilovolt transmission line that was constrained during winter peak periods, leading to voltage instability and the possibility of collapse. Building a new transmission line or new generation was not a viable option at the time; a non-wires approach was needed. The team, led by PNNL, included Bonneville Power Administration, three local electric power providers, IBM's Watson Research Laboratory, Invensys Controls, and Whirlpool Corporation. The project showed that an incentive signal sent to 112 homes with smart thermostats and appliances, along with two diesel generators—located at commercial building sites—and five municipal water pumps in the region could reduce peak load. The key R&D achievement was accumulating data showing that congestion stresses on a transmission line could be relieved using "smart" loads that respond to an incentive signal from the grid. Over the course of a year, the project resulted in average 15 percent reduction in peak load, up to a 50 percent reduction in total load for short periods, and approximately 10 percent average customer savings. [Source: D. Hammerstrom "Pacific Northwest GridWise™ Testbed Demonstration Projects." October 2007.]

Grid Benefits from Responsive Loads. *Pacific Northwest Smart Grid Demonstration Project—application of interoperable communication and control infrastructure using incentive signals to coordinate a broad range of customer and utility assets.* This project, supported by DOE's Office of Electricity Delivery and Energy Reliability, engaged multiple types of assets across a broad, five-state region and reached from generation through customer delivery. Assets included demand response, distributed generation, energy storage, and distribution automation. The project installed 30,696 smart meters—27,376 residential, 2,961 commercial, 359 industrial—and 12,822 feeder monitors for identifying fault locations, collecting over 350 billion data records over the course of the project. At the end of the project, participating utilities reported that smart meters eliminated 2,714 service calls, saving $235,000 annually. Reliability enhancements included 17 percent fewer outages, 12 percent shorter outages, and 353,336 avoided outage minutes. Fault detection reduced outage time from 119 minutes to just 51 seconds. [source: D. Hammerstrom "Pacific Northwest Smart Grid Demonstration Project Technology Performance Report." June 2015.] In just one community—Fox Island, in Washington State's Puget Sound—the local utility installed modules in 500 homes to help curtail the load of electric water heaters. During this project, one of the two cables providing electricity to the island failed, leaving the local utility with only with only 50 percent of its usual capacity. The utility was able to engage the modules to manage load throughout the winter—its peak demand season. The utility leveraged direct load control to turn water heater controllers on or off, preserving energy and avoiding power failure on the island.

Integration and Optimization of Multiple Buildings. *PNNL Campus Testbeds—integration of low cost sensors with open-source platforms, data analytics, and novel control algorithms to reduce energy across multiple buildings and reduce peak demand charges.* PNNL's Richland, Washington campus uses 94,000 megawatts of electricity at a cost of $4.9 million per year. In any given year, 30 percent of this cost is peak demand charges, reflecting consumption that in some way stresses the grid. With support from DOE's Building Technologies Office, the Office of Electricity Delivery and Energy Reliability, and the Washington State Clean Energy Fund, PNNL is using information from 9,000 sensors deployed in 12 of our buildings in addition to advanced control algorithms that manage how our campus uses energy. The instrumentation on our own campus generates 11 million data records per day, and more than 34 billion in the 18 months over which we've been conducting experiments. Our researchers apply several hundred different diagnostic algorithms to this data to monitor performance, identify and prioritize needed corrections, and initiate control actions that manage energy consumption. To date we have shown that we can reduce peak energy consumption by 10 to 20 percent in several buildings and have identified a number of operational changes to permanently reduce average energy consumption. We have also been developing and testing methods for managing building energy consumption as a response to a grid "service" request (e.g., a request from our utility to reduce load by a given percentage to reduce stress on the grid). We hope PNNL will become a national test bed available to all government agencies and private industry to increase building efficiency and improve grid reliability and resiliency.

In addition, PNNL has partnered with universities to extend the impact of our research. Washington State University is focusing on using on-campus generating and storage assets to provide power to critical City of Pullman, Washington assets—such as the city hall and police station—during sustained outages. The University of Washington in Seattle, Washington, is leveraging advanced data management and cloud-based data analytics to extend the suite of analytic capabilities available to support optimization of building operations. Case Western Reserve University is reviewing PNNL experiments, enhancing models and methods, and is replicating key PNNL experiments for validation. The University of Toledo is applying PNNL-developed control methodologies to coordinate building loads and batteries with a one megawatt photovoltaic array to mitigate stresses to the local grid resulting from variations in solar plant generation.

Technology barriers, research and development directions

I mentioned earlier that future building systems require technology that is low-cost, turn-key, interoperable and cyber-secure. In order to realize this goal, automated data collection, predictive data analytics, and real-time sensing and control solutions are needed. Specifically this entails:

- **Automatic collection of big data needed for optimizing building operations.** Today this is not available in 85 percent of commercial buildings and virtually all residential buildings. This limits the ability to optimize building performance and is a major barrier to providing information about building energy consumption status to the electric grid.

- **Advanced data analytic and machine learning.** New analytic methods are needed to convert building operational data into information that enable new insights about building performance and new, automated control actions.

- **Advance control theories.** The convergence of new sensing technology and much more affordable computing capacity can now support new, advanced control methods that were unimaginable before. Many theories are emerging, with early results suggesting great promise, but the complete suite of methodologies and the underlying theories are not yet adequately developed and have not been experimentally validated.

- **Stakeholder engagement.** DOE, national laboratories and industry stakeholder groups should work together to define mechanisms to address two barriers that, if removed, would accelerate innovation. The first is definition and consistent implementation of best practices as "default" control conditions rather than tailored solutions. The second is achieving the level of interoperability necessary to accommodate the anticipated profusion of connected devices that will reside in buildings all of which must be addressed by control and optimization systems.

- **Cybersecurity best practices.** Public-private partnerships should be created to help ensure that cybersecurity is built into all new systems and that appropriate cybersecurity best practices are developed and adopted by industry stakeholder groups. Further, such partnerships could define and implement risk-based approaches that address all aspects of the industry—from product development and integration and operation, to maintenance and "patching" of legacy systems. By considering the complete lifecycle of products, best practices can be used to add cybersecurity awareness, education, training of workforce, and supply chain of building automation products.

Conclusion

More advances in science and technology are required to capitalize on the coming technology and information revolution in buildings. Integrated and coordinated R&D will enable:

- Building systems that will be continually monitored and automatically optimized, a key step toward reduced building operating costs, and long-term energy savings while maintaining occupant comfort;
- Building systems that will be more resilient to off-normal events;
- The integration of large numbers of buildings over wide geographic areas, which in turn enables coordination of building loads with the grid at scale; and
- Security and resilience for all parts of the system.

Thank you again for the opportunity to testify on this important topic. I would be happy to answer any questions you may have.