U.S. Department of Energy's Advanced Sensing and Controls for Energy Efficient Buildings: A Cross Cutting Project

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ABSTRACT

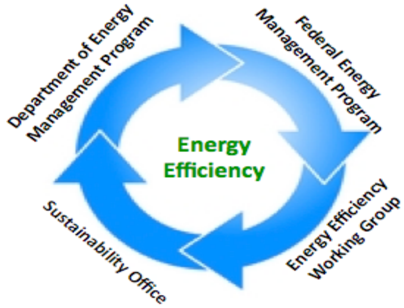
The Department of Energy (DOE) Industrial Technologies Program (ITP) is widely recognized for its contribution to bringing the wireless revolution to the industrial marketplace. The result has been the commercialization of wireless sensors that are meant for the industrial setting. The DOE Building Technology Program's (BTP) emphasis on developing technologies and methodologies that will provide significant energy savings in buildings has instituted a program that is focused on adapting the ITP-sponsored wireless sensor results into an inexpensive, robust system that is tailored to energy-efficiency optimization of commercial building operation. The BTP project includes a demonstration facility where the developed sensors are integrated into the existing building automation system. While private sector building optimization efforts are underway, their "focus" is not addressing the practical needs for inexpensive, wireless sensors tailored to monitoring parameters for HVAC optimization as well as parameters that directly impact the occupants' comfort. The development of the crosscutting ITP+BTP sponsored activity described in this paper leads to the possibility of a change of culture in the perception of a "living building" that can meet the need for reduction in energy usage while enhancing the occupants' comfort while in the building. The presentation will discuss the technology developments, demonstration results, energy savings for widespread adoption of the developed systems, and examination of the culture change associated with an energy-efficient "living building".

Introduction – The Role of the Government

Every perceived direction in post-industrial society confirms the logic – it's time to become energy efficient. Be it commercial, residential or industrial in nature, the numbers – both economic measurements and the slightly more intangible carbon footprint estimates – reveal how energy efficiency can be sustained and how the rewards of doing so are not intangible. In terms of federal facilities, a number of executive orders and acts have been issued to provide specifications and targets for the energy efficiency of such sites. The Energy Independence and Security Act of 2007 [1], the Energy Policy Act of 2005 [2], and Executive Order 13423, Strengthening Federal Environmental, Energy, and Transportation Management [3], combine to present the mandate that more widespread and deeper energy efficiency improvements in both existing and new federal facilities and activities is necessary. The demonstration of Federal commitment to efficiency, increased use of renewable energy sources, advanced utility metering and other practices, as well as procurement of energy-efficient equipment is economically prudent and wise.

In an attempt to provide a coherent policy for the aforementioned Acts and Orders, the DOE has initiated a coordinated suite of programs and activities that are directly applicable to improvement of energy use.

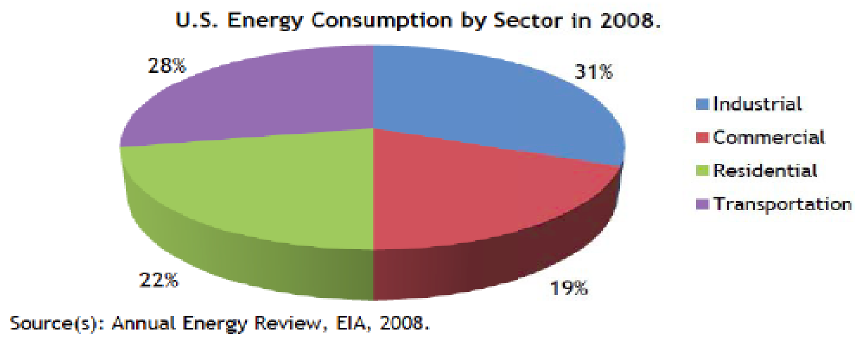
Figure 1. Coordinated Programs for Energy Efficiency



Through this effort, DOE is attempting to steer the nation's energy efficiency effort by providing specific tangible guidance for individuals who have to their facility's energy efficiency.

The motivation for this development effort is, as shown in Figure 2, the commercial sector consumes approximately 19% of all energy used in the U.S [4]. Improvements in energy efficiency in commercial buildings have a direct impact on the nation's energy usage and reliance on energy imports (which currently exceed $1B/day).

Figure 2. Energy Consumption, Circa 2008

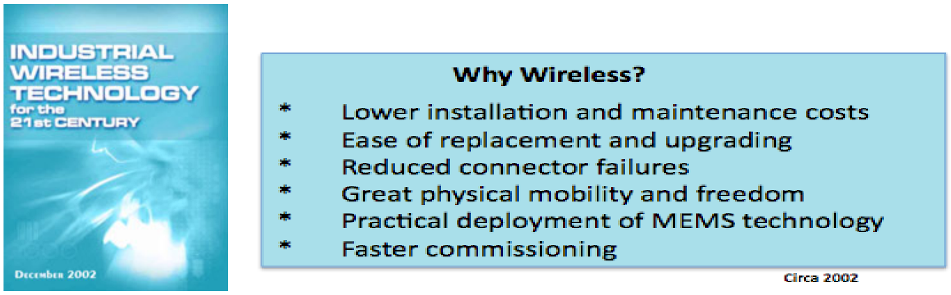


DOE Building Technologies & Industrial Technology Cross Cutting

A collaborative effort between DOE-Building Technologies and DOE-Industrial Technologies programs regarding wireless instrumentation for energy efficiency in both sectors involves taking ITP-sponsored activities and leveraging the efforts into the public and private sector to decrease the cost of devices and systems that are used in commercial buildings. Discussions with owners and operators of such buildings show that if a wireless sensor - easily deployed and measuring parameters to allow for quick and efficient commissioning of building systems - has a low cost (~$20), then deployment could be widespread leading to significant energy savings in the commercial building sector [5].

Discussions on low cost, high volume (and high deployment) wireless sensors dominated the DOE/ORNL Future of Instrumentation workshop discussions [6]. The low cost requirements from the commercial building sector, versus the intrinsically safe / explosion proof, high price tag wireless sensors needed in the industrial sector, implies that there is a need for quicker to produce devices (volume). The design and development of such low cost, high volume wireless sensor systems will bring Moore's law volume pricing / performance increases to engage in the wireless sensors arena. The net result is a paradigm shift for the industrial world with the entry of “Peel and Stick” inexpensive sensors that are meant for rapid deployment with the ease of use required for commercial buildings that is considerably different from the long-lived, very expensive wireless sensors deployed in the industrial sector. The discussions from the 2010 Future of Instrumentation workshop reinforced the findings reported in [7].

Figure 3. The Findings of a 2002 DOE-ITP Workshop on Industrial Wireless Technology are Relevant in circa 2011



This DOE workshop led to the creation of a standard for industrial wireless technology, ISA100 (www.isa.org/isa100). ISA100 Work Group 8, End Users, has been vibrant in providing guidance to the major automation companies as to what the wireless device should be able to do (measure vibration, etc). They have also continued to examine the impediments to the adoption of wireless, a set of quasi-guidelines for technical, logistical, reasonable issues are impediments to the widespread adoption of wireless devices).

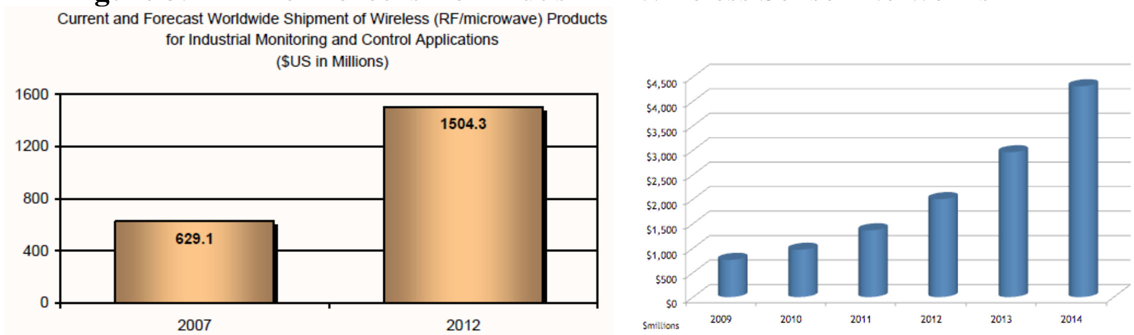
While ISA100 was originally chartered to examine the industrial sector, the scope has expanded to include the commercial buildings. A reexamination of the barriers to adoption was conducted with representation from both the industrial sector and the building technology sector. With a target goal of deploying wireless sensors and systems in industrial settings, the ISA100.WG8 findings pertaining to impediments to adoption of wireless technology, as reported in their 2009 WG Report [8] are presented as Figure 4.

Figure 4. Adoption of Wireless Technology in the Building and Industrial Sectors have the Same Barriers

Barriers to Achieving the Targets					
R&D Funding/ Collaboration	System Vulnerability	Regulatory Standards	Technical	Culture	Cost
• Lack of formal process for scaling up lab technologies/ addressing key needs • Need to foster business partnerships to advance technology • Adequate funding for R&D • Need greater participation by sensor manufacturers • Lack of integrated, dual perspective: technology and application areas - plus IT	• System vulnerability concerns • Vulnerability to intentional jamming, industrial espionage, etc.	• Lack of well-written standards that promote inter-operability • Spectrum policy—FCC allocation of open spectrum • Regulatory agencies	• Increased energy density and power density of power sources • Unproven immunity to RF interference • Possibility of new devices interfering in broadband • Lack of objective measurements for various aspects of systems	• Impacts on maintenance workers (job security) • Technical training needed for workforce • Requires change of culture/attitude • Compatibility with legacy systems (integration) • Lack of industry confidence (end-user through supplier) • Complexity of the technology • Public perception of privacy implications	• Perceived higher cost • Need to generate demand among end-users • Lack of material to help convince management of value • Lack of end-user understanding of value proposition • Lack of certification plan or government clearinghouse

Various reports on the industrial wireless sensor network market forecast have been developed. Adoption curves, such as that presented as Figure 5, predict increasing use of wireless devices [9, 10].

Figure 5. Market Forecast for Industrial Wireless Sensor Networks

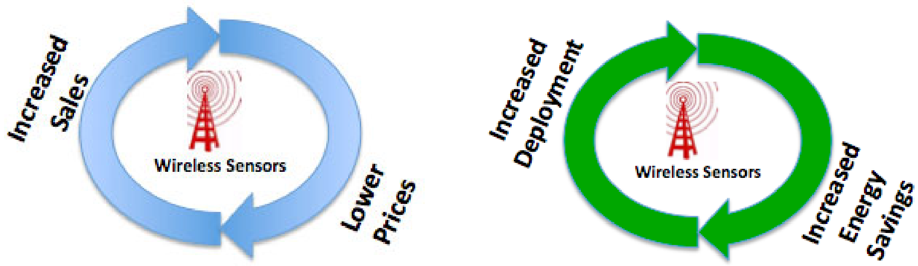


The underlying data upon which Figure 5 is based is dominated by deployment of wireless sensors, with a cost of approximately $1600, in the petrochemical arena which places a number of packaging requirements (explosion proof, intrinsically safe) on the deployed devices and systems. US-based, multinational companies are currently dominant in this market, but the total volume of sales is in the tens of thousands – not enough to have significant impact on either employment or energy use reduction in the nation. In addition, the total balance of system cost (device+installation) of wireless sensors is approximately three times (3x) the wireless sensor (circa 2011) cost. Coupled together, this is an overall price envelope that is unacceptable for wide-scale adoption within the building (commercial and residential) arena.

A "Johnny Sensor Seed" Deployment Strategy

The industrial market price of wireless sensors and systems is simply too high for wide scale adoption in the building sector. Representatives of commercial buildings have described their needs for assistance in devices that can aid in (retro)commissioning (specifically) and energy efficiency (in general), but at a price point (<$20 for a device and installation) that is palatable for wide scale deployment. The joint BTP+ITP activity aims at taking device and systems that were initially tailored for the industrial setting and develop easy-to-deploy, inexpensive wireless sensors for the commercial buildings sector. With their Moore's law volume and pricing, low-cost wireless sensors are suitable for a "Johnny Sensor Seed" deployment model. From a technology transition perspective, as the sensors and communications advance, the price point for such "Peel and Stick" wireless sensors means that the devices are so easy to use and deploy that they are essentially expendable (less expensive to simply replace rather than take down and redeploy) – a point that was vetted at the Future of Instrumentation meeting with both End Users and vendors. The core tenet for the drive for an inexpensive sensor is that as adoption rapidly increases the price per device will decrease, depicted in Figure 6. With increased deployment in commercial buildings comes energy efficiency optimization for the same structures leading to increased energy savings for the building owners/operators. With the advent of such an inexpensive wireless sensor and easy to deploy model, the cost is so low that individuals will continue to sow sensors into the same location and ignore the sensors that are no longer working, sprinkling them around areas where sensor visibility will provide financial benefits.

Figure 6. Adoption Drives Lower Costs Which Drives Adoption. Similarly Increased Deployment Increases Energy Savings Which Increases Deployment



Prototypes of such easily deployable (magnetic mount), small form factor, battery/energy harvesting powered wireless sensors, developed in a DOE-BTP funded project, are shown in Figure 7. The wireless sensors shown are from Left-to-Right: wireless temperature+humidity sensor, deck of cards (for scale), wireless temperature and chemical sensor, miniaturized wireless temperature+humidity+seismic sensor, AA battery (for scale)). These devices are within 3-4x of the target price point and have embedded intelligence to allow easy integration into new and existing Building Automation Systems (BAS). Using current informatics for the analysis of potentially high volume wireless sensor systems leads to applications where trends in the measured values may reveal predictive maintenance indicators, such as correlations between sensor readings across a geographical area; or correlations between BAS operations across facilities revealing optimal settings for similar structures.

Figure 7. Prototypes of Inexpensive, High Performance Wireless Sensors Developed in the ITO-BTP Effort

In a control model, where the sensors' readings are used to commission and optimize the energy efficiency of heating and cooling systems in light commercial buildings, the low cost, easy to deploy wireless sensors are in essence network-centric collaborative devices. They self-assemble, create an intelligence, determine an answer, pass the answer up to control system, then disassociate. Their role may be very short lived (e.g. for commissioning) or longer lived (used for ongoing optimization of the energy profile) which plays into the natural obsolescence of devices (the "Peel and Stick", "Johnny Sensor Seed" deployment strategy of throw-away priced sensors).

The idea of a "Johnny Sensor Seed" deployment model is not novel to the BTP project. In fact the cover of an issue of The Economist [11] (presented as Figure 8) illustrates the concept. The companion special report discussed the benefits and various technical challenges associated with ubiquitous wireless sensors. Coupled with a special issue pertaining to ubiquitous smar sensing [12], the net result was the possibility of a substantial improvement in energy efficiency in buildings and structures (including residential) with the availability of wireless sensors having the attributes discussed earlier in this paper.

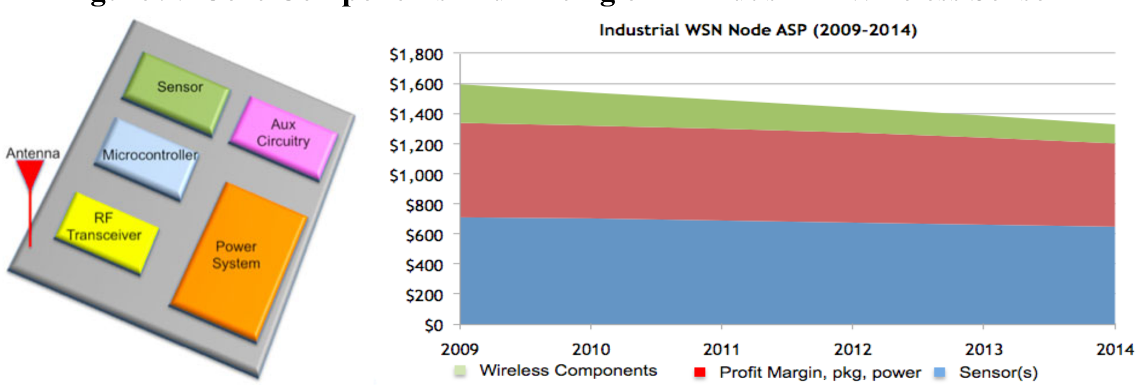
Figure 8. Cover of The Economist Special Issue on Wireless where a New Model of Sensor Deployment is Described as "Johnny Sensor Seed"

Wireless, Wired, Sensors in Industrial and Building Settings

There has been a fundamental acceptance of certain flavors of wireless technology worldwide, most notably cellular and Wi-Fi (802.11) with over 2 billion cellphones and 500 million wi-fi devices currently. While various sociological studies have reported on the reasons why individuals are so accepting of wireless [13] -the most common reason is the most obvious: ease of mobile communications, the second being social networking. Hidden in the increased deployment of wireless for personal communications is the fact that the user has been conditioned to – and is tolerant of - having to redial/reconnect on dropped calls and the variability in Internet communications.

The industrial sector has demanded very high levels of communication "availability", in essence, zero downtime. With such demands comes a high price charged by vendors and suppliers of such equipment, shown in Figure 9. For the commercial building sector, the parameters to be measured for increased energy efficiency include: temperature, humidity, light level, CO2, electrical current signatures, air flow, damper position. The sensing accuracy needs to be "pretty good" (typically 1-2% [14]) – which reduces the sensor component cost – with the BAS (or similar software component) using statistics to determine average readings. This method is comparable to a biological paradigm where a "census study / population study" is used rather than relying on individual sensor (which also becomes a single point of failure).

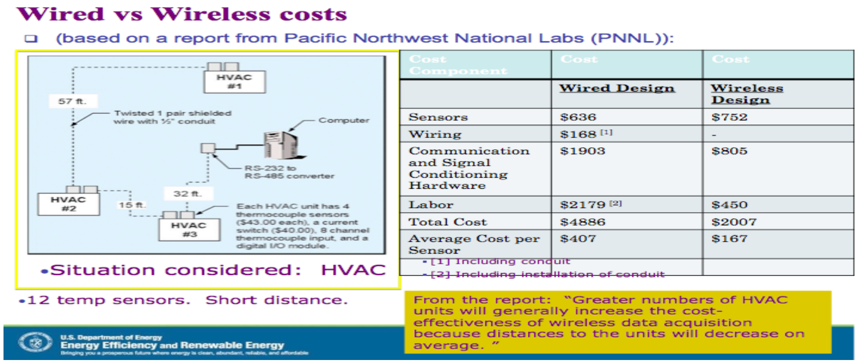
Figure 9. Core Components and Pricing of an Industrial Wireless Sensor



(Source of Pricing Information: OnWorld Industrial Wireless Sensor Networking report, 2010)

Figure 9's data is based on information provided by the major automation companies. In consort with surveys conducted by the Wireless Industrial Networking Alliance (www.wina.org) and ISA100 WG21 (Industrial Asset Tracking), the Building Technology project determined that using consumer-off-the-shelf (2011) components and devices, the cost for the sensors required for commercial wireless sensors are in the ~$10 range with a comparable cost for the wireless (RF transceiver) and microcontroller.

Figure 10. PNNL Study, Circa 2006, Showing Wired and WIRELESS costs for HVAC Installations



Cost Component	Cost	Cost
	Wired Design	Wireless Design
Sensors	$636	$752
Wiring	$168 [1]	-
Communication and Signal Conditioning Hardware	$1903	$805
Labor	$2179 [2]	$450
Total Cost	$4886	$2007
Average Cost per Sensor	$407	$167

• [1] Including conduit
• [2] Including installation of conduit

While the PNNL study referenced in Figure 10 showed that it is economical to use wireless devices for HVAC monitoring, DOE-Building Technology has a target price of substantially less than even the $20/device mentioned earlier – with an ease of deployment that drastically reduces the $450/device labor cost shown in Figure 4: namely, <$5/device.

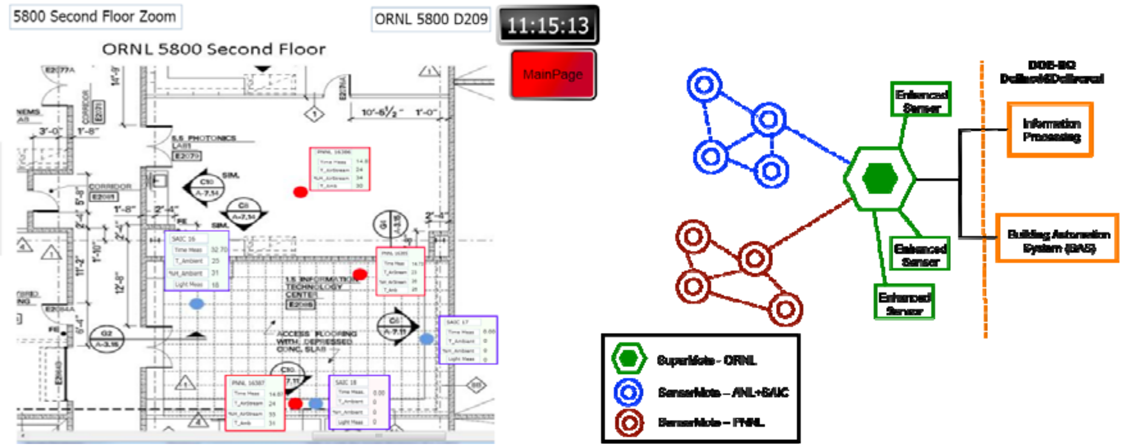
Such a radical change in pricing requires that the fabrication of wireless sensors leaves traditional methods and evolves to "printing" of wireless sensors. DOE-ITP is investigating such trends to ascertain how to leverage private sector developments to the fabrication of ultra-low-cost wireless sensors.

Striving for Demand-Based Control and Market-Based Grid Responsiveness

This network of devices then allows the building owner or operator to fine-tune their operation to provide an acceptable level of performance (temperature distribution, humidity control, lighting control) that is adjustable (e.g., the sensors indicate that Room xyz is vacant, therefore it is acceptable to turn-off/dim that room's lighting plus also vary air flow to that room). There are a multitude of scenarios where the BAS becomes an economic information center (EIC) informing the owner / operator of the energy cost that the building is incurring at that moment. The human decision-maker can then assess the EIC information, align it to realtime energy pricing information, and make market-based decisions pertaining to energy consumption responding to pricing fluctuations in the energy grid.

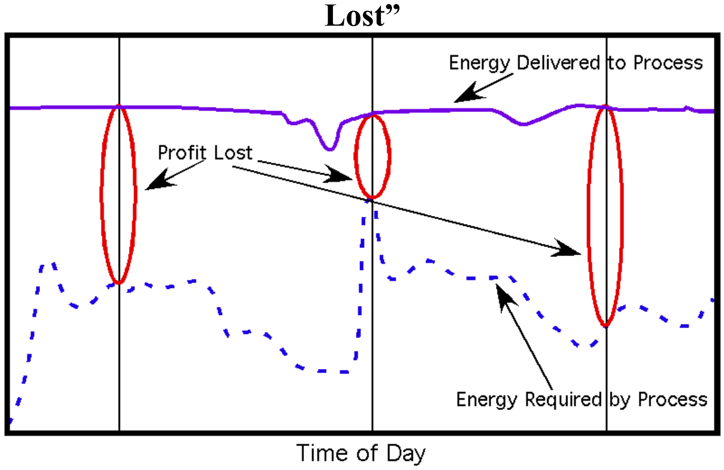
The BTP project's developed system architecture, shown in Figure 11 along with a screenshot of the visualization of live sensor readings, illustrates how measurements from wireless sensors (in this case designed and built by different DOE national laboratories), deployed in varying locations are assembled in one location, augmented by additional information, then passed on to a BAS and a parallel information processing system for analysis and delivery to the owner / operator.

Figure 11. Building Technology System Readings and Architecture



The reason as to why a building owner uses inexpensive, easy to deploy wireless sensors is illustrated in Figure 12. As the processes used in the facility (a manufacturing line, a commercial building, an industrial setting) change their power consumption profiles during the day, the energy delivered to the process may be reduced from a near-constant state to a demand-based state. The energy saved equates to an increase in profit (decrease in energy expenditure). The funds may be used for a multitude of actions including possible expansion of the facility's work force.

Figure 12. The Difference between Energy Delivered and Energy Represents a "Profit Lost"



The possibility of inexpensive wireless sensors with actuation capabilities (i.e., devices which are able to respond to control signals) opens the possibility for demand-based control of commercial buildings which, in turn, reduces this wasted energy expense.

Summary

The effort reported involved the leveraging of wireless devices and system developments initially begun for the industrial sector (ITP) to the building sector (BTP). While certain operational and deployment factors differ between the two settings (such as explosion proof, intrinsically safe devices not required in the vast majority of commercial buildings), lessons learned in the ITP sponsored work helped guide the BTP sponsored activities in delivering high performance, inexpensive wireless sensors. Devices were deployed at ORNL in a proof-of-concept demonstration. The designs are to be distributed to all interested parties for private sector adoption, fabrication, and offerings providing the commercial sector with rugged, inexpensive wireless sensors that will help the owners and operators reduce their energy losses and provide them with the measurements necessary for increased energy utilization optimization.

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