FEMP
Technology Installation Review
A New Technology Demonstration Publication
DOE/EE-0319
Federal Energy Management Program

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Wireless Temperature Sensors for Improved HVAC Control

An assessment of wireless sensor technology

Executive Summary

This *Technology Installation Review* describes the installation of a wireless temperature sensor network at the U.S. Environmental Protection Agency (EPA) National Health and Environmental Effects Research Laboratory in Duluth, MN. The objective of the wireless sensor demonstration was to showcase the technology so the experiences with the technology and benefits of the project may be replicated throughout the federal sector.

A wireless temperature sensor network, consisting of 37 sensors, 3 repeaters, 1 receiver and 1 integration module, was installed and integrated into the facility's Johnson Controls Metasys® building automation system (BAS). The entire installation was performed in one day with the help of one Pacific Northwest National Laboratory (PNNL) staff member and a Johnson Controls contractor.

The wireless sensor technology functioned flawlessly during the 7-month demonstration (March through September 2005). The total cost for the installation, including hardware and labor, was estimated to be about $190 per sensor when purchased through a controls vendor. The wireless temperature sensors measured primarily zone temperatures and provided valuable insights into the HVAC operation, which led to the following operational improvements: 1) Because of the ease of moving a wireless temperature sensor, inaccurate existing temperature sensors can easily be identified. EPA found a faulty temperature sensor during system setup. 2) EPA staff felt sufficiently confident to increase the zone set-point temperature because, with a wireless temperature sensor in every office, they had the ability to monitor the zone air temperature and watch for excessive temperatures. EPA initially reset the zone temperatures by 2-degrees Fahrenheit and made this change permanent after a few days of monitoring.

One of the outcomes from this demonstration project is EPA plans to incorporate wireless sensors for HVAC control in the EPA architectural guidelines. In addition, EPA shared the successful demonstration project in an article published in the December 2005 issue of Energizing EPA, the EPA Office of Administration and Resources Management's newsletter on Energy Conservation and Sustainable Facilities.

Introduction

This Technology Installation Review describes the installation of a wireless temperature sensor network at the U.S. Environmental Protection Agency (EPA) National Health and Environmental Effects Research Laboratory in Duluth, MN. Discussed are the lessons learned during the deployment and use of the technology, as well as operational and energy improvements attributable to the use of the wireless technology. The demonstration was funded by the U.S. Department of Energy, Federal Energy Management Program (FEMP).

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

The objective of the wireless sensor demonstration was to showcase the technology so that the experiences with the technology and benefits of the project may be replicated throughout the federal sector. While energy savings are expected, the main goal was to demonstrate the functionality and enhanced capability available through the use of wireless sensors. The EPA's Mid-Continental Ecology Division National Health and Environmental Effects Research Laboratory, in Duluth, MN, provided an excellent demonstrationsite because of the committed engagement by the building management and EPA's energy managers. EPA reviewed the applicability of wireless sensors for building operations for incorporation into the EPA's architectural guidelines. EPA is expected to modify its guidelines to encourage wireless sensors (see http://www.epa.gov/greeningepa/facilities/index.htm).

On March 10, 2005, Pacific Northwest National Laboratory (PNNL) staff visitedthe EPA facility in Duluth and, together with EPA facility contractors, installed and fully integrated 37 Inovonicswireless temperature sensors into the building automation system.

Facility Description

EPA's Mid-Continental Ecology Division National Health and Environmental Effects Research Laboratory, in Duluth, MN, hosted the demonstration of wireless sensors for improved HVAC control. The primary mission of the laboratory is to provide research support to various EPAs offices. The facility is located on the east side of Duluth, about 300 feet, from Lake Superior. The facility's total floor area is about 90,500 ft^2, with research laboratories, office space and a conference center. The wireless PROGRAMsensor technology demonstration was limited to a section of the main building, see Figure 1.

The EPA site was built in 1967. There have been two additions to the main building; the first in 1984 adding 2000 ft2, and a second in 2001 adding 13,000 ft2. A side view of the main building is shown in Figure 2.

Description of the Wireless Technology

The wireless technology used in the demonstration project is the wireless temperature sensor solution from Inovonics Wireless Corporation.[1] The technology encompasses temperaturetransmitters, repeaters, usually one receiver, and one integration module

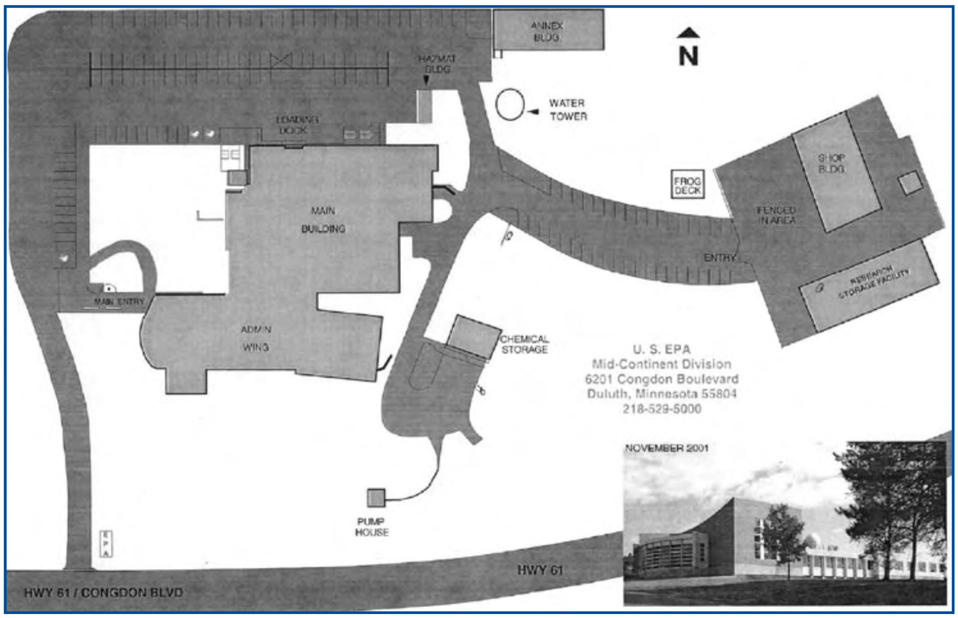

Figure 1. Map of EPA Facility in Duluth, MN..

Figure 2. View of the Main Building, seen from its northwest corner.

[1] More information can be found at http://www.inovonics.com.

(called a translator). The technology connects the wireless temperature sensors to a Johnson Controls N2 network [Johnson Controls, 1996]. The individual components of the wireless temperature network are shown in Figures 3, 4, 5 and 6.

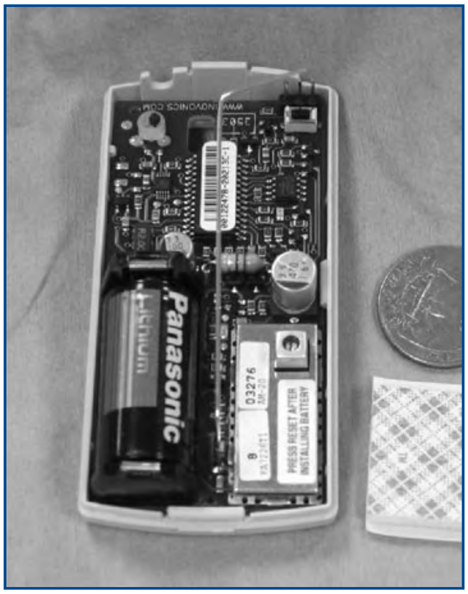

Figure 3. Battery-powered transmitter.

Figure 4. Repeater in NEMA Box with backup battery and power adapter.

The operating frequency of the wireless network is 902 to 928 MHz, which requires no license per FCC Part 15 Certification (FCC Part 15, 1998). The technology employs spread spectrum frequency-hopping techniques to enhance the robustness and reliability of the transmission [Weisman, 2002].

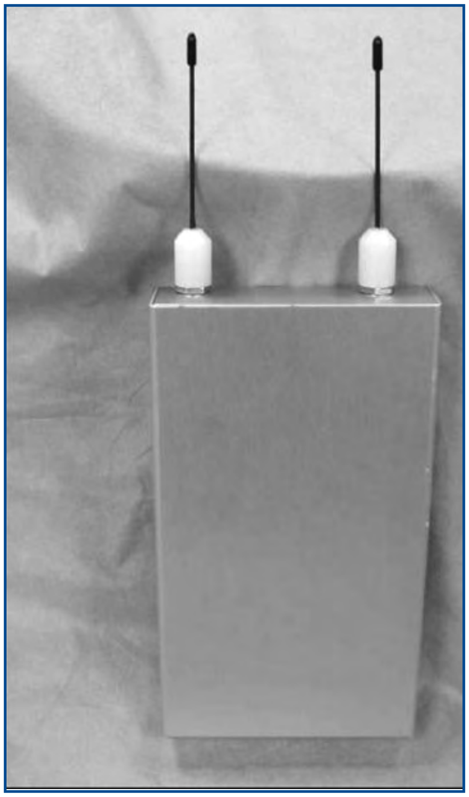

Figure 5. Receiver. (The receiver is connected to the translator shown in Figure 6. The receiver is powered by the translator.)

Figure 6. Translator.

The transmitter (shown in Figure 3) has an open-field range of 2500 feet and is battery-powered with a standard model 123, 3-volt, $LiMnO_2$ battery with a nominal capacity of 1400 mAh. The battery life depends on the rate of transmission, which can be specified in the transmitter. The manufacturer estimates the battery life up to 5 years with a 10-minute update rate. The transmitter has a battery test procedure with a "low-battery" notification via the wireless network. This feature will alert the facility operator through the BAS that the useful life of the battery in a specific transmitter is approaching its end. The temperature sensor uses a 10-kΩ thermistor. The operating range is between -13- and 140-degrees Fahrenheit. The temperature sensor accuracy is ±0.3-degrees Fahrenheit.[2]

The repeater is powered by the 120-volt AC from the wall outlet, with a battery backup (see Figure 4). The repeater operates at higher output power than the transmitters and, thus, extends the range to 4 miles in open field.[3] The repeater receives transmitter signals and amplifies each received signal. No setup is required for the repeater, other than connecting the power adapter and the backup battery to the respective terminals in the repeater.

The receiver (shown in Figure 5) is powered by the translator. The receiver communicates all recognized temperature signals to the translator via an RS 232 serial link. Signals that are not recognized to be compatible with the temperature sensor product line are suppressed in the receiver.

The translator is physically connected to the receiver and the N2 bus via a three-wire RS 485 cable, as illustrated in Figure 6. The primary function of the translator is to communicate the received temperature signals to the BAS via the N2 bus. To be recognized by the BAS on the N2 bus, the translator emulates N2 devices. Up to 100 N2 devices can be represented by each translator. For wireless networks with more than 100 temperature sensors, an additional translator, including a receiver, is necessary. The translator requires a brief setup

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[2] Derived from the device accuracy performance characteristics obtained from Inovonics.

[3] While the transmitters have an open-field range of 2500 feet, building structures will limit the useful range within the facility. Repeaters are used to ensure signals make it to the receiver.

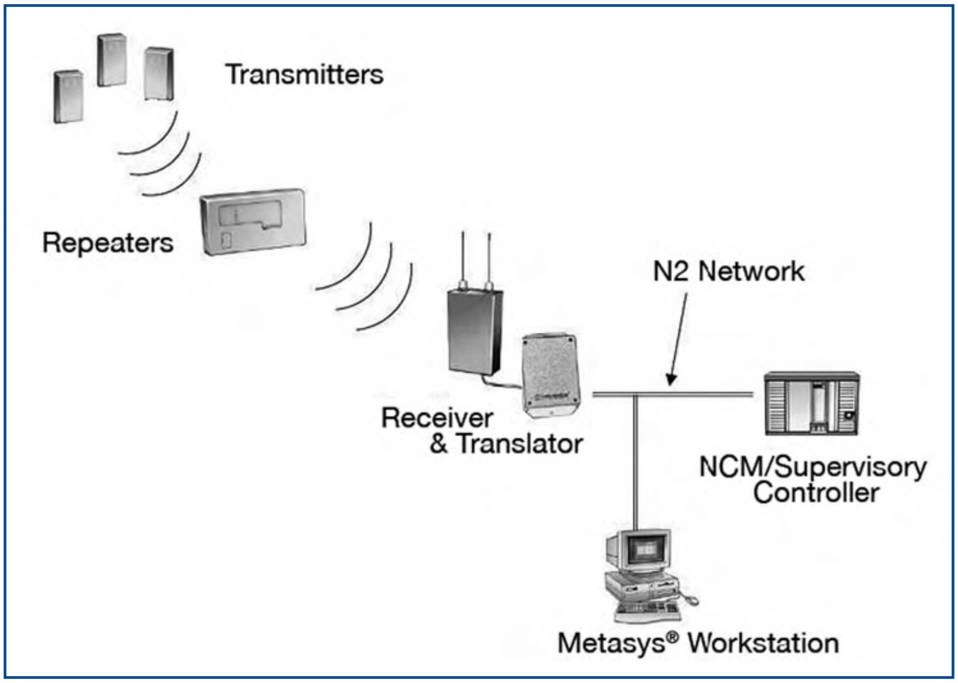


Figure 7. Wireless Temperature Sensor Network Integration into the BAS.

that registers the available temperature transmitters on the wireless network and allows the operator to assign specific names to each temperature sensor. Each temperature sensor must be registered in the translator for the BAS to recognize the temperature sensor. The configuration of the translator is performed using Inovonics' ComfortWave™ software, supplied with the translator [Inovonics, 2003]. ComfortWave™ runs on an MS Windows computer and connects to the translator via an RS 232 port (see Figure 6). The translator is powered by a 24-volt AC power supply, which is generally available at an N2 bus control panel. The translator provides 12-volt DC power to the receiver.

Figure 7 illustrates the wireless temperature sensor network integration into the wired BAS.

Facility Description

A total of 37 wireless temperature transmitters, 3 repeaters, 1 receiver, and 1 translator were installed and integrated into the BAS at the EPA facility. The 37 temperature sensors were installed in individual offices and hallways of the two-story Main building (see Figures 8 and 9). The floor is made of re-enforced steel-concrete construction and is generally more difficult to penetrate by RF signals than wooden floor construction. The receiver and translator were installed in the core section of the first floor in direct proximity to the network control module (NCM) for the air-handling unit (shown in Figure 10). Two repeaters were placed at the second floor toward the end of the East/West hallway to amplify the signals from all 2nd floor transmitters, so the repeated signal would reach the receiver on the first floor. Because the receiver was in close proximity to metal piping and metal equipment in the core area on floor 1, a third repeater was installed in the center of the first floor core area to assure sufficient signal strength to the receiver (see Figure 11). Figure 8 and Figure 9 depict the locations of the temperature sensors within the floor space of the Main building. Figure 12 shows a wireless sensor taped to the wall.

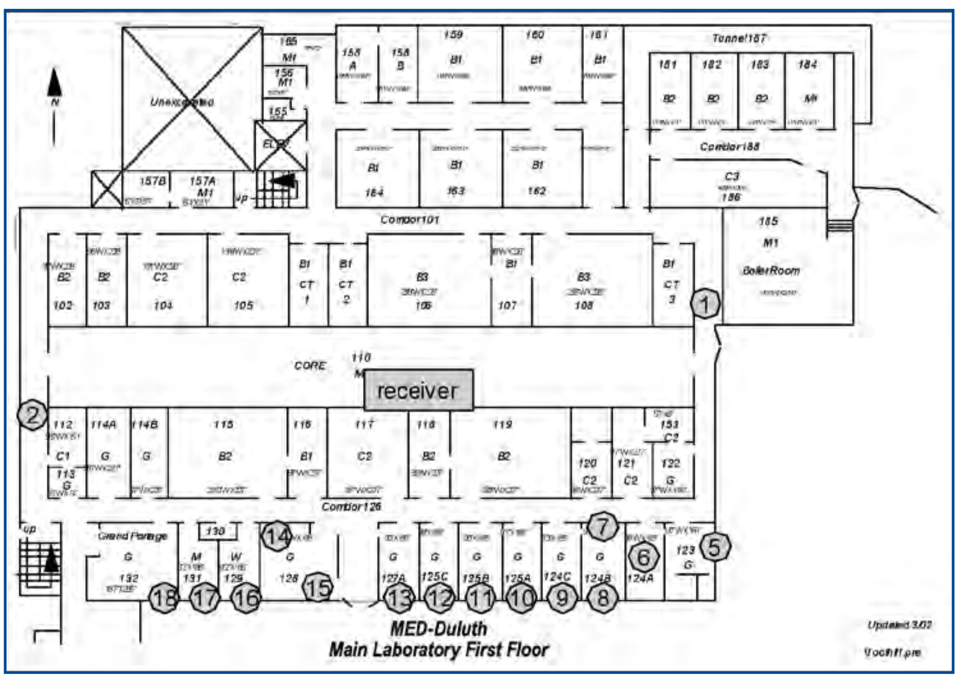


Figure 8. Detailed Layout, First Floor, Main Building.

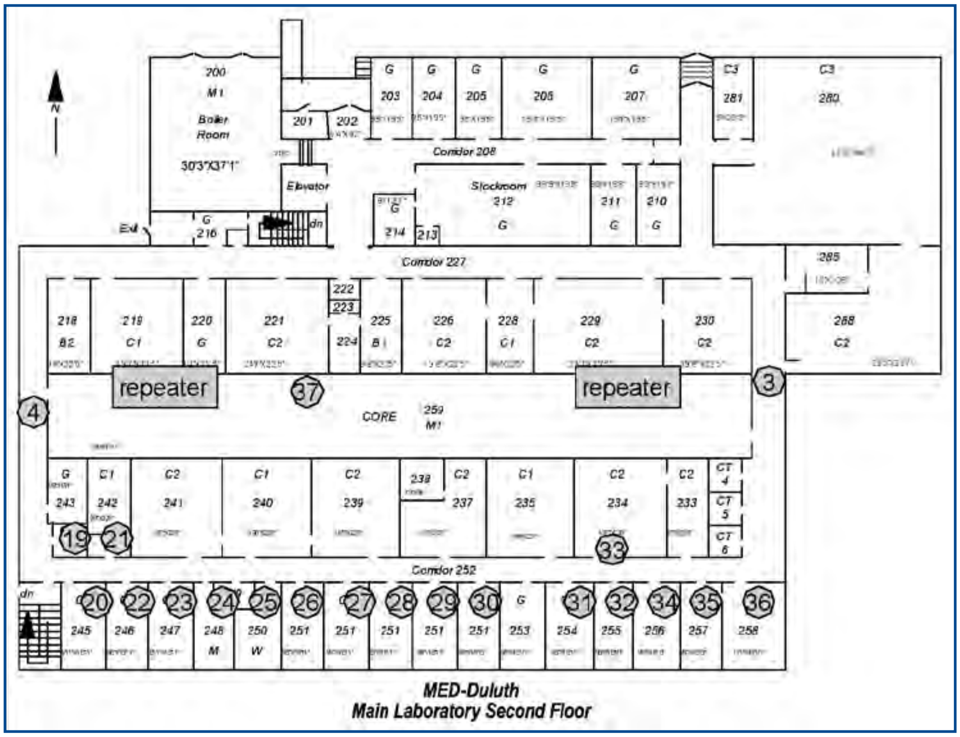


Figure 9. Detailed layout, second floor, main building.

Figure 10. Inovonics receiver and translator integrated into Johnson Controls NCM panel located on first floor.

The transmitters were attached to the walls using double-sided tape, except for four transmitters, which were placed inside fan coil units to measure supply air temperatures. Placing a wireless transmitter inside the metal casing of a fan coil unit significantly reduces the transmission range by shielding the RF signal. However, no degradation of the wireless transmission was noted. All 37 transmitters and 3 repeaters were

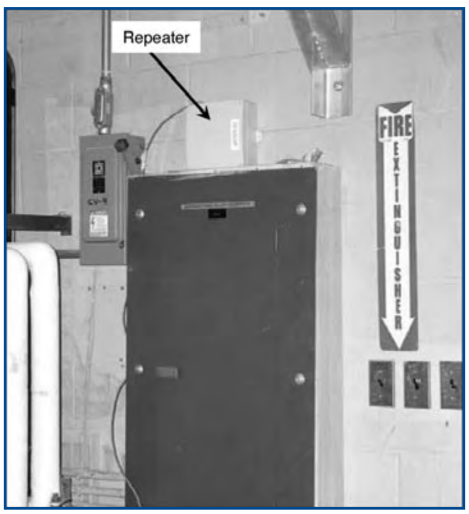


Figure 11. Location of repeater in core area of second floor.

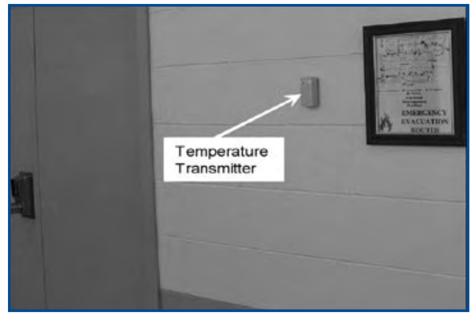
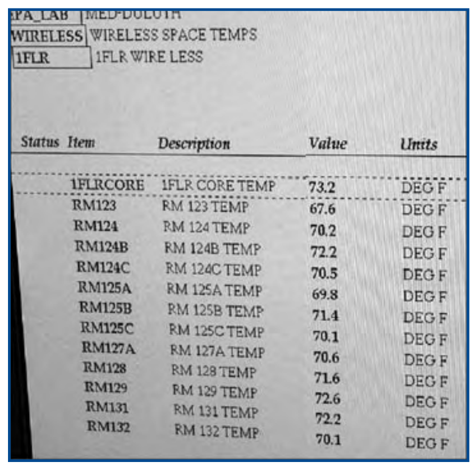


Figure 12. Wireless Temperature Sensor attached with double-sided tape to the wall.

registered in the translator using a laptop with the ComfortWave™ software. The controls contractor configured the BAS such that the wireless temperature sensors were recognized and logged in the system.

Figure 13 shows a sample of temperature readings from the wireless sensors located on the first floor using the BAS.

Analysis of the Operation of Wireless Temperature Sensors



EPA_LAB MED-DULUTH
WIRELESS WIRELESS SPACE TEMPS
1FLR 1FLR WIRE LESS

Status	Item	Description	Value	Units
	1FLRCORE	1FLR CORE TEMP	73.2	DEG F
	RM123	RM 123 TEMP	67.6	DEG F
	RM124	RM 124 TEMP	70.2	DEG F
	RM124B	RM 124B TEMP	72.2	DEG F
	RM124C	RM 124C TEMP	70.5	DEG F
	RM125A	RM 125A TEMP	69.8	DEG F
	RM125B	RM 125B TEMP	71.4	DEG F
	RM125C	RM 125C TEMP	70.1	DEG F
	RM127A	RM 127A TEMP	70.6	DEG F
	RM128	RM 128 TEMP	71.6	DEG F
	RM129	RM 129 TEMP	72.6	DEG F
	RM131	RM 131 TEMP	72.2	DEG F
	RM132	RM 132 TEMP	70.1	DEG F

Figure 13. Setup of wireless sensors.

The evaluation of the wireless sensor technology at the EPA demonstration site addressed the following questions:

1. What is the setup time for the wireless technology? And how difficult was the installation?
2. What is the operational reliability of the sensors and the wireless communication?

3. What are the operational improve ments using the wireless technology at the EPA facility?
4. What is the cost of the wireless technology?
5. What is EPA experience with the wireless technology?

Setup and Configuration of Wireless Sensor Network

In total, 37 temperature sensors, 3 repeaters, and 1 receiver and translator were set up, configured in Metasys®, and tested in one day. PNNL staff familiar with the wireless technology performed the wireless network setup, which consists of:

- Developing a list of locations of wireless sensors. This list is necessary for labeling the transmitter when registered in the translator and when configured in the BAS.
- RF survey of the facility. The result of the survey determines the needs and location of repeaters. Inovonics provides a survey kit with user-friendly instructions. Unless facility staff plan to install Inovonics wirelessproducts themselves, a control vendor will perform the RF survey. The RF survey kit consists of a field-strength meter and a trans mitter that transmits continuously. The RF survey transmitter is placed into the most distant location from the receiver for a prospective wireless temperature sensor. As one walks away from the continuous transmitter toward the receiver, the field strength of the receiving RF signals decreases. The field strength meter will indicate when the range limit is reached, at which point a repeater shall be placed. The RF survey was performed in about 30 minutes for the placement of 37 transmitters.
- Setup of the wireless network including the registration of trans mitters in the translator using Inovonics' setup software.

In total, the wireless network setup took between 4 and 5 hours time to install, set up, configure and test all 40 transmitting devices (37 transmitters and 3 repeaters).

The controls contractors installed the receiver and translator and performed the configuration of 37 temperature sensors, which became new network devices on the BAS network. The contractor also established trend logs for all 37 new temperature sensors and tested the proper communication of all 37 wireless temperature sensors. The contractor started his work after the wireless sensor network installation and setup was completed, and completed the activity in about 3 hours.

In this particular demonstration installation, PNNL provided the wireless technology expertise and performed the setup of wireless sensor network, such that the controls vendor did not need to have any knowledge or familiarity with the Inovonics system. When connected to the BAS network, the Inovonics translator was recognized as a set of N2 devices with characteristics similar to wired analog network devices. The controls vendor did not have problems recognizing and configuring the wireless temperature sensors.

Table 1 summarizes the labor elements of the wireless sensor network installation.

Setup and Configuration of Wireless Sensor Network

Measurements from the 37 wireless temperature sensors were logged in the BAS over a period of about 7 months (March through September 2005). During this period, no problems with the measurement or the wireless communication were detected. We did find nine instances during the entire 9-month monitoring period where the logged data set indicated missing or unavailable data for one 30-minute trending period.

Table 1. Summary of the labor for Wireless Temperature Sensor Network installation.

No	Setup element	Performer	Time estimate
1	Develop list of locations for temperature sensor placements	PNNL and EPA staff	30 minutes
2	RF survey	PNNL staff	30 minutes
3	Registration of all transmitting devices	PNNL staff	2 hours
4	Placement of transmitters and repeaters	PNNL and EPA staff	1–2 hours
Labor for wireless sensor network setup			**4–5 hours**
5	Installation of receiver and translator into NCM panel	Controls contractor	1 hours
6	Configuration of the BAS to recognize wireless temperature sensors	Controls contractor	1 hour
7	Setup of trend logging in Metasys®	Controls contractor	1 hour
Labor for integration into existing controls network			**3 hours**
Labor for entire installation			**7-8 hours**

We determined this to be attributable to the BAS trending procedure and not caused by the wireless sensor network because of the consistency of the missing data.

The wireless sensor network has worked very reliably beyond the monitoring period, which ended in mid-September 2005. This result is consistent with other demonstration installations performed by PNNL.[3]

Operational Improvements

The higher spatial resolution of the zone temperatures provided valuable insights into the HVAC operations, which led to the following operational improvements:

1. Diagnostics capabilities of existing thermostats and temperature sensors. Because of the ease of moving a temperature sensor, inaccurate existing temperature sensors can easily be identified.
2. Control improvements. Thermostat reset in the summer time to a higher set point during the occupied period.

Diagnostics Capabilities

On the first day of testing, EPA staff recognized that one of the existing wired temperature sensors located at the first-floor east hallway was out of calibration or faulty. This problem was recognized by a notable temperature difference between the readings of the wireless and wired sensors that were only one foot apart. EPA staff verified the zone air temperature with a hand-held device and determined that the existing wired temperature sensor was out of calibration by about 7-degrees Fahrenheit. EPA replaced the thermistor of the wired temperature sensor. Both sensors were then in agreement. The resulting energy savings were difficult to estimate, and are probably minimal, because the faulty temperature sensor was in the hallway and did not directly control an occupied office space. However, this example is indicative of diagnostics potential for other existing temperature sensors that may lead to energy savings.

Because of the ease of the placing and removing a wireless temperature sensor, EPA staff configured one spare temperature sensor as a diagnostics sensor to be used for short-term temperature verifications.

Control Improvements

While it was not possible to directly attribute energy savings to the installation of the wireless temperature sensor network at the demonstration site, the added wireless temperature sensors led indirectly to energy efficiency improvements in the facility. EPA performed repair and retrofit work that eliminated concurrent heating and cooling in fan coil units located in several offices. The solution of this energy-wasting problem led to additional discussions of what else could be done with the repaired fan coil units and the wireless temperature sensors. EPA staff felt sufficiently confident to increase the zone set-point temperature because, with a wireless temperature sensor in every office, they had the ability to monitor the zone air temperature and watch for excessive temperatures. EPA initially reset the zone temperatures by 2-degrees Fahrenheit and made this change permanent after a few days of testing. No complaints were received as a consequence of this change. Figure 14 shows the impact to the temperature reset for offices 129 and 131. The thermostatic reset was done on August 20, 2005. The ability to observe zone temperatures office-by-office was noted as a key motivator for exploring creative reset strategies, which in turn may lead to improved energy efficiency. Because air temperatures are available at a high spatial resolution, facility staff are more comfortable experimenting with new control strategies, such as more

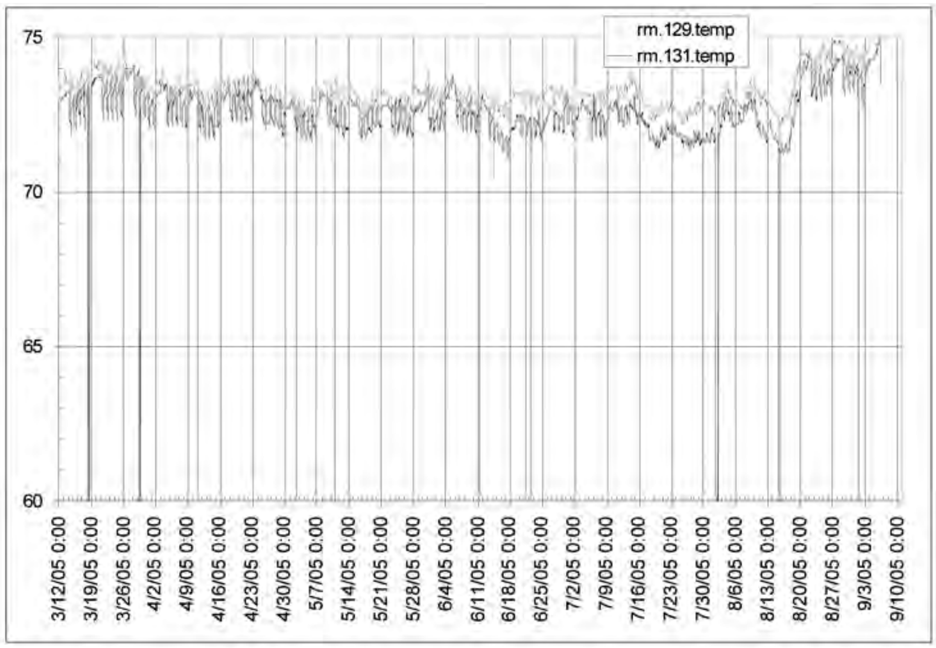


Figure 14. Zone air temperature for offices. Note: Thermostatic reset on 8/20/05 by 2-degrees Fahrenheit.

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[2] Derived from the device accuracy performance characteristics obtained from Inovonics.

[3] While the transmitters have an open-field range of 2500 feet, building structures will limit the useful range within the facility. Repeaters are used to ensure signals make it to the receiver.

aggressive night set-back or delayed morning startup.

Cost of Wireless Temperature Installation

The cost for the wireless sensor network, including installation and integration into the BAS, was estimated to be $3,858, with a per-sensor cost of $104. See Table 2 for more details on the cost. The hardware cost is representative of wholesale prices. For retail prices, multiply the hardware costs in Table 2 by a factor of between 1.8 and 2.0. Therefore, using a factor of 1.8, the total retail cost is estimated to be approximately $7,036, or $190 per sensor.

Table 2. Setup cost for the Wireless Temperature Sensor Network

	Cost per unit	Qty.	Total
Hardware			
Temperature sensors	$50 ea	37	$1,850
Repeater	$235 ea	3	$705
Receiver	$200 ea	1	$200
Translator	$423 ea	1	$423
Total hardware cost			$3,178
Labor			
RF Surveying (labor)	$80 /hr	0.5	$40
Wireless sensor setup and placement (labor)	$80 /hr	4.5	$360
Integration by controls contractor (labor)	$80 /hr	3.5	$280
Total labor cost			$680
Total cost estimate			$3,858

Although a cost estimate for a wired temperature sensor alternative was not developed, some qualitative comparison between wired versus wireless technology can be made. Labor costs, for installation of the wired technology, are replaced with the cost of the innovative wireless technology. While the wireless sensor may be more expensive compared to a standard wired sensor, the cost of labor associated with running wires may dwarf the hardware cost of the wireless technology. The fact that 37 temperature sensors were installed and tested in one day (with approximately 8 hours of labor) is unlikely to be matched for wired retro- fit sensor solution. Other wireless temperature sensor demonstration activities compared wired to wireless sensor solutions and concluded that the wireless sensor technology, with as few as 33 sensors, was the lowest cost solution [Kintner-Meyer, 2004]. As the number of sensors for any given installation increases, the per-sensor cost decreases because no further network infrastructure costs are incurred. This suggests that wireless installations with many sensors tend to be more cost-effective than a wire solution.

It should also be mentioned that this project was a retrofit installation. For new construction with easy access to cable conduits, wireless sensor technologies may not be cost-effective. The real cost advantage of wireless is in retrofit applications, where the labor cost component is large.

EPA's Experiences

EPA staff was very engaged in all phases of this demonstration project and demonstrated an interest in exploring other wireless sensor technology for other sites and other building applications. For the Duluth facility, EPA identified an additional application of the wireless technology. The application involved monitoring of water temperatures in small water tanks, in which EPA performs scientific experiments. EPA expressed interest to expand the wireless sensor network with additional sensors that measure the water temperature in the water tanks and to use the alarm notification features of the BAS to monitor the water temperatures.

One of the outcomes from this demonstration project is EPA plans to incorporate wireless sensors for HVAC control in the EPA architectural guidelines. The new guidelines are expected to be released in the summer of 2006. In addition, EPA shared the successful demonstration project in an article published in the December 2005 issue of Energizing EPA, the EPA Office of Administration and Resources Management's newsletter on Energy Conservation and Sustainable Facilities [EPA, 2005].

Conclusions

A wireless temperature sensor network with 37 sensors was installed and integrated into a BAS at an EPA site in one day. The wireless network setup required some familiarity with RF technology and an RF survey to determine the need and location for repeater technology. The integration of the wireless technology was done by a controls contractor with no familiarity with wireless technology. An integration module provided by the wireless technology vendor (translator) made the integration relatively simple for any controls contractor or facility staff knowledgeable in configuring networks. The wireless sensor technology functioned flawlessly during the 7-month demonstration. The total cost for the installation, including hardware and labor, was estimated to be about $190 per sensor when purchased through a controls vendor.

EPA staff enthusiastically supported the demonstration project and generated creative ideas for other applications of the wireless temperature sensor technology. EPA disseminated the successful outcome of the wireless sensor demonstration in its nationally circulated newsletter Energizing EPA [EPA, 2005]. Wireless sensor technologies are slated for adoption into EPA's architectural guideline to be released in the summer of 2006.

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General Contacts

William Lintner
New Technology Demonstration Program Manager
Federal Energy Management Program
U,S. Department of Energy
1000 Independence Ave, SW, EE-92
Washington, DC 20585
Phone: (202) 586-3120
Fax: (202) 586-3000
william.lintner@ee.doe.gov

Steven A. Parker
Pacific Northwest National Laboratory
P.O. Box 999, MSIN: K5-08
Richland, WA 99352
Phone: (509) 375-6366
Fax: (509) 375-3614
steven.parker@pnl.gov

Technical Contact

Michael Kintner-Meyer
Pacific Northwest National Laboratory
P.O. Box 999, MSIN: K5-08
Richland, WA 99352
Phone: (509) 375-4306
Fax: (509) 375-3614
Michael.Kintner-Meyer@pnl.gov

Produced for the U.S. Department of Energy, Energy Efficiency and Renewable Energy, by the Pacific Northwest National Laboratory

DOE/EE-0319
May 2007

U.S. Department of Energy
Energy Efficiency and Renewable Energy