Wireless Sensors and Controls for Building Applications

Improving the Actual Operating Efficiency of Commercial Buildings

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Battelle

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Outline

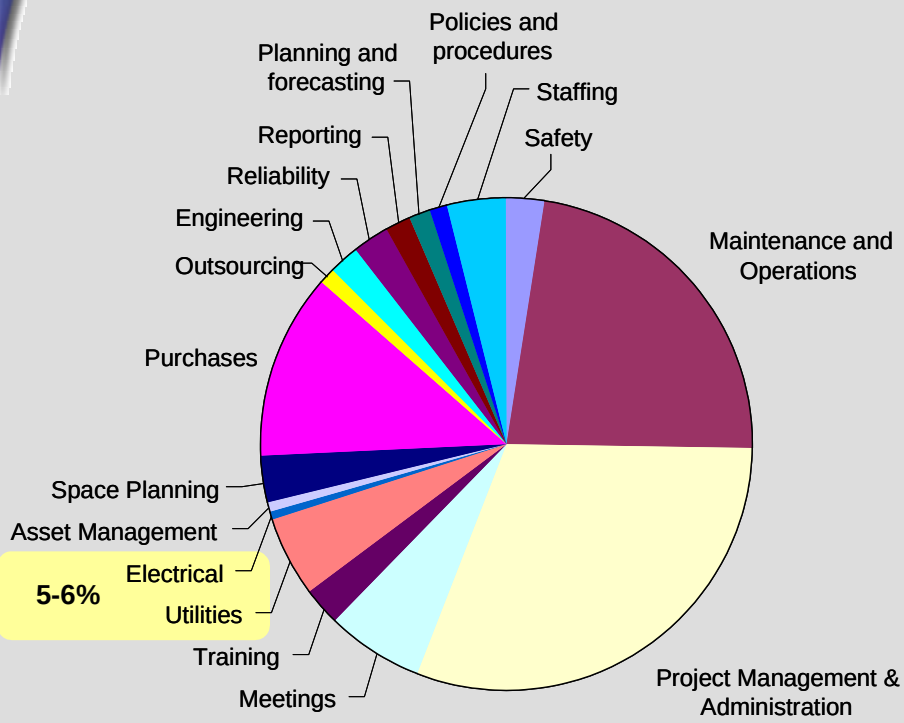
- Why wireless
- What is the opportunity for building operation
- Overview of wireless sensors
- Demonstration projects at PNNL
- Trends

Why Wireless?

- You can't control and maintain what you don't measure and monitor
- Sensing is the foundation for good operation, control and maintenance—it's an enabling technology—but it's too expensive ($200 to >$1000 per point)
- Wiring represents 20% to 80% of a sensor point in commercial buildings
- Cost savings: substitute technology for labor for installation and servicing
- More sensors will enable performance monitoring, automated diagnostics, automated real-time commissioning → higher performance systems

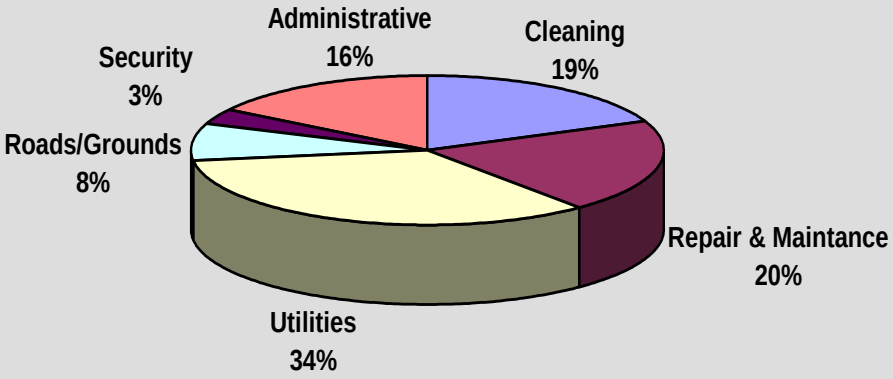
Time versus Cost

Proportions of time devoted to facility management tasks



Source: NorthWrite Inc. unpublished survey, 2002

Fractions of annual purchases by facilities globally

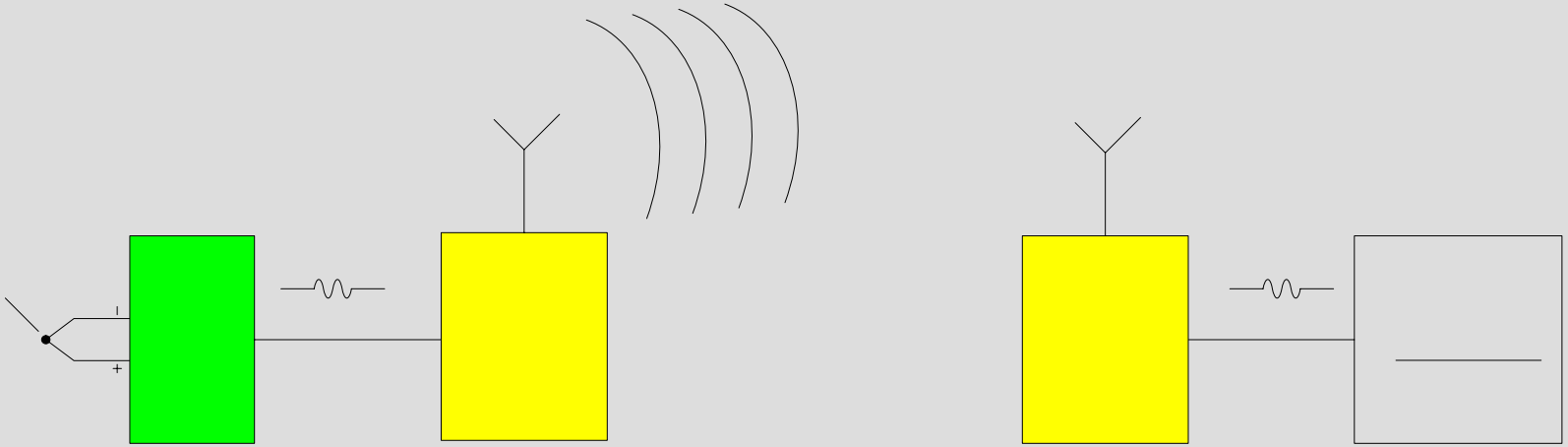


Source: 1998 BOMA Experience Exchange Report 2002

Opportunities of Wireless Sensors and Controls for Building Applications

- Key driver: low-cost will enable ubiquitous sensing
- Operational benefits
  - Thermal comfort improvement (high-spatial resolution sensing)
  - Extended life-time (conditioned-based maintenance)
  - Energy efficiency (trouble-shooting)
  - Demand responsiveness, load management
  - Inventory control by RFID tags
  - Safety and security improvement

Components of a Wireless Sensor One-directional



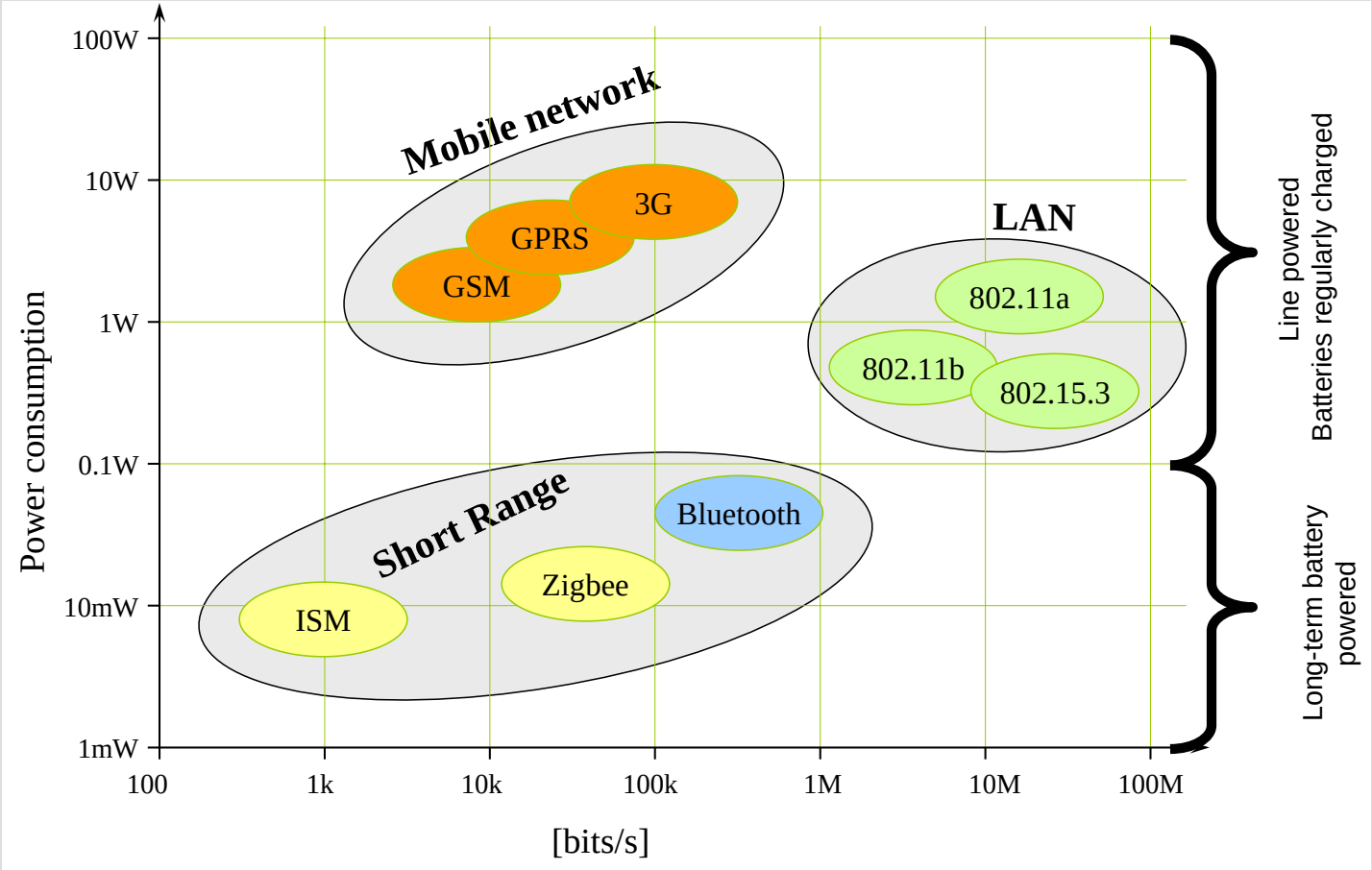
Components of a Wireless Sensor Two-directional

Reader

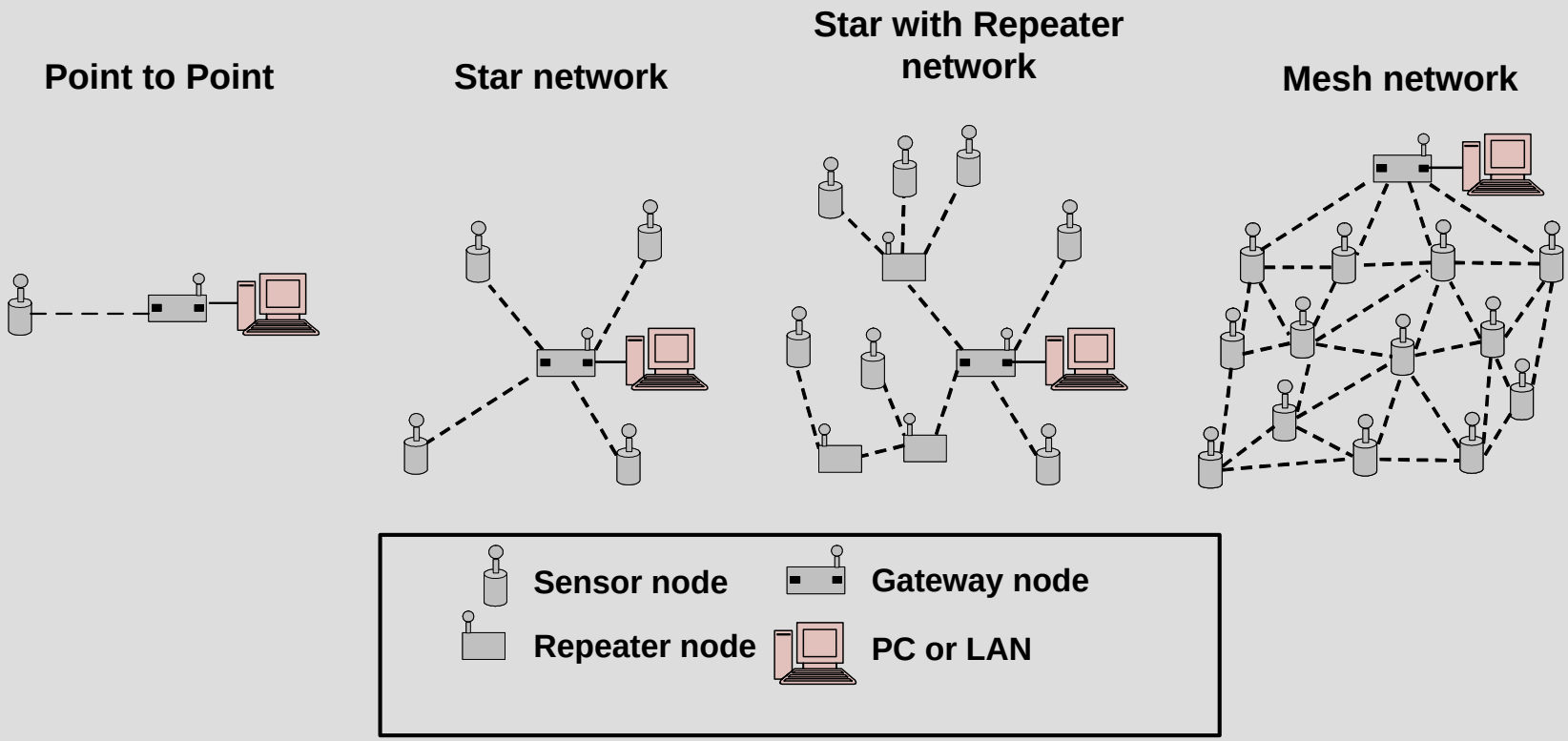
Overview of Wireless Sensors

- Differentiation of wireless sensor technology
  - One-way vs. two-way
  - Communication frequency (ISM)
  - Spread spectrum vs. single frequency
  - Communication protocol
  - Network topology
  - Battery operated versus line powered
  - Integration
    - Stand-alone
    - Web-enabled
    - Integration to existing wired controls networks

Wireless Devices and Communication Protocols



Network Topology



PNNL Demonstration Projects

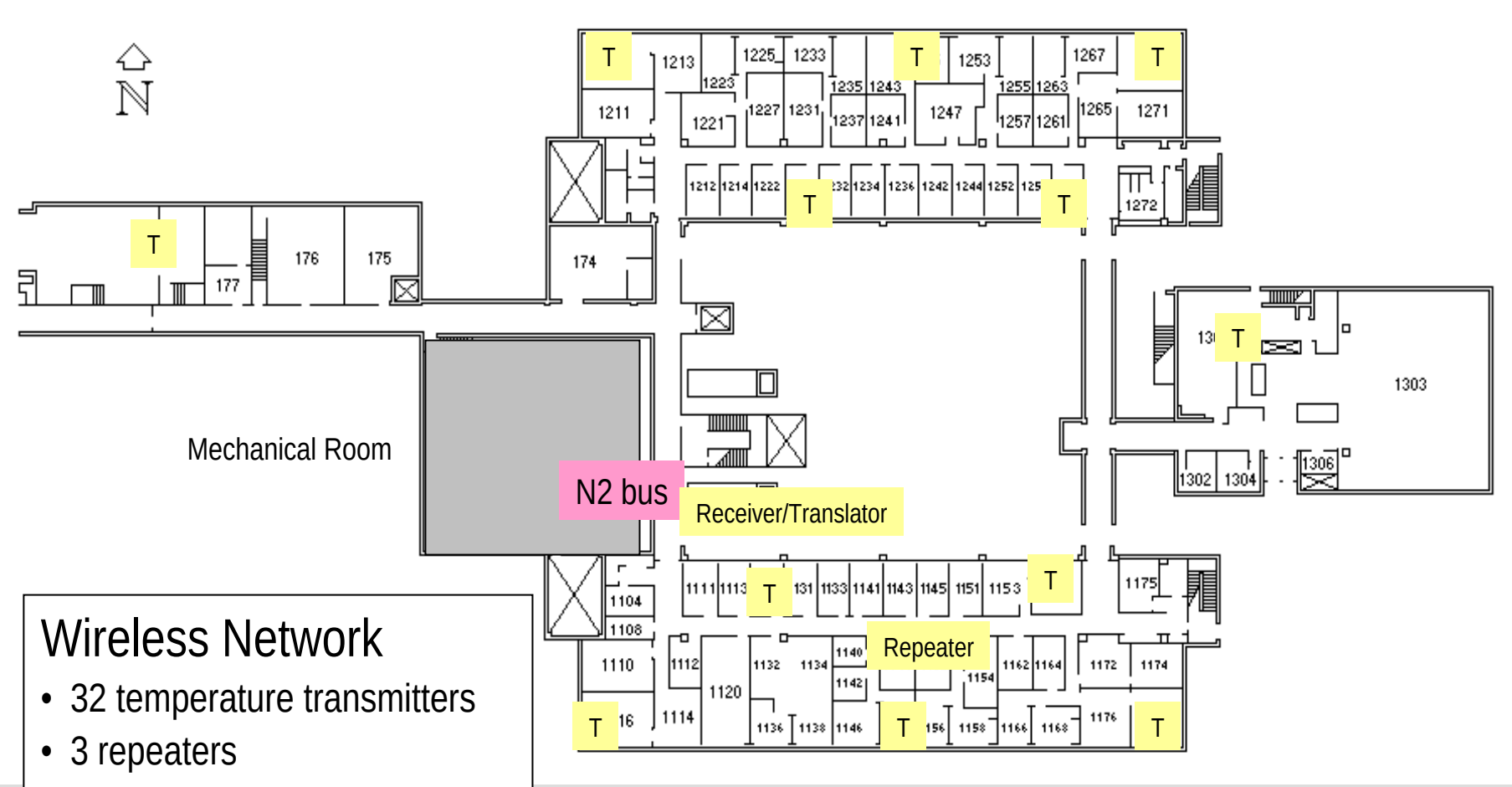
- Started in 2002
- 3 buildings
  - 2 applications inside office buildings
  - 1 application with rooftop HVAC equipment
- Analyze cost-effectiveness of wireless sensors in large office buildings
  - Analyze installation efforts
  - Test robustness of communications
  - Analyze maintenance requirements
  - Compare cost (wireless vs. wired systems)
  - Lessons learned
    - What are the issues in set-up and maintenance of wireless
    - Other considerations

Building 1

- about 70,000 sq. ft. office space
- steel-concrete construction
- 3 floors
- Built-up HVAC system

- Federally owned
- Operated by Battelle

Wireless Network Topology
Building 1



Wireless Network

- 32 temperature transmitters
- 3 repeaters
- 1 receiver/translator

Wireless Sensor Network Technology

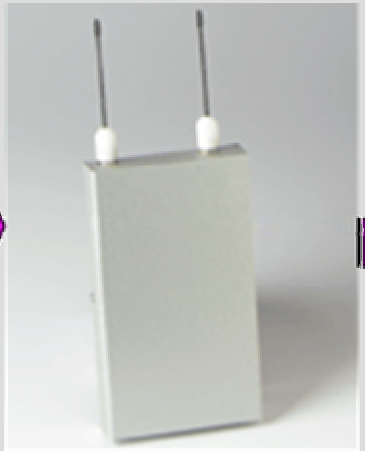
Battery-powered Temperature **sensor** and **transmitters**

Repeater

Receiver

Translator
From wireless to N2 bus

BAS



- **900 MHz**
- **FHSS**
- **Range: 2500 ft.**
- **Battery life: 3 y**
- **Sensor: RTD**

- **Line powered**
- **Range: 4 miles**

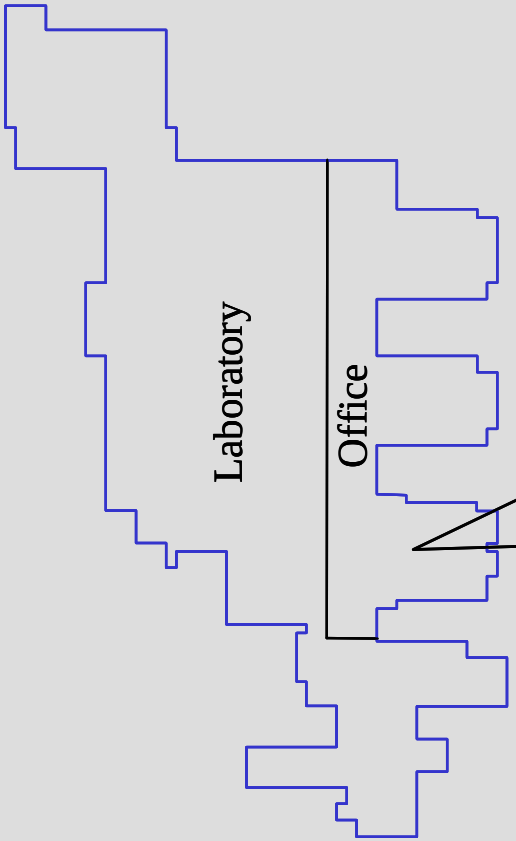
- **Up to 100 transmitters**

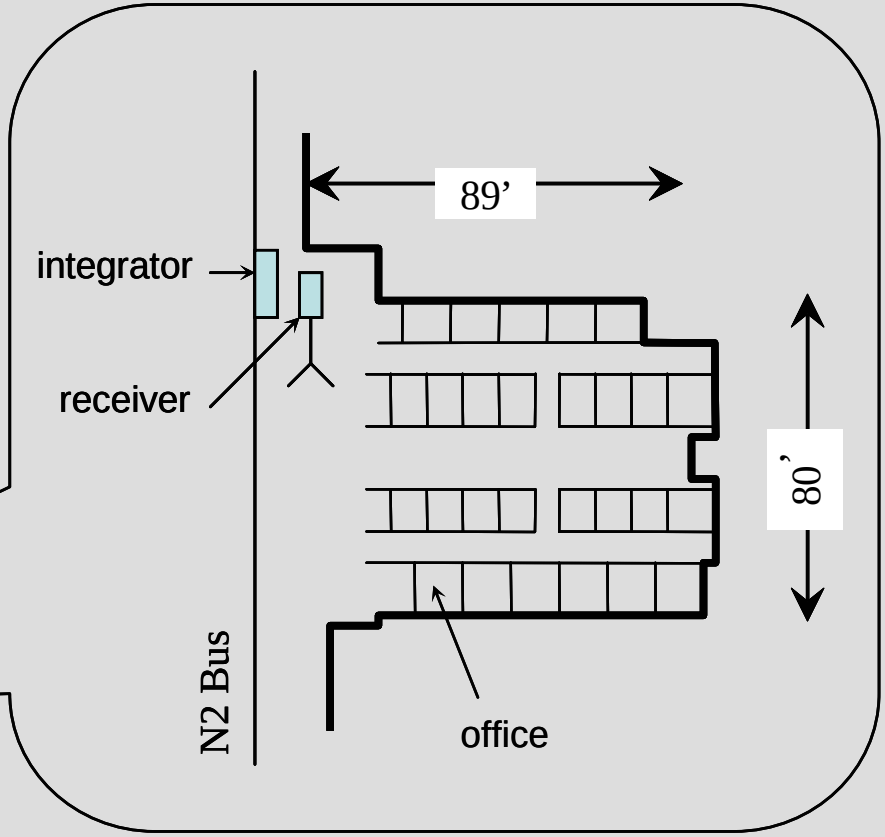
Building 2

- 45,000 sq.ft.
- 2 Floors
- Central open space
- 170 offices on two corridors
- Walls
  - Metal studs
  - Gypsum wall board
- Ceiling:
  - Metal sheeting
  - Concrete floor

Wireless Sensor Network
Building 2

Total of 120 wireless temperature sensors in building





40 wireless temperature sensors distributed in one wing

Cost of Wireless Installation

Building 1

- **WIRELESS:** wireless system for 32 nodes
  - **About $134/sensor** for wireless
  - Installed cost: $4300
  - Recurring cost of replacement of batteries (3-5 years) not included
- **WIRED:**
  - **$220/sensor**, including temperature sensors

Building 2

- **WIRELESS:** wireless system for 120 nodes
  - **About $78/sensor** for wireless
  - Installed cost: $9400
  - Recurring cost of replacement of batteries (3-5 years) not included
- **WIRED:**
  - ?

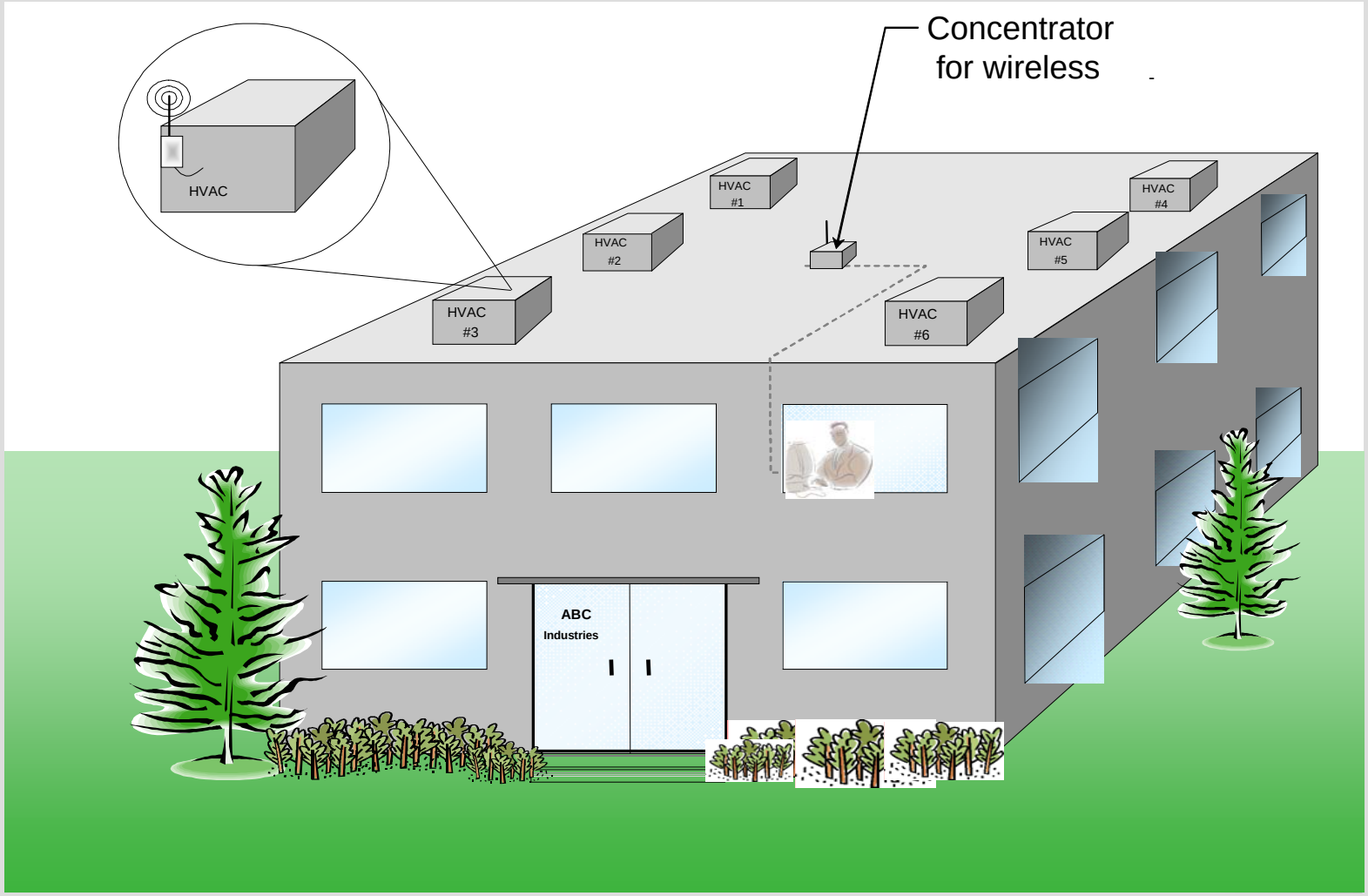
Lessons Learned, Building 1

- Implementation
  - 32 wireless temperature sensors
  - 3 repeaters
  - 1 receiver, 1 translator
  - Integrated into JCI Metasys
- Benefits
  - Control:
    - Chilled water reset strategy based on averaged zone temperatures
    - $6000 cost savings per year
    - payback <1 year.
  - Troubleshooting
    - Identification of cold spots in zones led to reset of the entire building temperature, thus avoiding overcooling and use of space heaters
    - Significantly improved thermal comfort (hot/cold calls down)
    - Heat buildup in kitchen
- Observations
  - Wireless networks work very reliably, since Spring 2002
  - Facility staff fully embraced wireless technology as enabling technology
    - Suggested additional applications
      - Monitoring emergency lighting ballasts
      - Occupancy sensing
  - Communication to occupants was necessary to explain new technology

Lessons Learned Building 2

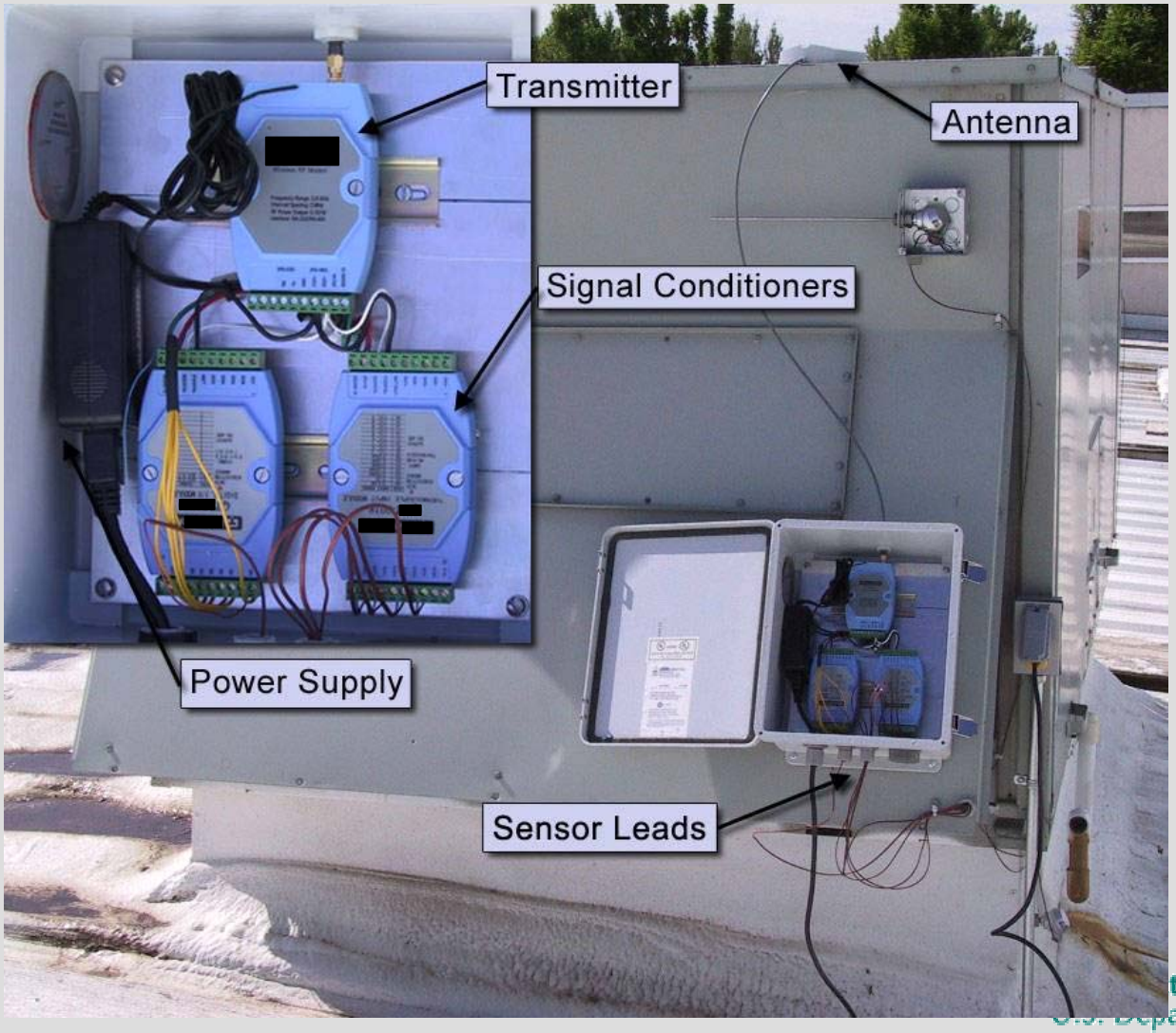
- Implementation
  - 120 wireless temperature sensors in individual offices
  - no repeaters
  - 3 receiver, 3 translator
  - Integrated into JCI Metasys
- Benefits
  - Control:
    - Shut off ventilation system after 6p.m. as long as ALL offices maintain 55F<T<78F
- Observations
  - Wireless networks work very reliably, since Summer 2003
  - Facility staff fully embraced wireless technology as enabling technology
  - Suggested additional applications
    - Monitoring critical laboratory experiments
    - Occupancy sensing
- Considerations
  - Vulnerability clearance for wireless system
  - Theft

Rooftop Application



System Types Tested

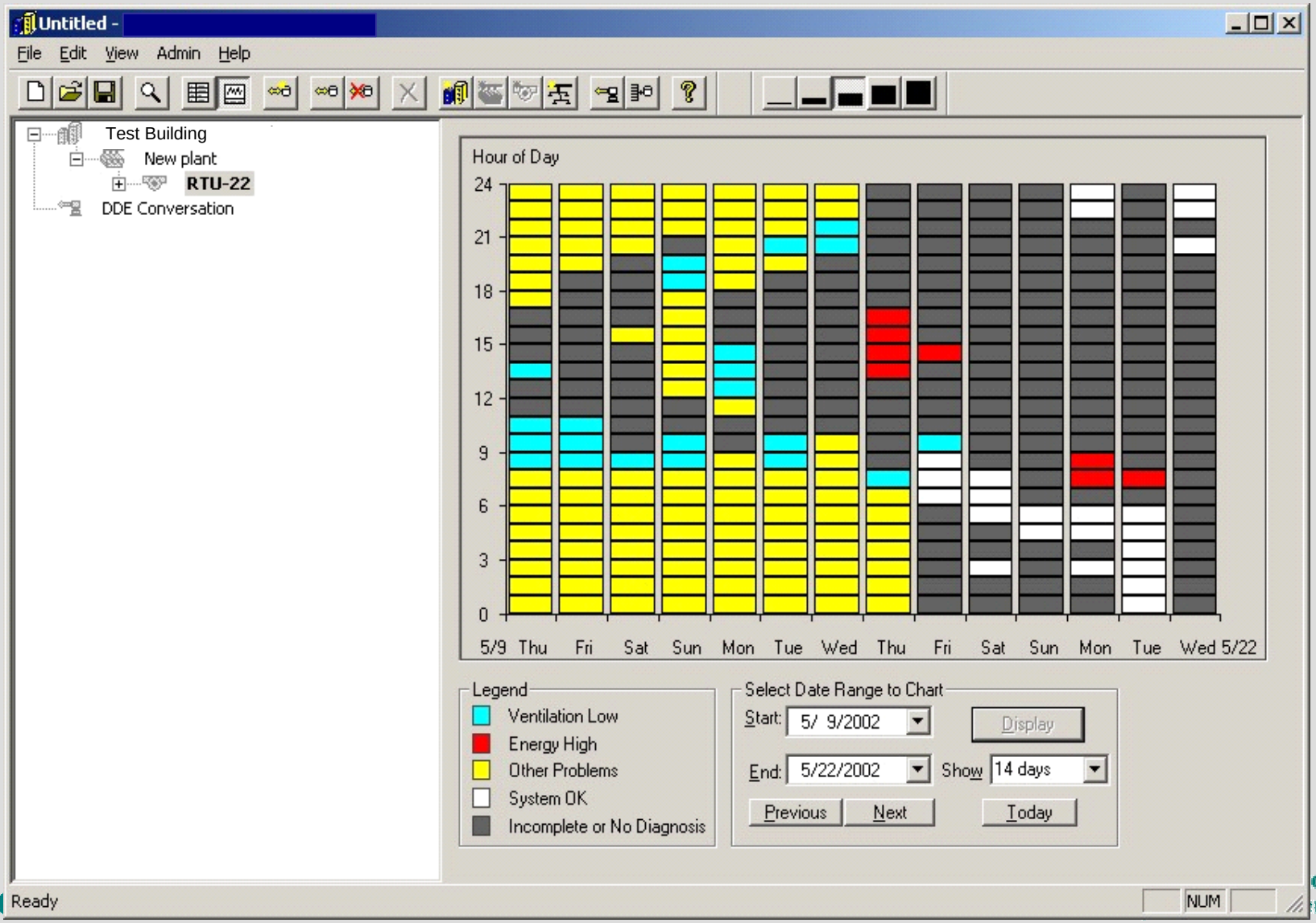
- System configured from generic components – applied to one unit



System Types Tested

- System specifically manufactured for package unit monitoring – applied to 4 units

Converting Data Into Information
Fault Detection and Diagnostics



Cost Competitiveness

Cost Component	Cost	
	Monitoring System for Three Packaged HVAC Units	
	Wired Design	Wireless Design
Sensors	$636	$636
Wiring	$68[1]	---
Communication and signal-conditioning hardware	$1903	$1500
Labor	$1179[2]	$450
Total cost	$3786	$1950
Average cost per sensor	**$316**	**$163**

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

Interim Findings and Conclusions For Rooftop Application

- Initial problems with reliability of hardware (most have been overcome)
- Technical challenge:
  - Right combination of components that provides adequate accuracy, reliability, persistence, and cost
- Several units can be monitored using <u>one</u> wireless RF receiver
- Wireless costs per sensed point decrease as the number of units monitored by a receiver increases

Summary of Demonstration Projects

- In 2001, there was no commercial wireless product for building application available
- For in-building application, products worked well
- For rooftop application, the right product yet to be produced
- Wireless sensors are cost competitive today in retrofit applications
- Wireless technology particularly attractive
  - Flexibility
  - Expandability with incremental cost for adding one sensor

Trends

- Industry is in early stages of technology/product development
- Industry is dynamic and fluid dominated, by small companies
- Key market driver: Huge market size of wireless sensors (several orders of magnitude larger than expected IP nodes)
- Building automation is one of many target markets. Others are
  - Home automation
  - AMR
  - Industrial process control
  - Automotive
  - Medical monitoring
  - Asset tracking
- "OnWorld" projects sales of wireless sensors (all sectors)
  - 6 million (2004)
  - 465 million (2010)
  - Significant cost reduction (no one knows how low prices for end-user will go)

- Self-powered devices
- Expected to be a glut of data coming from thousands of sensors. This will drive new applications
- Opportunities for building application
  - End-use power monitoring
  - Comfort (thermal, IAQ, lighting) monitoring
  - Equipment monitoring