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Photo credit: Gail Porter/NIST

The NIST Advanced Measurement Laboratory (AML) Complex, Gaithersburg, Md., is considered to be the most technologically advanced research facility of its kind. It features five wings with stringent environmental controls on air quality, temperature, vibration and humidity.

BACnet[®] Measures Up

By **Steven T. Bushby**, Member ASHRAE

The National Institute of Standards and Technology (NIST) has two campus facilities, the main one in Gaithersburg, Md., near Washington, D.C., and a smaller facility in Boulder, Colo. The Gaithersburg facility is 234 hectares (578 acres) and has more than 35 buildings and more than 232 000 m² (2.5 million ft²) of floor space. The range of activities at NIST is reflected in the needs of the buildings and facilities that support them.

The buildings range from typical office environments to laboratories with environmental constraints not found in any other buildings in the world. One

example of the latter is high-accuracy temperature-controlled laboratories that maintain a constant temperature within $\pm 0.01^{\circ}\text{C}$. Despite the unique nature of some

of NIST's facilities, most problems faced by the facilities staff are common.

Most NIST buildings on the Gaithersburg campus were designed in the 1950s and built in the 1960s. Renovation of building control systems literally requires an act of Congress. Procurement of control systems must involve open competition. Because NIST is a government facility, financial resources for facility maintenance and improvement are limited by competition, not only with the primary research, measurement and standards mission of NIST, but also with

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all of the other competing uses of federal funds. In addition, all procurement and contracting processes must follow strict government openness and competition requirements. As a result, control system modernization is a process that takes years and inevitably results in a mixture of products from many companies and several generations of control technology.

When BACnet products were introduced to the NIST Gaithersburg campus, the facilities staff was unfamiliar with BACnet technology and had little experience and knowledge of direct digital control (DDC) technology. Nearly all building control systems on campus were pneumatic and training resources were, and still are, limited. The staff was stretched thin keeping up with daily maintenance issues, making learning a new technology a challenge. Constraints of this type are still common, and contribute to the promise of BACnet and the difficulties of taking advantage of its full potential.

Evolution of BACnet Use at NIST

NIST Building and Fire Research Laboratory staff have played a leadership role in developing BACnet from the inception of ASHRAE Standard Project Committee 135 in January 1987. NIST helped to shape the emerging standard and also led the way in developing test procedures and tools to measure product conformance to the standard. The result of that work can be seen today in BACnet's companion testing standard, the BACnet product testing and listing programs active in the United States and Europe, and the very existence of BACnet International, which began as a humble cooperative research and development project between NIST and several control system manufacturers. NIST continues to play a role in the ongoing efforts to maintain the standard, enhance its capabilities and link the U.S. efforts to international standards.

In 1993 a storage facility in one of the campus buildings was converted into office space. The change required the addition of a rooftop air-handling unit to condition the new office space. One of the first commercially available BACnet products, based on what was then a draft version of the standard, was installed as a stand-alone system. After that humble beginning, similar small, stand-alone BACnet installations began to appear on campus where isolated control projects were needed. Lack of funds to modernize the 1960s era pneumatic controls on most of the campus was the main obstacle for growth of BACnet use.

In 1993, NIST also began engineering studies to construct a

new facility on the Gaithersburg campus that was envisioned to become the most advanced measurement laboratory complex in the world. Its purpose was to promote innovation and competitiveness of U.S. industry through research in fundamental measurement problems under conditions so carefully controlled that environmental influences could almost be eliminated. Design contracts were awarded in December 1993, and a preliminary design was completed in March 1997. BACnet was first published during that design phase in December 1995. When the design was completed, the project was shelved due to lack of funding.

Three years later in 2000, Congress approved funding to begin the Advanced Measurement Laboratory (AML) project. The design was updated to accommodate changes in building codes, construction contracts were awarded and the \$235 million, 49 846 m² (536,538 ft²) project began. Construction of the five-wing complex, with two wings buried 12 m (39 ft) underground to provide vibration isolation, took four years. The project was completed 11 years after the original studies began.

Today, the AML houses 338 reconfigurable laboratory modules, including a 1295 m² (13,936 ft²) nanofabrication facility, most of which is a Class 100/ISO 5 cleanroom. Examples of

research enabled by the facility are measurements to identify and manipulate individual molecules, determining the size of an electrical current by counting, one by one, the number of electrons flowing by, and measuring the strength of individual chemical bonds between an antibody and a virus particle.

When the AML was conceived and the original designs completed, BACnet was just emerging. Because of the unique control requirements and the critical nature of the controls to the success of the project, potential contractors were required to demonstrate their ability to achieve temperature

control in the high-accuracy laboratories to the $\pm 0.01^\circ\text{C}$ design conditions in a laboratory mock-up constructed in a large environmental chamber on the NIST campus. The control specification required the use of BACnet for most of the facility, but allowed the use of non-BACnet products for the high-accuracy laboratories, which comprise about 25% of the laboratories in the AML. For non-BACnet products, a gateway was required to provide integration with the rest of the control system. In the end that is what happened, although limited use of gateways did not turn out to provide the level of integration that was desired.

While the AML project was evolving, an unrelated, large BACnet project on the Gaithersburg campus began. In re-

Why Choose BACnet

- To integrate products from multiple vendors;
- To enable open, competitive procurement;
- To gain the flexibility to choose products based on their ability to meet the desired application;
- Upgrade campus control systems in stages over many years with multiple generations of products;
- Compatibility with modern network technology;
- Integration with IT applications;
- Designed to enable interconnection of multiple buildings in a campus environment;
- Enable future interconnection of geographically separated facilities; and
- Enable future integration of HVAC controls with fire, security and lighting control systems.

sponse to the Energy Policy Act of 1992 and Executive Orders 13123 and 12902, NIST began a project to reduce energy consumption from various office spaces on campus through an energy-savings performance contract. The project involved lighting retrofits, renovation of air handler motors and drives and new BACnet controls. This competitively bid project involved the office space of most buildings on campus, with laboratories excluded from the bid process. Implementation of the changes occurred in 2004.

In 2005 another project was undertaken to retrofit the original chemistry building as an office building. This project involved gutting the interior of the building and was a test case for a long-range plan to make improvements over a period of years to other buildings on campus. BACnet compatibility was a requirement for all of the controls in the newly retrofitted building.

Today, selected ongoing upgrades are in process to laboratory facilities in buildings that have BACnet controls for office space. All of these projects are independent, but the use of BACnet and connection to the campus BACnet networks is a requirement.

Network Architecture

Today, the NIST Gaithersburg campus has a mixture of legacy pneumatic control systems a few stand-alone pre-BACnet DDC systems, and a growing number of BACnet products. Control products from nine different companies are used, four of which have provided BACnet systems.

Figure 1 is a diagram of the multivendor campus BACnet internetwork. The high-speed backbone is provided by a dedicated fiber optic network, which is part of a system of fiber optic networks that interconnect all major buildings on campus. Individual fibers are reserved for the general computing infrastructure, the physical access control system, the fire alarm system and for HVAC control. The isolation of these applications is part of the network security plan for the site. The BACnet backbone carries both BACnet/IP traffic and BACnet/Ethernet traffic. A router is used to link the two BACnet message streams that are conveyed over the same physical network.

Within each building, other BACnet local area networks provide communication for the individual controllers that interface with the mechanical systems in the building. One of the advantages of BACnet is that it provides a mechanism for a future controlled integration of the HVAC, fire detection and access control systems, while maintaining enough isolation to meet the high standards of security and reliability that are needed.

Future Plans

The NIST Gaithersburg campus has BACnet HVAC products from four vendors that share a common building automation network infrastructure. Because of the variety of contracting mechanisms and the overlapping timing of the projects, the system is not as fully integrated as it could be. For example, separate workstations exist for each vendor's portion of the

Lessons Learned

A successful multivendor BACnet implementation requires careful planning, clear, well-written specifications and careful monitoring of contractors.¹ Important items to keep in mind from our experience are:

- Develop clear integration plans that lay out long-term goals and constraints;
- Impose strict requirements on network numbering, device instance numbering and object naming conventions;
- Have a strategy for handling maintenance in a multivendor environment;
- Establish clear goals and requirements for operator workstations that address the reality that in today's market configuration and programming tools come bundled with the workstation;
- Enforce strict requirements for delivering documentation of control system configuration that can be used by another vendor for a later addition;
- Creative financing approaches such as energy savings contracts can be very successful but require careful planning and stringent oversight during execution to ensure installed products meet long-term integration plans;
- Gateways are potential trouble spots that require special attention and must be avoided when possible;²
- Staff training on BACnet basics and product-specific features is vital; and
- System commissioning needs to include verifying correct BACnet configuration details.

system even though BACnet provides a way to combine all of this information in a single user interface. The long-range plan is to continue the migration of the legacy control systems to BACnet technology as resources permit, to continue to build BACnet expertise in the facilities staff and to take advantage of integration opportunities in stages as the technology matures and operating experience grows.

BACnet Products as a Research Tool

At NIST, BACnet products are not just used for automation and control of the facilities. BACnet products also are used by the Building and Fire Research Laboratory for research applications. One example is the integration of the controls for environmental chambers with laboratory data acquisition and control software to manipulate temperature and humidity conditions as part of fault detection research for residential heat pumps. Another example is the control of environmental conditions for a particle velocimeter facility to research heat transfer characteristics of finned-tube coils used for vapor compression systems. Future plans include using BACnet controlled environmental chambers to characterize the performance of two-

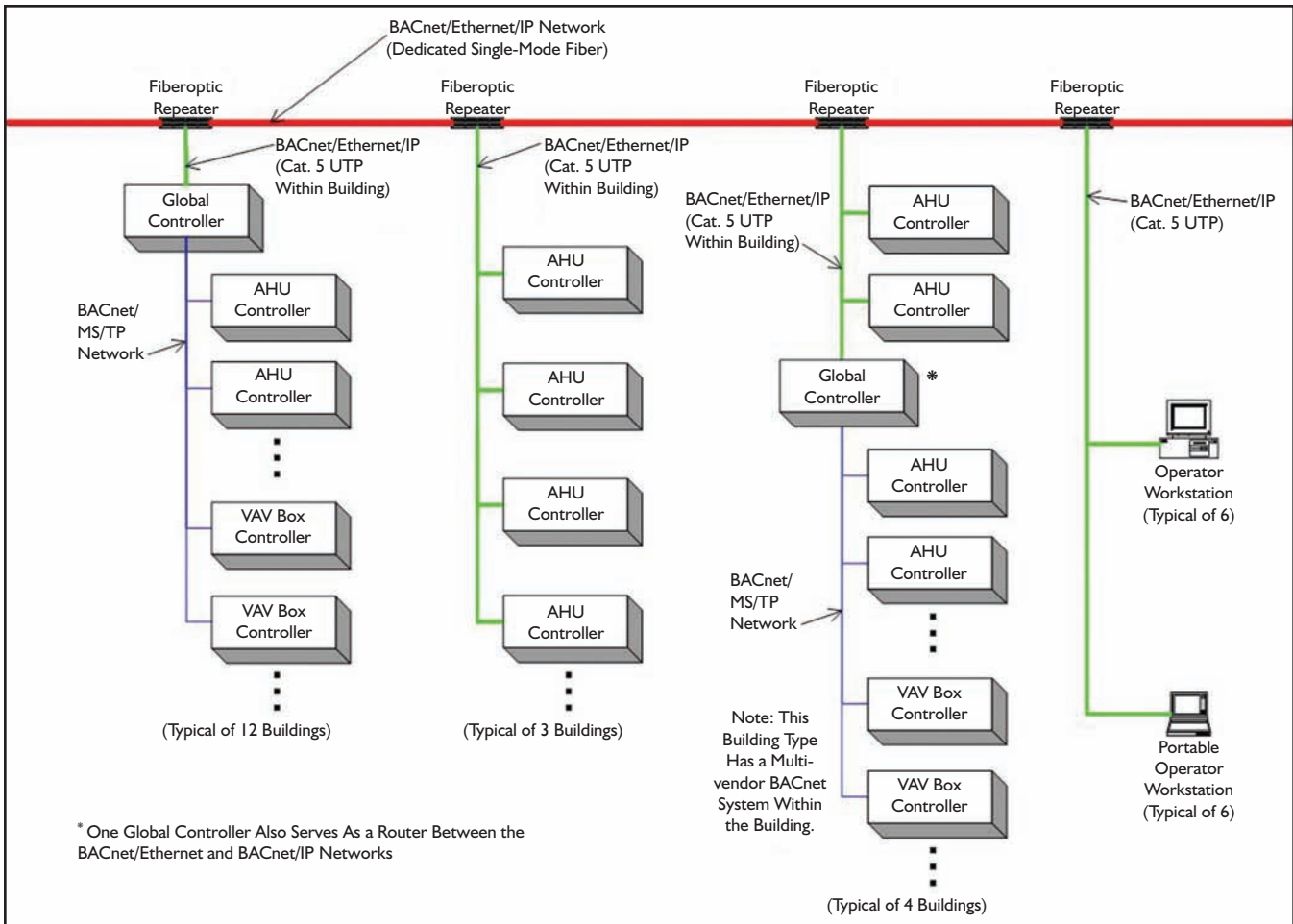


Figure 1: Diagram of the multivendor campus BACnet internetwork.

speed and variable-speed condensing units for residential vapor compression systems. The ability to directly couple BACnet controllers to experimental data acquisition apparatus to control and measure test conditions has been a great asset.

Another example of BACnet products as a research tool is the Virtual Cybernetic Building Testbed (VCBT). This facility links multivendor BACnet products to computer simulations to emulate control of a building under carefully controlled conditions. Key values from the simulations, such as temperatures, pressures and flows, are connected to the sensor inputs of the controllers through digital to analog converters of a data acquisition system. The control outputs are linked back to the simulations through the same mechanism. The result is the controllers think they are seeing real sensor data and controlling real building equipment.

The VCBT facilitates research in automated fault detection of HVAC systems, automated HVAC commissioning tools and studies the complex interactions of building systems under emergency conditions such as fire.

Conclusion

NIST played a key role in developing the BACnet standard and the companion testing standard that is now used as the basis

for BACnet Testing Laboratory listed products. Now BACnet technology is the key to bringing integration and harmony to the disparate building automation and control products used on the NIST campuses. BACnet provides a way for NIST to manage the reality that facility upgrades can take decades, systems from multiple generations of technology need to be integrated, and competitive procurement is a must. BACnet also provides a tool to advance some of the research objectives of the Building and Fire Research Laboratory.

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