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A Remotely Accessed HVAC Laboratory for Distance Education*

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The widespread use of computer controls for optimizing the efficiency of mechanical and electrical systems in commercial buildings has created a unique opportunity for delivering lab-based distance education. Facility engineers routinely use building automation systems to access real-time performance data (e.g., chilled water pressure, temperature, and flow) over the Internet. This network capability has been applied in an educational setting to deliver laboratory experiments to large numbers of undergraduate students. Although educators need to be aware of the limitations of commercially available building automation systems, remotely accessed Heating, Ventilating, and Air Conditioning (HVAC) equipment is an excellent way to demonstrate real-world principles of thermodynamics, fluid mechanics, and controls.

INTRODUCTION

A REVIEW OF engineering education literature shows that remotely accessed labs are becoming more common and more sophisticated. One of the most impressive and useful efforts to date is a multidisciplinary mechatronics/process control remote laboratory [1]. This project was funded by the United States National Science Foundation and can be accessed at http://mechanical.poly.edu/faculty/vkapila/controllab.htm. In addition to a variety of remotely accessed experiments, the site features a live video stream that shows the online experiments taking place.

Another ambitious project is a collaborative effort between computer science and engineering at Florida Atlantic University [2, 3]. Although their remote labs are currently limited to relatively simple electric circuits and a mechanical beam that can be found at http://jupiter.cse.fau.edu/directory.html, their ultimate goal is much broader. The Center for Innovative Distance Education Technologies was formed to help make Florida Atlantic University a leader in technologies for all types of distance education media.

A simple working model of a manufacturing enterprise with Internet control provides a good indication that remotely accessed labs will eventually become commonplace [4]. This project involved a group of Mechanical Engineering students from the University of Greenwich, England, who used the internet-ready features of commercially available software to put a project online in less than six weeks. With very little prior experience, they developed an online working model that included a manufacturing system, a warehouse, and a customer location.

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Although no previous success stories about leveraging the Internet capabilities of commercially available building automation systems for lab-based distance education were discovered, the unique opportunities of this approach have been recognized. In an article for an industry trade journal, a facilities engineering consultant recognized that an entire building could become an educational laboratory for energy-related investigations [5].

REMOTE ACCESS IS AN INTEGRAL FEATURE FOR MOST MODERN COMMERCIAL BUILDINGS

Although there have been modest improvements in mechanical equipment and electrical distribution systems over the past 20 years, there has been a tremendous revolution in how large commercial buildings are operated and controlled. Since energy costs are usually the biggest part of a building's operating budget, significant savings and improved comfort can be achieved by using computers to manage energy use. In the case of a building's mechanical systems, sophisticated computer algorithms save money by modulating heating, cooling, airflow, and other parameters, depending on the time of day, outdoor conditions, and level of human occupancy.

Remote access is a crucial feature of these building automation systems. It is simply not feasible for a facility engineer to personally visit and monitor every mechanical and electrical room under his/her supervision. At a college campus, hospital, or office complex, one individual may be responsible for multiple buildings, each of which may contain a wide variety of mechanical and electrical equipment for maintaining comfortable indoor conditions. It was out of necessity that Heating, Ventilating, and Air Conditioning (HVAC) control vendors starting packaging remote access with their building automation systems. Prior to 1990, building automation systems were accessed by dial-up modems. In the last ten years or so, most HVAC control vendors have shifted to remote access via the Internet because of its convenience and speed.

In responding to the needs of facility engineers, HVAC control vendors have inadvertently provided a unique opportunity for educators. Today's complex HVAC systems are ideal for demonstrating real-world applications of thermodynamics, fluid mechanics, and controls. For one example, the cooling coil of a commercial air handler is typically a water-to-air heat exchanger. The basic temperature differentials and flow rates routinely monitored by a building automation system provide the necessary information for energy-balance calculations. For another example, temperature control in one zone of a building usually provides a simple, but helpful, example of closed loop control. The data-logging feature that is an integral part of most building automation systems will demonstrate how a proportional-integral-derivative algorithm works to make the temperature variable match the temperature set-point.

BORROWING BUILDING AUTOMATION TECHNOLOGY FOR DISTANCE EDUCATION

The Department of Mechanical Engineering Technology (MET) at Purdue University operates from seven different locations across Indiana. Rather than functioning autonomously, the programs cooperate to provide a high-quality technology education that is readily accessible from almost anywhere in the state. The backbone of the statewide technology program is that the same lectures and lab experiments are replicated at each site. A thermodynamics course taught in West Lafayette, Indiana, is the same as one taught hundreds of miles away at Elkhart, Columbus, Muncie, Richmond, New Albany, or Kokomo.

Maintaining continuity between the different MET programs is an ongoing challenge. The MET program at West Lafayette has the most students and the most extensive laboratory facilities. Although the six smaller MET programs at the other statewide locations do not have the resources to duplicate all the laboratory equipment at West Lafayette, building automation equipment may ultimately allow shared resources. During the 2001–2002 academic year, approximately 200 MET students at seven different locations enrolled in the same introductory thermodynamics course. A remotely accessible HVAC laboratory is already serving large numbers of students at West Lafayette. The ultimate goal is to allow any MET student, located anywhere in Indiana, to have simultaneous access to the same equipment as students physically located in West Lafayette.

The remotely accessed HVAC laboratory at Purdue University has three primary mechanical/electrical systems. A forced-air system and a hydronic system demonstrate typical mechanical and electrical equipment used for climate control in commercial buildings. The lab also has flat plate collectors for solar heating. These three HVAC systems demonstrate principles of thermodynamics, fluid mechanics, and controls to large numbers of undergraduate students. Detailed descriptions of this equipment and how they have been integrated into the Mechanical Engineering Technology curriculum are available in references 6 through 11.

This paper discusses some of the different techniques used by HVAC control vendors to provide varying degrees of Internet-based remote access. The forced-air system and hydronic system are monitored by a building automation package from Automated Logic Corporation in Kennesaw, Georgia. KMC Controls in New Paris, Indiana, supplied the building automation equipment for the solar heating equipment. Subtle differences in the control hardware and software have a large impact on plans for distance education.

REMOTE ACCESS TO HVAC EQUIPMENT FROM A PERSONAL COMPUTER

Figure 1 shows eight flat plate solar collectors that are mounted on the roof of the Knoy Hall of Technology. The absorber plate of each collector is slightly different. Some have a reflective surface while others are black. Some have a smooth surface while others have fins. Each solar collector is individually instrumented with pressure, temperature, and flow sensors for monitoring system performance. In a typical laboratory experiment, MET students compare collector efficiency. 'Efficiency' is a broad term, but in this instance it is defined as the ratio of thermal energy collected to radiant energy available. Thermal energy is determined from temperature and flow measurements. Radiant energy is measured directly by a roof-mounted solar pyranometer. From an educational perspective, the most intriguing aspect of this basic solar energy experiment is that the entire project can be completed over the Internet.

Figure 2 shows the hardware for the solar collector's building automation system. Forty-two different sensors measure just about every parameter related to solar performance. There are sensors for temperature, pressure, flow, humidity, power consumption, and solar intensity. The building automation system automatically logs sensor readings into a buffer that holds about three days' worth of data. The buffer can be easily exported to a computer spreadsheet.

Fig. 1. Performance data for eight flat plate solar collectors is accessed remotely.

Remote real-time access for both monitoring and control is available from a built-in Ethernet port.

Figure 3 illustrates the network implementation of the solar heating equipment. One of the strengths of this system is that anyone with Internet access and the proprietary software can use the equipment. There are no hardware or software firewalls that limit access. On the down side, the proprietary software must be installed on each personal computer that accesses the solar collectors. The software is simple to install and run, but problems occur whenever updates are made. Each update must be distributed and manually installed on all remote personal computers. This approach can be cumbersome and inconvenient when frequent changes are made. As an example, two minor typographical errors were recently discovered on the graphic user interface for the solar collectors. To make the full correction, a new version of the graphic interface had to be distributed and installed on all personal computers that access solar collector data.

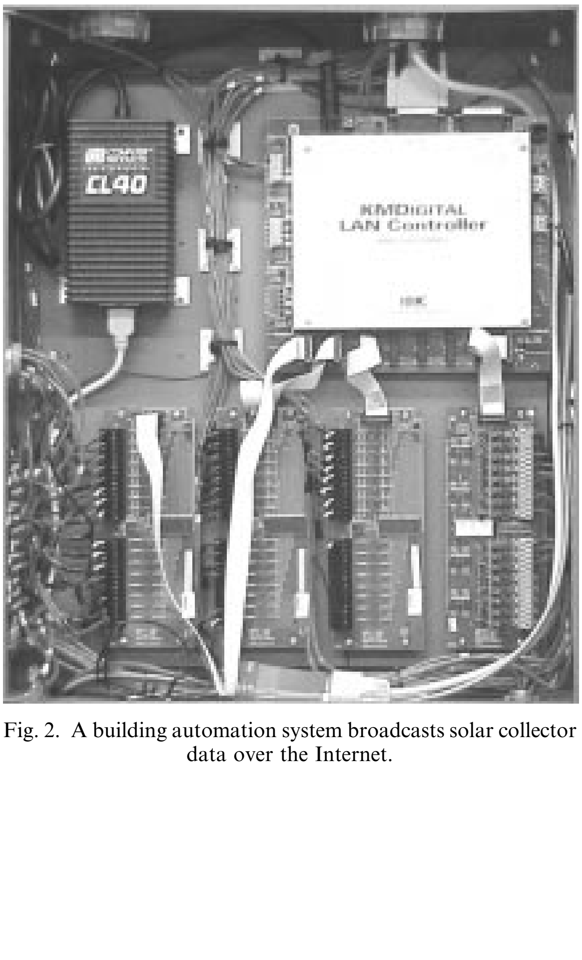

Fig. 2. A building automation system broadcasts solar collector data over the Internet.

REMOTE ACCESS TO HVAC EQUIPMENT FROM A SERVER

Figure 4 shows the graphic interface for the HVAC lab's forced-air system. As with full-size commercial HVAC equipment, the system displays a variety of real-time temperature, pressure, and humidity readings. Outside air enters the system from the lower left, where it is mixed with recirculated air before being cooled, heated, or humidified in the air handler. A fan with a variable speed drive provides the pressure differential to pull air through the system.

As with the solar collector equipment, the real-time data shown in Fig. 4 is remotely accessed over an Internet connection by large numbers of undergraduate students. Fig. 5 suggests that the basic architecture for this building automation system is somewhat restrictive. Since the software for this building automation system resides on a secure server, access is limited to students who are working within the confines of the Technology

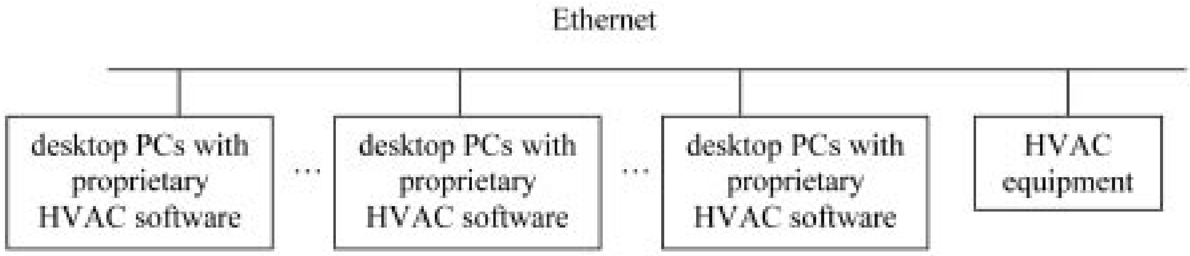

Fig. 3. The solar collector interface offers unlimited access to anyone with the proprietary software but lacks a central control point.

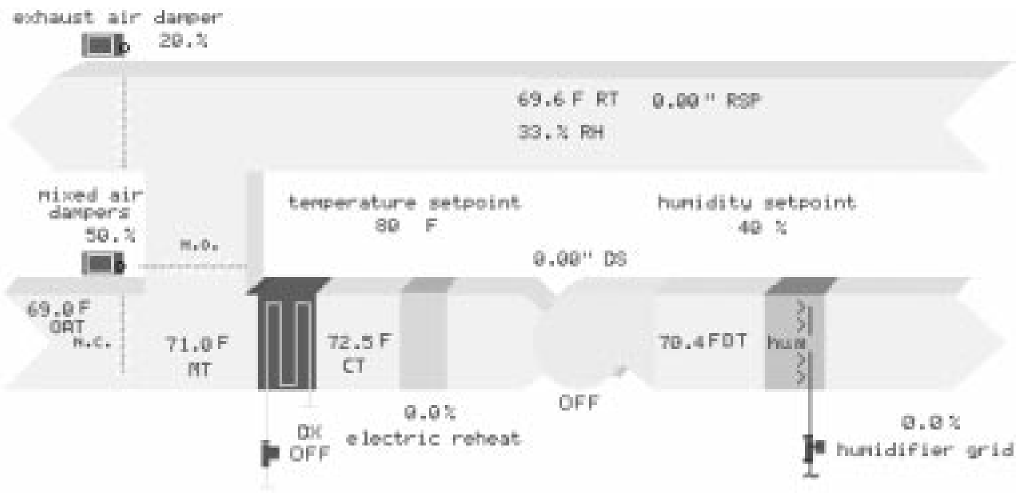

Fig. 4. HVAC performance data is available over the Internet.

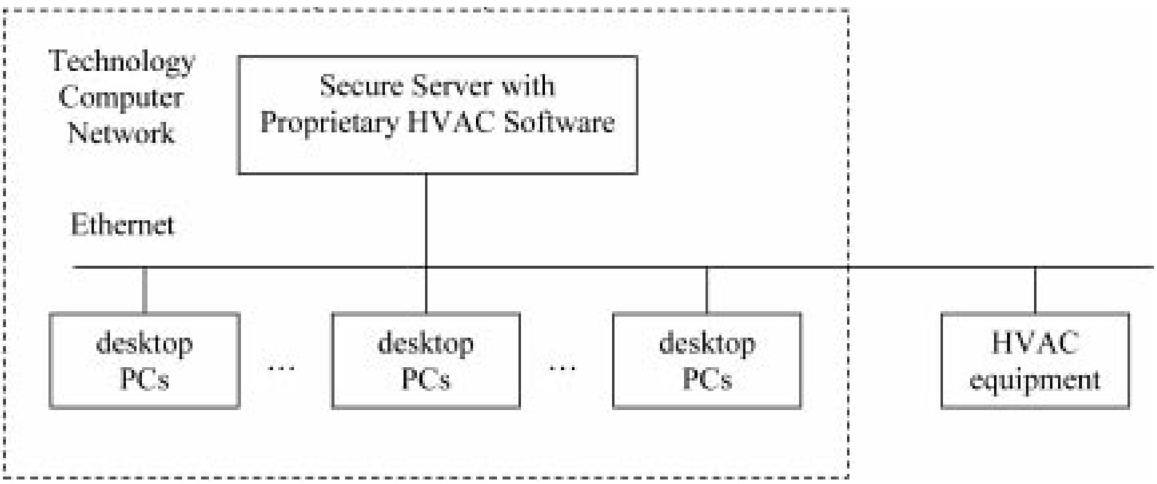

Fig. 5. The forced-air interface offers a central control point, but access is limited to those within the secure building network.

Computer Network. The benefit of a single server is that changes made from one location are immediately available to all other users. There is no need for individual updates to desktop PCs.

FULL INTERNET ACCESS TO HVAC EQUIPMENT

Figure 6 summarizes the newest strategy for Internet-based control, which is being rapidly adopted by HVAC control vendors. This new approach makes it easier to access HVAC equipment from any remote location. Full Internet access is provided from a java-based program that resides on a web server. The building automation system and web server talk back and forth. Temperature, pressure, and flow readings are broadcast to the web server at regular intervals. The beauty of this strategy is that communication has become as simple as surfing the web. Anyone with a standard Internet browser, such as Windows Explorer or Netscape, can interact with the HVAC equipment.

Another key advantage of the web-based approach is that all data is housed in one central

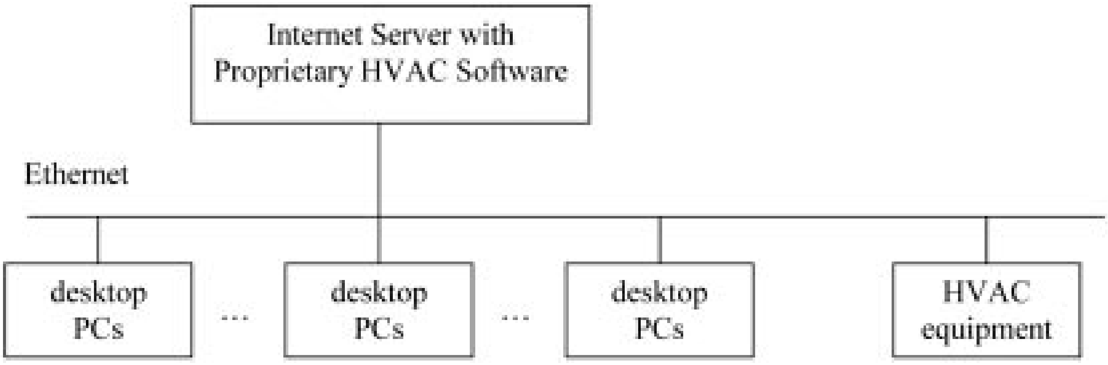

Fig. 6. An Internet server offers a central control point and unlimited access to anyone with a common Internet browser.

location. When changes to the graphics or the control program are made, they are instantly available to anyone who uses the system. Unlike the solar collector equipment, there is no need to manually distribute software updates.

The only possible drawback to the full Internet configuration is the security risks that go along with unlimited access. All the building automation systems discussed so far include a secure password access feature. Different users have different levels of access. Students are frequently 'view-only'. Teaching assistants have passwords that allow changes to set-points and operating schedules. The operators and programmers have a high-level password that allows changes to all parts of the system.

Before full Internet access was available, password protection was less important, because only 'pre-selected' personal computers had remote access. For the solar collector system described earlier, only personal computers with the proprietary software have access privileges. For the forced-air system described earlier, only computers within the Technology Computer Network had remote access. Just as the name implies, full Internet access means that anyone surfing the web could potentially use the system. This opens the door not only for legitimate users, but also for those with malicious intent. The password structure still presents a software-based firewall, but it is much more susceptible to hackers.

HOW MUCH DOES A REMOTELY ACCESSED HVAC LABORATORY COST?

The MET Department at Purdue University made a conscious decision to develop an autonomous HVAC laboratory. In other words, the HVAC systems described in this paper are independent of the primary heating and cooling systems for the larger building that houses the teaching laboratory. This approach offers the greatest flexibility. The surrounding environment does not affect laboratory experiments for thermodynamics, fluid mechanics, or controls. Laboratory technicians have full control of all HVAC components. Table 1 is a rough estimate of the equipment and labor costs of building a comparable facility from scratch. The overall $225,000 price tag for developing a comparable system may be prohibitively expensive.

There is another intriguing option that avoids all the costs summarized in Table 1. In fact, this creative approach does not even require a physical laboratory. Why not take advantage of the fact that all modern commercial buildings use building automation systems to optimize energy consumption? As outlined in reference 5, the remote access feature can transform an entire building into an educational laboratory for energy-related investigations. Passively monitoring a building's mechanical and electrical systems, without actually controlling them, could be very educational. This approach will become more feasible as building automation systems with full Internet access become more widely available. At that point, all that is necessary is a computer with Internet access, the IP address of a building automation system, and low-level password access.

SUMMARY

Remotely accessed building automation systems offer an innovative and inexpensive opportunity to

Table 1. Developing a remotely accessed HVAC lab from scratch is an expensive proposition

System	Approximate Cost of HVAC Equipment (mechanical and electrical)	Approximate Cost of Building Automation Equipment (sensors, actuators, and controls)	Total
Forced Air	50,000	25,000	75,000
Hydronic	50,000	25,000	75,000
Solar Heating	50,000	25,000	75,000
		approximate grand total:	$225,000

enhance the educational experience of engineering and technology students. Students will gain a greater appreciation of 'energy' once they have seen the sophisticated energy conservation strategies that are implemented in mundane commercial buildings.

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