Related Commercial Resources

CHAPTER 41. COMPUTER APPLICATIONS

COMPUTERS are used in a wide variety of applications in the HVAC industry. Rapid technological advances and the decreasing cost of computing power, memory, and secondary storage have changed many aspects of the HVAC industry. New HVAC design tools allow optimal solutions to be found in engineering applications. Building operations benefit from low-cost networking to achieve multivendor control system interoperability. Consulting engineers can search manufacturers' equipment and specifications online. Designers can collaborate from remote locations. More powerful applications that are also easier to use are now affordable by a wider segment of the industry; many HVAC calculations, such as heating and cooling loads, can be performed easily and automatically.

Business applications and infrastructure have also positively affected the HVAC industry. Open communications standards and internetworking allow fast, efficient communications throughout company and industry circles. HVAC design, manufacture, installation, and maintenance functions benefit as businesses build computing infrastructure through corporate information services (IS) or information technology (IT). Many cloud computing advances in the business community have been adopted by the HVAC industry as de facto standard practice.

1. INTRODUCTION TO COMPUTING TECHNOLOGIES

Because of rapid advances in computer technology, computers offer tremendous power at very low cost. However, the total cost of ownership of a personal computer is not limited to the cost of the computer hardware. Software, network connectivity, support, and maintenance expenses quickly surpass the initial cost of hardware.

Selecting a computer platform includes a wide variety of issues, such as

- Analysis of application needs
- Corporate computer support architecture and standards
- Vendor support, including guaranteed response time
- Central processing unit (CPU) power, random-access memory (RAM), graphics processing units (GPUs), and secondary or hard disk storage capacity
- System compatibility and interoperability between vendors
- Ease of use and required training
- Data back-up strategy: how will the data on the computer be restored in the event of a system failure?
- Security issues: what data will be accessible, and how will data be protected from unauthorized access?
- Network communications capability and compatibility
- Technical support live and/or online, including driver update support
- Information system infrastructure/interoperability requirements
- Technology reliability and obsolescence
- Total cost of ownership

Virtually all personal computers and laptop computers now have more than enough speed for basic business applications such as word processing and spreadsheets. Personal computers differ in their ability to handle multimedia graphics and sound, which are useful in advanced software applications. More recently, cloud computing solutions with subscription models have become common in the industry for agile development and deployment of software applications and business services.

An information system comprised of computer networks depends on the ability of computers to communicate with each other in a standard architecture. Technological advances have resulted in computer systems becoming obsolete in less than five years. Therefore, it is important to plan for compatibility with future business computer requirements. Software and hardware must match the needs of the user, and be consistent with the business system architecture.

System architecture standards from organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the American National Standards Institute (ANSI), and the International Organization for Standardization (ISO) have resulted in well-defined standards such as Ethernet, TCP/IP (transmission control protocol/Internet protocol), and HTTP (hypertext transfer protocol). As part of TCP/IP, an IP address is a uniquely identifiable number allocated to a device on the Internet or local network that allows information to be sent between networked devices. The combination of popular standards has resulted in network and Internet accessibility from local computers, and the adoption of cloud computing using remote computer resources.

1.1 SOFTWARE AVAILABILITY

Software can be purchased from manufacturers, distributors, representatives, discount stores, and computer specialty stores. Software price, support, return policies, and distribution vary from vendor to vendor. During installation, most software displays a detailed software license granting *use* rather than *ownership* of the software program. This license gives specific restrictions on how the software is to be used. Most high-volume software does not offer direct support, but many software companies offer pay-per-incident and other fee arrangements if desired. Many applications have online discussion groups or message boards, where solutions to problems may be found. With the advent of cloud computing, software subscription services are becoming more common, allowing users to purchase access to software for a period of time rather than purchase a physical product. Besides proprietary software tools, HVAC applications are widely available as open-source software. Following are some of the open-source licensing types.

Freeware is copyrighted software that is free. The user can run the software but must obey the copyright restrictions.

Public domain software is available to the public for little or no charge. Public domain software, which is not copyrighted, is often confused with freeware, which is copyrighted. Public domain software can be used without the restrictions associated with copyrighted software.

Shareware is software available for users to try before buying it; after the trial period, users are expected to register or stop using the application. There is usually a nominal registration fee.

1.2 CUSTOM PROGRAMMING

Using an existing software package is usually preferable to designing a custom application, which is much more expensive and potentially riskier. This is especially true for large, mission-critical software such as client-server applications. If, after careful evaluation, prepackaged software will not suffice, the choice must be made between in-house and outside development. Custom software can be (1) contracted out to a specialized firm, (2) developed solely by internal staff, or (3) developed by internal staff with consultation help by an outside firm.

Contracting to an outside firm involves hiring a specialized outside party to define, estimate, schedule, and create the software. Funds should be budgeted for the outside organization to support modifications or enhancements not specifically covered in the contract. Contracting outside is suitable for an organization that does not have the resources or expertise to accomplish the project. Disadvantages of this approach include the expense and lack of control over the program. Licensing and ownership issues must be defined in the contract.

Developing the program internally is viable only if the skills and resources are available. Internal projects are easier to control because the people involved are co-located.

Consultation help from an outside firm involves a skilled outside party assisting internal staff, who may have insufficient skill in the area on their own. Outside firms can provide expertise to get a project going quickly. Long-term support and maintenance of the software are done in-house.

Specifications are key to the success of a software project. Calculations, human interface, reports, user documents, and testing procedures should be carefully detailed and agreed on by all parties before development begins. Software testing should be specified at the beginning of the project to avoid the common problem of low quality resulting from hasty and inadequate testing. Design testing should address the human interface, a wide range of input values including improper input, the various functions, and output to screen, disk, or other media. Field tests should include conditions experienced by the final users of the software.

With any development approach, good, understandable documentation is required. If for any reason the software cannot be adequately supported, the program will have to be replaced at substantial cost.

1.3 PROGRAMMING LANGUAGES

HVAC application software is written in a variety of computer languages. Most commercial software is written in C++, C#, or C, to allow fast speed and efficient use of resources. In addition, there are several programming and scripting languages such as Python, JavaScript, Ruby, Perl, Swift, and Rust used for web and mobile computing and customized software applications. The choice of programming language depends on several factors, including the programming paradigm (e.g., compiled versus interpreted, procedural versus functional versus object oriented), operating system, memory requirements, development environment, and user-interface features. The targeted deployment platform (e.g., stand-alone desktop, web-based application, a combination of both) often determines the programming language used. It is also more common to see several programming languages used to develop independent components of a software application and then integrated to deliver an end-user software tool. For example, energy simulation software tools use a procedural programming language to perform the calculations but use a different programming language for multiplatform user-interface development.

In addition, there are special application programming languages, such as MATLAB and R, used for mathematical programming and analysis of large amounts of data.

2. BIG DATA

The term "big data" is often used to reference related concepts, such as business intelligence and data mining, but differs in that it refers to data sets that are so voluminous and complex that traditional data processing application software is inadequate to deal with them. Big data challenges include capturing data, storage, analysis, search, sharing, transfer, visualization, querying, updating, and information privacy. There are four recognized dimensions of big data: velocity, volume, variety, and veracity (Figure 1); a fifth item, value, is sometimes added.

Data sets grow rapidly, in part because they are increasingly gathered by cheap and numerous information-sensing Internet of things (IoT) devices, such as mobile devices, aerial (remote sensing) devices, software logs, cameras, microphones, radio-frequency identification (RFID) readers, and wireless sensor networks. The world's technological per-capita capacity to store information has roughly doubled every 40 months since the 1980s; as of 2012, 2.5 exabytes (2.5×10^{18}) of data were generated each day. By 2025, market intelligence advisors predict data will exceed 160 zettabytes (10^{21}). One question for large enterprises is who should own big data initiatives that affect the entire organization.

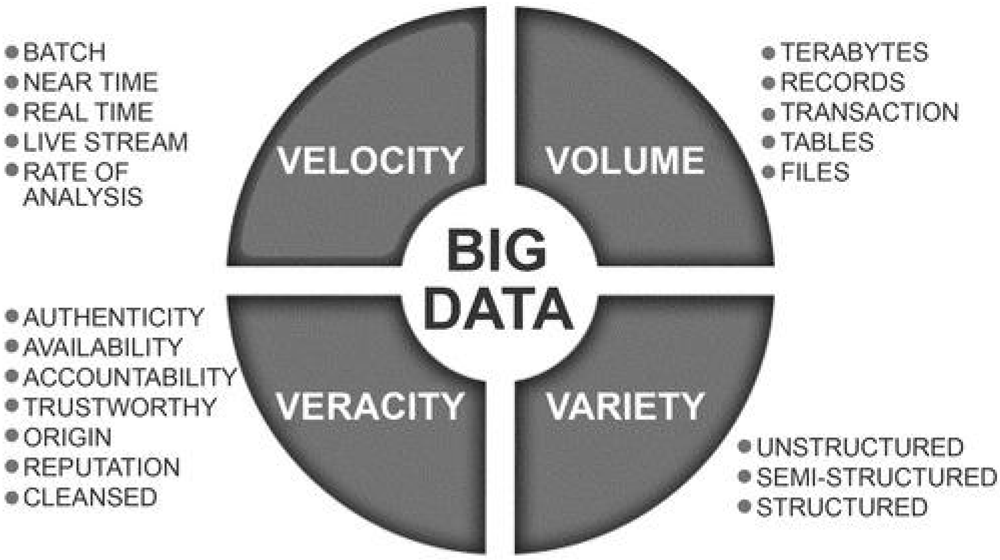

Figure 1. Four Vs of Big Data (Courtesy of Ennovision, ennovision.co.uk/)

Relational database management systems, desktop statistics software, and visualization packages often have difficulty handling big data. The work may require massively parallel software running on tens, hundreds, or even thousands of servers. What counts as big data varies depending on the capabilities of the users and their tools. Expanding data collection capabilities and maturing software tools make big data a moving target.

Big data entails a shift of analytical focus, from descriptive analytics to predictive and prescriptive analytics. Descriptive analytics handle questions about what happened in the past, typically in the form of reporting; predictive analytics tend to address what might happen next, and prescriptive analytics attempt to develop a response.

The main benefits of big data analytics are to (1) draw insight from data, (2) make better decisions based on that insight, and (3) automate those decisions and formulate them into a process. A big data solution may address a particular problem; it is valuable that a given solution is rooted in the original problem. For example, user churn prediction should reduce user churn and therefore avert a decline in revenue from subscriptions. Building a business case for big data analytics starts with a defined problem, not with data or technology.

2.1 HVAC APPLICATIONS

In the context of HVAC&R, big data tends to refer to the use of predictive analytics, user behavior analytics, sentiment analytics, operational analytics, or certain other advanced data analytics methods that extract value from data. Analysis of data sets can find new correlations to spot use trends, equipment interoperability problems, and so on.

With the explosive growth of the IoT, there are more connected devices offering more information than ever before. The ability to analyze this data has also vastly improved. Intelligent analytics tools have meant that data sets that previously would have been far too large to analyze for traditional methodologies are now a valuable source of insight into how to improve systems and behaviors. For instance, facility managers are now able to gather information from thousands of data points in a building. The installation of a vast array of information-gathering and intelligence/analytical technologies (e.g., smart sensors, smart meters, smart breakers) to inform operational decisions can be crucial to operator oversight of a facility.

Using data analytics, large volumes of building data can be transformed into actionable information that targets underlying problems and creates opportunities for energy savings. This type of management can save up to 20% annually on maintenance and energy costs by refining service programs and achieving optimal building performance and cost effectiveness. For example, with smart HVAC systems and the right sensors, a building manager can be made aware of system leakages where cool air may be migrating from the building, causing energy loss overnight.

Sustainability

This same technology can simultaneously assist in driving environmental sustainability. For example, by checking carbon dioxide levels to see if people are in the room, a building management system (BMS) can manage the HVAC systems to respond to presence appropriately, saving energy where possible. If someone is detected, a BMS may turn on ventilation to bring in fresh air, turn more lights on, and adjust the temperature out of a power-conserving deep setback. When people leave, everything goes back to an energy-saving state. Major drivers for investment in technology and building design are commonly a combination of saving operational cost, the need for innovation, increased productivity, and talent attraction/retention.

Economic Benefits

There are maintenance-cost benefits to getting equipment management right with big data and analytics. Smart systems offer embedded analytics, including automated fault detection and diagnostics (FDD). By automating detection and diagnosis of equipment health, FDD can help organizations better predict the timing of costly equipment failure. This allows them to make informed decisions when it comes to addressing problems and repairing equipment before critical failure. Problems such as unnecessary equipment operation, suboptimal strategies, faulty equipment, or poorly tuned loops that are undiagnosed and creating energy wastage and comfort issues, can be addressed by these analytical techniques.

For facility managers, the return on investment (ROI) of a project is often of primary concern. Though one-off investments in infrastructure may appear to be simple solutions, their long-term ROI is often uncertain. A new solar panel may promise a reduced energy bill; however, without proper analysis, it may not properly address a facility’s underlying energy inefficiency issues. When decisions are made without proper guidance by data and intelligence, those investments may prove troublesome or expensive.

Guided by experience and insight, the optimal use of an investment can be identified. When choices range from repairing/replacing existing and outdated infrastructure to analyzing and resolving system inefficiencies and/or recommending new infrastructure where necessary, the best ROI will be found by someone with extensive training and knowledge of the latest trends and technologies.

3. CLOUD COMPUTING

Since 2010, cloud computing has become a very common, cost-effective solution to access high-performance computing infrastructure and services on an as-needed basis. The National Institute of Science and Technology (NIST) defines cloud computing as “a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.”

Essential Characteristics

- On-demand self-service: provision computing capabilities such as servers, network storage, and databases
- Broad network access: accessibility of cloud resources from mobile devices, laptops, workstations, etc.
- Resource pooling: pooling resources to serve multiple customers independent of location of the physical resource
- Rapid elasticity: rapidly and elastically provide the computing resources automatically as needed
- Measured service: monitor, control, and report resource usage with a metering capability

Service Models

- Software as a service (SaaS): application software running on a cloud infrastructure, accessible over Internet
- Platform as a service (PaaS): tools for consumers to develop and deploy application software
- Infrastructure as a service (IaaS): capability provided to consumer for computer servers, storage, and resources

Deployment Models

- Private cloud: provided for exclusive use by a single organization comprising multiple users
- Community cloud: provided for exclusive use by a specific community, either on or off site
- Public cloud: provided for open use by general public
- Hybrid cloud: a composition of two or more of the preceding models that remain unique entities, but work together

Several leading cloud service providers have developed multiple data centers that provide a full range of cloud computing resources and infrastructure to support all these deployment models. HVAC industry applications have begun to adopt cloud computing for most aspects of design, documentation, data storage, and mobile device access to all building design and operational data. Big data and cloud computing together have enabled collection and analysis of BAS data for improving building operations and automation of fault detection and diagnosis.

4. MOBILE COMPUTING

There are two distinct, common types of mobile applications: web-based and native. Web-based means, as the name implies, that a web site has been designed to be functional and visually appealing on a smaller (mobile) screen such as a cell phone or tablet. For this reason, these applications require Internet access via Wi-Fi or cellular data because they are just a user interface for the full web site. Native mobile applications, though still designed to operate and be user friendly on a smaller screen, operate via a device’s operating system, so Internet access is not required to use the application. There are benefits and drawbacks to each type of mobile application.

Web-based applications are most common: examples include apps on a phone (e.g., navigation, social media). These are easy to use and easy to maintain. Computing does not require as much memory or computing space, and these applications typically work across all operating systems. This allows owners of the app to maintain updates more easily; updates can be sent out to all users at one time.

However, with any web-based application, users are at a higher security and privacy risk because all data is being sent out through the web. Some of these risks can be mitigated with privacy settings, but these could limit the application’s full operating abilities. Even common privacy settings, such as limiting access to location or photos and data, can prevent the application from functioning at its full capability.

Native applications are typically purchased or sold alongside another product and operate using a mobile device’s operating system. These are typically designed to work on one type of operating system. These apps rely on a device’s operating system, so they may not require Internet access (i.e., can operate at all times), and data is typically more secure. These applications are typically designed by industry experts (including but not limited to HVAC), so the user can be confident in the data/results provided.

However, because the data uses a phone’s operating system, backing up data can be challenging. Users must also be cautious in using these applications, because apps can be written in any language or for any operating system. In the case of HVAC design, if a designer is using more than one company to design a system (e.g., chillers and cooling towers), this potentially forces the user to design one subsystem at a time. This limits the designer to subsystem efficiencies, a disadvantage. Some of this can be avoided if the user is aware of the operating systems up front.

Companies that design mobile applications and mobile application platform software have also created **hybrid mobile applications**. Hybrid mobile applications are designed at a variety of levels that take the best of each application type. To choose the right application, various questions need to be addressed. As with any technology, those of greater capability also require more time and cost to develop and involve more difficult maintenance.

Important questions to ask are

- What is the budget?
- What is the (or the customer’s) required security level?
- How much time is available to implement a solution?
- How much does the end user know about mobile applications?
- What is the end user’s operating device capability?

- How user friendly/easily accessible should the mobile application be?
- How many end users will there be?

Many applications today are designed to have a combination of both web-based and native application traits. Some companies even have a mobile application platform advanced enough to take multiple native applications and provide a means of operating all applications at once. Once the selection questions are answered for a given project, the appropriate route can be taken. For those in HVAC looking to add mobile app development to a business, there are a couple of options. As with most business concepts, solutions can either be developed in house or outsourced to an expert. This depends on the complexity of the project and the software development capability at a given company.

If outsourcing, there are various companies that provide enterprise mobile application solutions (i.e., mobile applications designed for more complex projects that are typically associated with enterprise-size projects, with the complexity determined by the answers to the questions previously listed). Complexity increases with the number of users, or more back-end data analysis (native application capabilities) is needed. Lack of time for a solution or a high first-cost, more user-friendly application both increase complexity.

When outsourcing, look for products/platforms that can

- Allow a designer to build a mobile application
- Design multiple levels of hybrid native/web-based mobile applications
- Combine mobile apps that a company already has available

The best option is not the same for every company or project, and it is up to the project lead or company managers to determine the best course of action. However, a clearly defined goal and project specifications help optimize use of mobile applications.

4.1 MOBILE APPLICATIONS IN THE HVAC INDUSTRY

HVAC companies often develop their own mobile application platform for their employees. However, to provide HVAC industry members with tools necessary to the industry, ASHRAE has supported development of several mobile applications. The applications are intended provide members with tools that can be used quickly in the field to check compliance with ASHRAE standards and equipment performance. The following is a brief introduction into some of the most commonly used ASHRAE supported applications.

Psychrometric App. The ASHRAE HVAC Psychrometric App is designed for users to easily view a psychrometric map while out in the field. This app allows users to plot points and processes on a fully customizable psychrometric chart. Then, if necessary, results from the points can be shared via e-mail for later use. Figure 2 shows the standard home page of an example psychrometric chart. Cross hairs enable the user to know exactly where the cursor is pointing on the map. To plot, users double-tap on a point in point mode.

Because it is only available on iPad® or iPhone®, this application is intended for users who are in the field or in a conversation with a customer when full use of their tools is not available. For this reason, both individual point processes and a PDF of a psychrometric chart can be e-mailed using the e-mail icon.

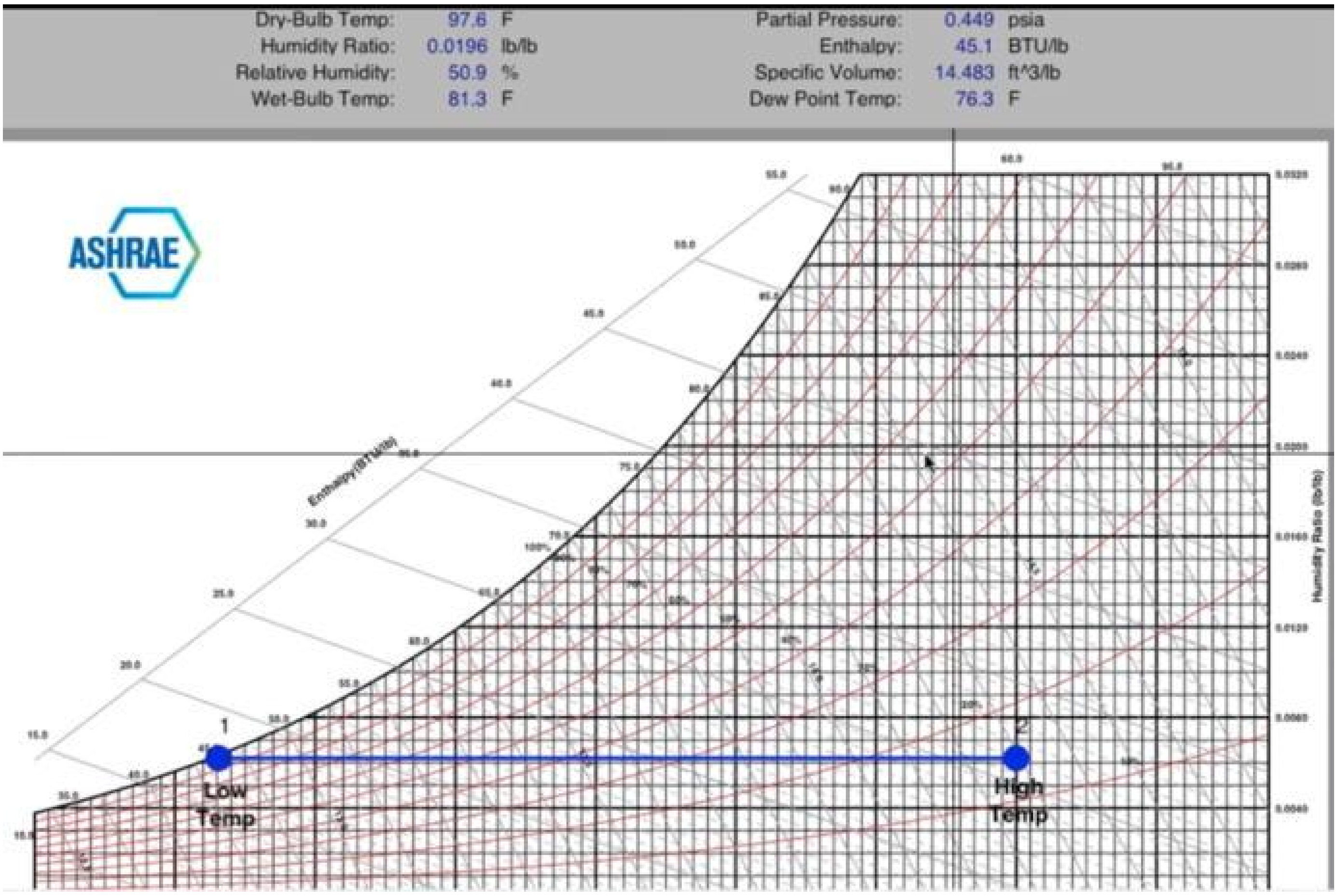

Figure 2. Psychrometric Chart Example

Duct Fitting Database. This application, based on ASHRAE's desktop *Duct Fitting Database* tool, allows users to produce pressure loss calculations for the more than 240 ASHRAE duct fittings from the field. Calculations can be in SI or I-P units and can easily be shared via e-mail for further use or analysis.

90.1 Energy Cost Budget Application. This ASHRAE-sponsored tool enables users to model compliance with ASHRAE *Standard* 90.1-2010. This application follows the energy cost budget form in the *User's Manual* (ASHRAE 2016a) and allows users to enter all available site details and then export the data into the energy cost budget report in Excel®. This application is web based, and the data can be accessed via any device that has Internet access.

HVAC ASHRAE 62.1. This application allows users to perform calculations from the 2007 and 2013 versions of ASHRAE *Standard* 62.1,Ventilation for Acceptable Indoor Air Quality. It loosely follows the 62MZCalc.xls Excel® spreadsheet from the ASHRAE (2016b) *62.1 User's Manual* for each project; however, as with most applications, the capabilities exceed that of manual entry documents. Users can create an unlimited number of projects. Each project can be created quickly, and calculation results can be shared via e-mail for a detailed analysis when the user is no longer in the field.

HVAC PT Chart Application. This application makes quick calculations of refrigerant properties in the field. Users can choose the refrigerant and units they are interested in to obtain refrigerant pressure or temperature.

HVAC Duct Sizer Mobile Application. This application is simple compared to some of the others described here, which involve more intricate calculations. However, it is still useful for easy field calculations: it allows users to size ducts based on airflow and or dimension. To get to these calculations, the user simply follows the appropriate prompt.

5. CYBERSECURITY

Cybersecurity is the methods and practices of protecting devices, data, and networks from attacks. This section focuses on information related to cybersecurity on **operational technology (OT)** networks that typically host HVAC and related systems, infrastructure, and interfaces, but there are many parallels to cybersecurity on **information technology (IT)** networks. Cybersecurity must be a consideration throughout the entire life cycle of a building and requires sound planning and continuous maintenance and monitoring. As cybersecurity attacks evolve over time, training and policies must change to meet new threats.

Industry guidelines for cybersecurity exist for computer system administrators and for network administrators. These guidelines are relevant to IT and OT networks and should be the basis of any cybersecurity plan. The latest versions of these guidelines can be found online. One source, NIST *Standard* SP 800-82 contains guidance that is more relevant to

HVAC systems and is based on NIST *Standard* SP 800-53. BACnet Secure Connect (BACnet/SC) is designed to meet the needs of IP infrastructures, providing a critical piece of the security plan for networked building technologies.

5.1 BASIC CYBERSECURITY PRACTICES

Keeping devices that support HVAC control systems secure requires some basic security practices and procedures. These procedures can be used for company-owned devices but are also applicable for personally owned devices.

Importantly, every person who will use a computer on any network operated by their business must be aware of basic cybersecurity concepts. HVAC equipment on the OT network may be protected by a **virtual private network (VPN)**, but it will still not be secure if the IT network is compromised. Free and low-cost online cybersecurity training is available. Be sure to select training that is matched to the employees' roles. A budget should be allocated for employees who have roles that require specialized training.

Many types of malware are spread through fraudulent e-mail that is designed to look legitimate. Malware may also be disguised as a different program offered for download. Training employees to recognize malware is an important part of the strategy to defend your network.

The best practices for all electronic devices (e.g., PCs, laptops, tablets, phones) are very similar. Listed here are some tips to improve the security posture of these devices.

Operational Technology Network System Isolation

Users should not connect to untrusted networks or systems, and outside computers should not connect to an OT network. Many control systems have been connected to the Internet to provide convenient, 24/7 operation and maintenance support, remote monitoring capabilities, and data collection for analysis. However, most control systems have not been designed to operate in the cyber-contested environments that have had negative effects on critical infrastructures throughout the world. Until control systems have robust security measures integrated throughout the equipment stack, it is recommended that these systems remain in an isolated network environment that connects only to trusted, secure networks. If circumstances do not allow isolation, then remote connections or any other connections from or into the control system network to other networks should be through a protected communications channel such as a VPN. A dedicated computer could be maintained for vendor use.

Only dedicated devices should be used for control systems on the OT network. To save money, many devices are used for multiple purposes and are connected across multiple networks. However, this introduces inherent risk that can propagate viruses, ransomware, and other malware across multiple systems. Due to the lack of cybersecurity resilience, it is recommended that users avoid this practice to minimize potential contamination of the control system environment. E-mail, web browsing, and other Internet activity should never be done from a computer on the OT network.

Password Security

A strong password is crucial. Password selection is one of the few areas where the actions of each user can affect the security of the entire BAS. The strength of a password is determined by both the length and range of characters used. A short password will be weak regardless of complexity. A long password, usually with 12 or more characters, including numbers, uppercase letters, and symbols would be strong. Modern systems should allow a password up to 64 characters. Length is the more important factor: it would be better to have a long password with only a few numbers or symbols, than a short password with many. A short phrase may be easier to remember than a long password, and more difficult for an attacker to break. Generally, the longer the password the better. The strength of the password should reflect the importance of what it is protecting.

If it is in the dictionary, do not put it in a password. Except in a long passphrase, dictionary words should be modified by replacing characters with numbers/symbols or by inserting numbers/symbols in the word. Avoid any use of common words like "password" or sequences like "123" or "qwerty." Do not use company- and industry-related words. If replacing letters with symbols, do not use a predictable substitution, such as @ for a.

Do not use any personally identifiable information, such as birthday, social security number, address, etc., as part of a password.

Do not use the same password on more than one account. Default passwords should never be left on any account. Many attacks rely on default passwords not being changed. Also, do not share accounts and passwords. Each user of a system should have their own account and their own password.

Consider using a password manager. These are applications that can generate secure passwords for you, and use them to help you log in to web sites. Users then only need to remember one password.

For detailed guidance, consult the NIST *Standard* SP 800-63-3, Digital Identity Guidelines.

Account and Software Management

It is important to use an account with an appropriate privilege level. Using an account with security privileges that are too high creates greater vulnerability. Everyday use does not require administrative privileges.

Software updates are important to install. They are usually provided to fix problems with a current version of the software that may lead to poor performance or put the device at risk. If a device is company owned, there should be guidelines or policy governing updates. If a program is no longer supported and is not being updated, it should be removed from the device.

System updates update the software that runs a computer. Devices may be configured to tell users when these are available, if connected to the Internet. *Application updates* update a specific application or suite of applications. Many applications inform users of available updates when they start, but some may require users to check.

Only software from known sources should be installed. Random apps or utilities should not be installed, because they may disguise malware. Programs or apps to be installed should also be approved by IT personnel. It is essential to have antivirus software installed (it may be available for little to no cost). Computers on an OT network should only run software related to that purpose.

Backups are critical; in the event of a ransomware attack (wherein files are encrypted and a price demanded to regain owner access), it is the best method to recover files. Using software designed to perform backups will facilitate the fastest recovery. Files copied to a network drive may also be affected by a ransomware attack; backups should be kept offline.

Antivirus software is very important to have on every computer system connected to a network. Even if a computer is not used to access the Internet, it could be vulnerable if other computers on the same network become infected. Antivirus software may be included with your operating system or available as a standalone program.

Avoid software services such as e-mail and personal web browsing on the OT network. These two services are the primary malware attack vectors. Removing these two services will greatly enhance the security of the system.

Internet Security

It is important to have effective security practices on the IT network and on personal devices. Many attacks come through websites, so it is important to strengthen the security of web browsers. This can be accomplished by installing extensions, which are small browser add-ons that often act like a utility program; they may help with bookmarks, tabs, or security. This section discusses some types of extension that improve security. Note that, although most web sites are safe, caution is always advised.

Ad Blocker. One common attack method for malware distribution is malicious links hidden in online advertising. Some attacks only require the user to move their mouse cursor over an advertisement. Ad blocker extensions stop or limit the downloading of advertisements and are highly recommended.

Antivirus. Antivirus software producers also have browser extensions available. They typically offer a range of security-related functionality. They may be available for free or as part of an antivirus software package.

JavaScript Blocker. JavaScript is a computer language used to add functionality to web pages. As with any tool, it is also often misused. A JavaScript blocker extension allows users to specify which websites are allowed to run JavaScript on the browser. This can be selective, with the JavaScript required to display a page allowed and the JavaScript that could present a security risk blocked. This type of extension is highly recommended.

Phishing. Phishing attacks are a type of social engineering attack where criminals attempt to obtain information from victim(s), or trick victims into giving the attackers access to their computers or networks. The information may be personal (financial, social security, etc.) or business related (business secrets/plans, passwords, etc.). Phishing attacks may come in many forms, including e-mail, phone, or text message. Any e-mail requesting personal or business information should be treated with suspicion. Other flags include an unknown or suspicious sender address, poor formatting, links that appear strange, and grammar or spelling errors. They commonly create a false sense of urgency in the message to get the recipient to respond before they analyze the message or wonder whether it is appropriate to respond. Protect users and networks by looking for those clues when reading email. If an e-mail looks suspicious, report it to the IT department.

Safe Browsing. It is important to be wary when following links, especially those found in chatrooms or search results. Malware distributors post links in chatrooms, or design pages to match common searches. Use of encrypted pages allows greater security. Almost every website allows users to request an encrypted version by changing the "http" in the address to "https." This is important if the page contains forms with personal data. Most web sites now use https by default. Browser extensions can also be installed to enforce use of https.

Other resources are available on control systems cybersecurity that can provide specific, detailed guidance for implementing cybersecurity in HVAC systems. The International Society of Automation's ISA/IEC *Standard* 62443 addresses cybersecurity standards for industrial control systems. More information can also be obtained from the U.S. Department of Homeland Security's Industrial Control Systems—Computer Emergency Response Team (ICS-CERT), whose mission it is to reduce the risk of systemic cybersecurity and communications challenges in cyberdefense and incident response. ICS-CERT, aligned under the National Cybersecurity and Communications Integration Center (NCCIC), offers a free tool that provides a systematic approach for evaluating a system's security posture using the selected security controls listed in NIST *Standard* SP 800-53. The Cyber Security Evaluation Tool (CSET) is a desktop software tool that guides owners and operators through a step-by-step process to evaluate their system security practices.

Physical building security measures are discussed in Chapter 61. ASHRAE *Guideline* 13 also has guidance on physical and cybersecurity measures.

6. SOFTWARE APPLICATIONS

Computer software applications have revolutionized work processes and practices in the building industry. From drafting tables, to HVAC load calculations, to duct fabrication, software applications have transformed the tasks performed by designers, construction managers, and building operators from manual to automated ways of working. Computerization of work processes promises improved productivity and quality along with decreased cost, time, and environmental impact. Computerization also brings learning curves, disruption of time-honored practices, and its own set of issues to be resolved.

This section discusses a range of software applications currently in use in the buildings industry, as well as some emerging trends. It is not meant to be an exhaustive listing of applications, nor a comprehensive discussion of their use. Rather, this is meant as a broad introduction to the variety of software applications currently available, and as a starting point to further reading and exploration.

6.1 EXAMPLE SOFTWARE APPLICATIONS

Numerous software applications are currently used in the cycle of building/facility design, construction, and operations and maintenance. These software applications are tools that support practitioners in their work processes in each of these stages. The extent to which these tools are adopted is based on industry segment, company/firm, and individual practitioner methods. However, the overall trend is toward increased use and more rapid change both in individual tools and in industry practices.

Design

Architectural Design (Massing, Space Layout, Rendering). Simplified energy simulation tools can provide easy and quick performance analysis at early stages of design, thus assisting designers and architects in making decisions. Simple tools do not require much detailed information as inputs, instead using standard defaults and modeling processes in place of building specifications that might not be available at the early design stage (e.g., schedules, internal loads). Simple tools can be very useful for preliminary energy performance prediction and for informing early design decisions.

MEP Design (HVAC Sizing, Selection, Layout; Electrical, Plumbing). There are several mechanical, electrical, and plumbing (MEP) design software solutions that can integrate building information models (BIM) and calculations in an intelligent computer-aided design (CAD) environment. These can help engineers design, detail, estimate, fabricate, and install MEP building systems more quickly and accurately. Software can either have an integrated BIM capability or provide a capability to import BIM models created by other tools, by reading the file itself or through a Green Building Extensible Markup Language (XML) (gbXML; www.gbxml.org) import.

These tools can read the physical properties of the BIM objects to calculate the HVAC loads space by space. They can also help define air duct and piping networks, taking into consideration flow rates, pressure drops, and other parameters and provide the ability to develop piping/ducting networks in two and three dimensions. Some tools even provide complete documentation, including detailed calculation sheets, technical reports, bill of materials, bids, and more.

Energy Simulation. Whole-building energy simulation tools are used for characterizing energy flows and analyzing the impact of building characteristics, thermal loads, and system performance on building energy consumption, thermal comfort of occupants, etc. A building energy simulation tool allows a user to provide inputs for local weather; building geometry; building envelope characteristics; internal heat gains from lighting, people, and plug loads; heating, ventilation, and cooling (HVAC) system specifications; operation schedules; and control strategies. The simulation engine then calculates the building energy performance using complex physics-based models to determine thermal load, resulting energy use, and related metrics such as occupant thermal comfort and carbon emissions.

Code Compliance. Numerous jurisdictions (within the United States and elsewhere) require energy code compliance of building designs prior to issuing building permits. Many code compliance software applications have been developed to assist in the process of testing and documenting energy code compliance. Some of these applications focus on so-called prescriptive approaches to compliance that provide rules for various aspects of a building design, such as minimum window performance characteristics and window-area-to-floor-area ratios. More sophisticated performance-based approaches rely on energy performance simulation to test and document code compliance. In all instances, each jurisdiction will provide a list of approved code compliance software applications.

Construction

Construction Document Production. The use of architectural and MEP design applications during the design phase can greatly aid the production of construction document (CD) packages. This has been true since the development of two-dimensional design tools, but has become even more common and productive since the development and adoption of three-dimensional and BIM-based design applications. These models, if created following best-practice standardized techniques, can easily generate CD packages for hand-off to construction planners and managers.

Construction Planning and Execution. BIM and 3D building models created during design that include MEP systems details and physical layout and architectural features (e.g., walls, floors, rooms) can be used for applications beyond that of CD production.

Automated clash detection is one such application, in which piping, ducts, and electrical runs that interfere spatially (either with each other or with architectural features) can be detected and brought to the attention of designers and contractors for resolution before actual construction.

Even more sophisticated applications, such as four-dimensional construction planning, also are possible with well-developed three-dimensional/BIM building models. Four-dimensional construction planning involves applications that add the dimension of time to a model, supporting construction sequencing for complex projects where trade coordination and materials delivery are critical.

Facility Handover. The true benefit of BIM is the capture of accurate building information that can be more easily updated throughout design and construction to create up-to-date as-built building models, which can be handed over to building owners and facility managers and operators for use in the longest phase of the building life cycle: occupancy. These building models, if kept accurate, can be used for a variety of applications, including occupancy space planning, space rent assessment, asset (e.g., furniture, moveable equipment, fixed equipment) management, maintenance scheduling, work order tracking, and more.

Energy Simulation. Value engineering often occurs during the construction phase. This process, along with change orders and redesign, can significantly impact the eventual energy and occupant comfort performance of the constructed building. Energy simulation applications can be used during these processes to assess the performance impact of changes from the original design and provide important feedback to ensure desired whole-building performance.

Operations and Maintenance

Software applications to be used during the operations and maintenance (O&M) phase of a building life cycle are generally less abundant than those for other phases. This may be due to the less computationally intensive nature of O&M work processes, but the computerization of these work processes promises substantial and longer-lasting benefits due to the duration of the O&M phase. Much of the application of software to this phase revolves around information management tasks such as asset (equipment) management, space and change management, occupant comfort (hot and cold calls), and maintenance work order management. However, newer applications such as fault detection and diagnostics, energy demand management, and continuous commissioning, along with the periodic use of energy simulation for HVAC system optimization and building audits and renovation (design and code compliance), presents many further opportunities for computerization.

Building Automation Systems. Building automation systems (BASs) provide both manual and automatic centralized control of a building's HVAC, lighting, and other systems, using a network of sensors and activators accessed and programmed through the BAS. The objectives of building automation include improved occupant comfort, efficient operation of building systems, and reduction in energy consumption and operating costs.

Computerized Maintenance and Management Systems. Computerized maintenance and management systems (CMMS) (also called facility management, enterprise asset management, or computer-aided facility management) are software tools that maintain a database of information about a building/facility and provide work order scheduling, asset and space tracking, and other capabilities to support O&M activities in buildings. These tools also often provide dashboards (high-level display of information in an organized format) and more sophisticated report generation capabilities.

Continuous Commissioning, Fault Detection, and Diagnostics. Building automation systems can also support enhanced analytics that use the continuously collected building system data to perform continuous commissioning and detect and diagnose faulty system operation. These analytics can lead to alarm notifications that allow building operators to identify energy- and cost-saving opportunities, occupant comfort issues, and mechanical system failures or inefficient operation.

Demand Management and Response. BASs also provide access to the real-time building energy use data and building system control, as well as access to outside information regarding utility grid energy use, required to perform active demand management and demand response control operations.

Energy Simulation. Energy simulation tools can also be used for a number of applications during the O&M phase of a building. This includes prediction of savings from building-audit-identified energy efficiency measures, design optimization and code compliance during renovation, ongoing HVAC system optimization, fault detection and diagnostics, and demand management and response.

6.2 BIM AND DATA INTEROPERABILITY

ASHRAE members and other professionals in the buildings industry use a wide variety of computer software applications. Historically, these applications have generally been stand-alone desktop tools, using unique custom, and often proprietary, data models to describe the information they require. Moving from one application to another (e.g., between architectural and mechanical design and energy simulation) has required manual recreation of often similar building information in different formats. This process consumes considerable time and effort and invites error in the different models of the same building.

BIM technologies and procedures have been developed over the past several decades to address this problem. The benefits of automated data exchange between disparate software tools, often referred to as **data interoperability**, have been recognized for years, but such exchange has still not reached a level of wide adoption. Some progress on this was made with ASHRAE research project RP-1468 (Clayton et al. 2016). However, BIM has recently been gaining traction, especially in the design and construction stages of the building life cycle.

Digital twin technology for manufacturing and the architectural, engineering, and construction (AEC) industries has rapidly evolved over the past couple of years. AEC digital twins are dynamic, up-to-date BIM representations of a building. With a complete collection of all data in one place, a building's digital twin evolves with the flow of real-time input from building automation system sensors, IOT sensors, and more.

Industry guidelines for cybersecurity exist for computer system administrators and for network administrators. These guidelines are relevant to the network portion of networked HVAC systems. The latest versions of these guidelines can be found online. NIST *Standard* SP 800-82 contains guidance on industrial control system security that is more relevant to HVAC systems and is based on NIST *Standard* SP 800-53.

7. BUILDING AUTOMATION AND CONTROL

Controls systems perform functions such as monitoring sensors, controlling equipment, scheduling, alarm reporting, energy use monitoring, and trend logging. Systems may use pneumatic or electronic control systems to perform some of these functions, but most modern systems use computers or controllers in direct digital controls (DDC).

Common types of DDC systems and their functions include the following:

- Building automation system (BAS): automating monitoring and control
- Energy monitoring and control system (EMCS): conserving energy by both automatic and manual control with the aid of energy monitoring
- Energy management system (EMS): conserving energy by specific automatic control programs
- Facility management system (FMS): HVAC control of a subset of multiple subsystems or buildings, including fire, security, elevator, or manufacturing systems

BAS has become the most popular term for description of a computerized control system that may provide one or more of these functions and is the term adopted by ASHRAE *Guideline* 13.

7.1 APPLICATION AND PURPOSE

BASs can be applied to achieve several different goals and outcomes, often simultaneously. Example applications include

- Control for energy efficiency/optimization
- Occupancy conditions and comfort, such as outlined in ASHRAE *Standard* 55
- Equipment and ventilation scheduling
- Lighting control
- Security
- Life safety
- Code compliance
- Utility-based demand load shedding
- Fault detection and diagnostics for preservation of capital and utility expenses
- Trending of building and building equipment conditions and operation
- Remote access

7.2 NETWORK ARCHITECTURE AND COMPONENTS

BAS components are usually arranged and interconnected in a hierarchical structure that can be described in four tiers (Figure 3).

Tier 1 comprises enterprise and site connectivity devices, which includes web servers, user interfaces, trend databases, time schedules, analytics, demand response, load shed protocols, IP Backbone, VLAN, and the Web. This tier is often the point of connection for remote access and for data sharing with external optimization services. This is also the point that represents a cybersecurity risk from outside the network and requires coordination with building network personnel to maintain security while allowing the necessary connectivity.

Tier 2 is the building infrastructure and includes components that bridge Tiers 1 and 2. This may include routers that interconnect building systems such as HVAC and lighting for access to Tier 1. This tier is usually IP based and may also contain network controllers that operate equipment directly, such as a variable speed drive or programmable controllers. This is also the tier where open building control protocols such as BACnet® or LonWorks® originate to connect subsystem components.

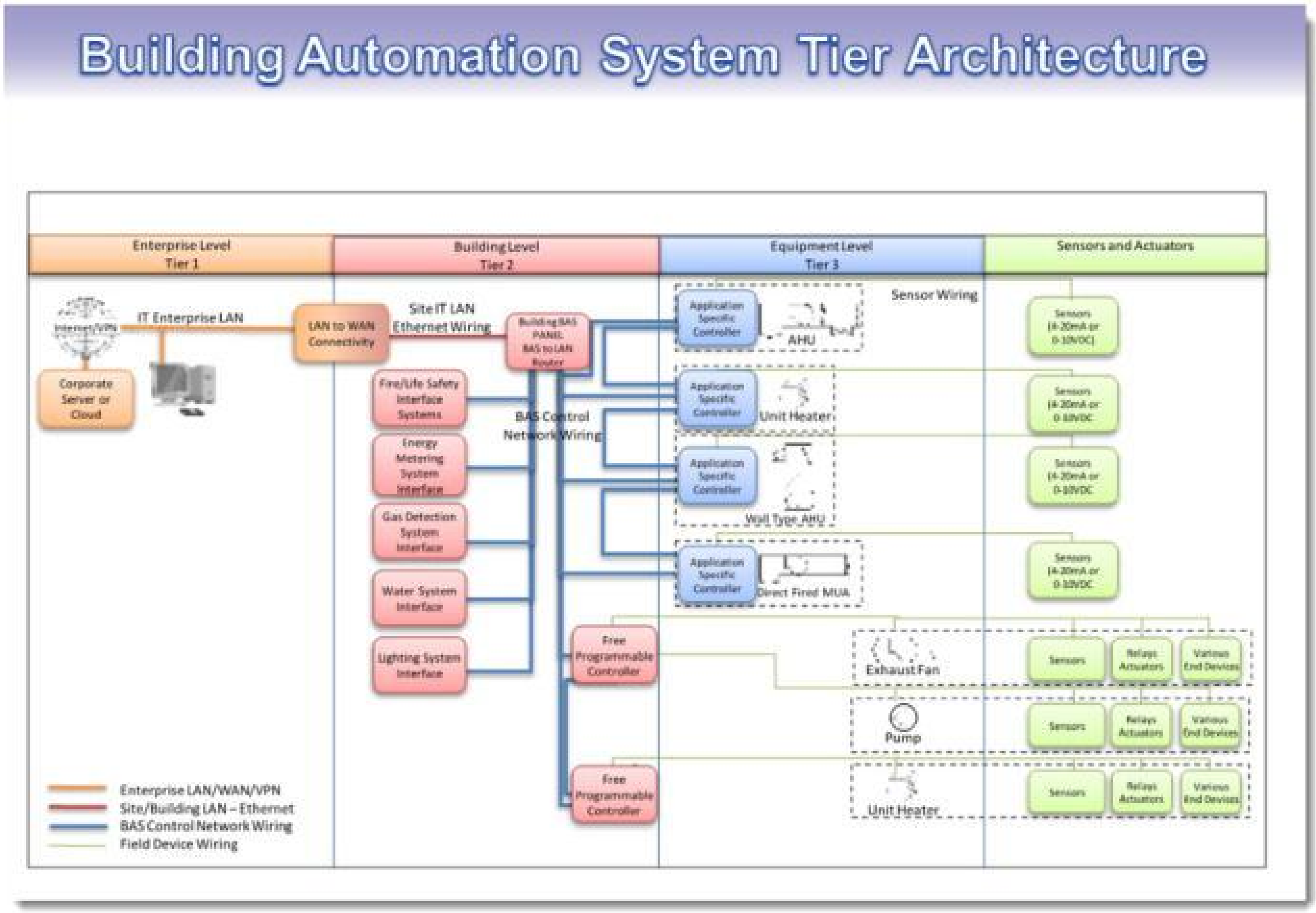

Figure 3. Tiers of BAS (ASHRAE *Guideline* 13)

Tier 3 contains application-specific controllers (ASCs) that control equipment or subsystems. ASCs can interconnect to other system components through the building control network but are generally used as the main controller of equipment and may include the point of connectivity to system sensors.

The last tier contains sensors and end devices such as relays and actuators. In general, components on this level do not contain any control logic and are either input or output devices. The advent of network sensors and other devices may alter the structure whereby the devices connect from the last tier directly to Tier 2.

7.3 CONTROL COMMUNICATION PROTOCOLS

In the past, because all major HVAC equipment required some type of control system, control points were duplicated. Adoption of communication standards has greatly reduced total control costs and increased functionality by providing information (e.g., part-load performance criteria) to users that was previously only available from manufacturer testing. As the functionality of component control increases and associated cost decreases, component-level interaction makes building-wide system integration less critical.

HVAC manufacturers use direct digital control (DDC) microprocessors to create powerful, low-cost controls and feature-rich equipment. In the past, many control devices were proprietary and information was not shared between manufacturers. With standard communication protocols, diverse applications such as HVAC, energy, security, lighting, and fire controls in large buildings can use a single integrated control system.

Standard protocols allow application-specific component control systems designed for particular HVAC equipment to be included in building-wide strategies. For example, low-cost componentized DDCs provide operation, safety, maintenance, and even self-diagnostic information and control functions. Making a chiller or a variable-speed drive controller a part of a cohesive, building-wide control system is now possible because of standard protocols.

Standard communication protocols are developed in committee by professional societies, *open* protocols are created by manufacturers but available for all to use, and *proprietary* protocols are developed by manufacturers but not freely distributed. User needs should be determined before selecting a particular protocol for a given application. There are two major standard protocols used in HVAC building automation today: BACnet® and LonWorks®.

BACnet is the ASHRAE *Standard* 135 Building Automation and Control Networks Protocol. It provides mechanisms by which computerized equipment for a variety of building control functions may exchange information, regardless of the particular building service it performs. As a result, the BACnet protocol may be used by head-end computers, general-purpose direct digital controllers, and application-specific or unitary controllers. Working groups represented in BACnet include data modeling, lighting, applications, information technology, life safety and security, elevators, smart grid, network security, objects and services, protocol stack, semantic interoperability, and testing and interoperability. BACnet is based on a four-layer collapsed architecture that corresponds to the physical, data link, network, and application layers of the ISO/OSI (International Organization for Standardization Open Systems Interconnection) model. The application layer and a simple network layer are defined in the BACnet standard. BACnet Secure Connect (BACnet/SC) allows BACnet devices to create secure communications.

The **physical layer** provides a means of connecting devices and transmitting the electronic signals that convey the data. BACnet devices often use Ethernet networking, and can coexist with PCs on the same network.

The **data link layer** organizes the data into frames or packets, regulates access to the medium, provides addressing, and handles some error recovery and flow control.

Functions provided by the **network layer** include translation of global addresses to local addresses, routing messages through one or more networks, accommodating differences in network types and in the maximum message size permitted by those networks, sequencing, flow control, error control, and multiplexing. BACnet is designed so that there is only one logical path between devices, thus eliminating the need for optimal path routing algorithms.

The **presentation layer** provides a way for communicating partners to negotiate the transfer syntax used to conduct the communication. This transfer syntax is a translation from the abstract user view of data at the application layer to sequences of octets treated as data at the lower layers.

The **application layer** of the protocol provides the communication services required by the applications to perform their functions, in this case monitoring and control of the HVAC&R and other building functions.

LonWorks defines a protocol for interoperability between control and automation devices. Task groups represented in LonMark include HVAC, fire, industrial, lighting, vertical transportation (elevators), automated food service equipment, home/utility, network tools, refrigeration, router, security, semiconductor, sunblinds, system integration, and transportation. Building automation system networks are local area networks, even though some applications must exchange information with devices in a very distant building.

7.4 BAS SECURITY

BAS designs have many vectors for manipulation by unauthorized personal. These include physical access to equipment and controls and access through the BAS control networks. Inclusion of BAS on OT networks has provided many benefits but also introduced vulnerabilities, necessitating increased attention to cybersecurity for these systems. Security measures must be weighed against the risk associated with unauthorized manipulation. Physical building security measures are discussed in Chapter 61. ASHRAE *Guideline* 13 also has guidance on physical and cybersecurity measures.

7.5 ASHRAE RESOURCES FOR BAS SYSTEM DESIGN

- Chapter 7 of the 2021 *ASHRAE Handbook—Fundamentals* focuses on automatic control system concepts and common devices.
- Chapter 48 of this volume focuses on the application of controls systems of specific HVAC systems (air handlers, chillers, boilers, etc.).
- Chapter 65 of this volume addresses occupant-centric controls.
- ASHRAE *Guideline* 13 provides guidance for the designer to prepare a specification of a BAS for bidding to installation contractors based on the CSI specification format. The guideline includes discussion of system designs,

integration of different systems, common sequences of operation, security measures, and a sample specification.

- ASHRAE *Guideline* 36 establishes a set of standardized sequences of operation intended to offer energy efficiency and ease of implementation for BAS designers, programmers, and operators.

REFERENCES

ASHRAE members can access *ASHRAE Journal* articles and ASHRAE research project final reports at technologyportal.ashrae.org. Articles and reports are also available for purchase by nonmembers in the online ASHRAE Bookstore at www.ashrae.org/bookstore.

ASHRAE. 2017. Thermal environmental conditions for human occupancy. ANSI/ASHRAE *Standard* 55-2017.

ASHRAE. 2016. Ventilation for acceptable indoor air quality. ANSI/ASHRAE *Standard* 62.1-2016.

ASHRAE. 2010. Energy standard for buildings except low-rise residential buildings. ANSI/ASHRAE/IES *Standard* 90.1-2010.

ASHRAE. 2008. BACnet®: A data communications protocol for building automation and control networks. ANSI/ASHRAE *Standard* 135-2008.

ASHRAE. 2015. Specifying building automation systems. ASHRAE *Guideline* 13-2015.

ASHRAE. 2016. Documenting HVAC&R work processes and data exchange requirements. ASHRAE *Guideline* 20-2010 (RA 2016).

ASHRAE. 2018. High-performance sequences of operation for HVAC systems. ASHRAE *Guideline* 36-2018.

ASHRAE. 2009. *An introduction to building information modeling (BIM): A guide for ASHRAE members*. cms.ashrae.biz/bim/pdf/BIMGuide_Rev_110309.pdf.

ASHRAE. 2016a. Standard *90.1 user's manual*.

ASHRAE. 2016b. Standard *62.1 user's manual*.

NIST. 2011. Guide to Industrial Control Systems (ICS) Security. SP 800-82 (withdrawn). National Institute of Standards and Technology. Gaithersburg, MD.

NIST. 2013. Security and Privacy Controls for Federal Information Systems and Organizations. SP 800-53 Rev. 4 (R 2015). National Institute of Standards and Technology. Gaithersburg, MD.

Ryan, C. 2017. *HVAC and big data.* Facility Management Magazine, Melbourne, Australia.

BIBLIOGRAPHY

Abtahi, H., T.L. Wong, and J. Villanueva, III. 1986. Computer aided analysis in thermodynamic cycles. *Proceedings of the 1986 ASME International Computers in Engineering Conference* 2.

ASHRAE. 1997. *Thermal comfort tool CD*.

Badger, L., T. Grance, R. Patt-Corner, and J. Voas. 2012. Cloud computing synopsis and recommendations. NIST *Special Publication* 800-146. National Institute of Standards and Technology, Gaithersburg, MD.

Berners-Lee, T. 1996. *Presentation to CDA challenge by CDT et al*. www.w3.org/People/Berners-Lee/9602affi.html.

BuildingSMART. 2002. *Home page.* www.buildingsmart.com.

Clayton, M., S. Kota, F. Farias, W. Jeong, J.B. Kim,J.L. Bermudez-Alcocer, W. Yan, and J. Haberl. 2016. Development of a reference building information model (BIM) for thermal model compliance testing (RP-1468): Part 1: Guidelines for generating thermal model input files (OR-16-020). *ASHRAE Transactions* ESL-PA-16-01-01.

Diamond, S.C., C.C. Cappiello, and B.D. Hunn. 1985. User-effect validation tests of the DOE-2 building energy analysis computer program. *ASHRAE Transactions* 91(2B):712-724.

Fitzgerald, N. 1995. Virus-L/comp.virus FAQ v2.00. www.faqs.org/faqs/computer-virus/faq/.

Jeong, W., J. Kim, M. Clayton, J. Haberl, and W. Yan. 2015. A framework to integrate object-oriented physical modelling with building information modelling for building thermal simulation. *Journal of Building Performance Simulation* ESL-PA-15-02-01 (February).

Judkoff, R., D. Wortman, and B. O'Doherty. 1981. A comparative study of four building energy simulations, phase II: DOE-2. 1, BLAST-3.0, SUN-CAT-2.4 and DEROB. Solar Energy Research Institute *Report* SERI/TP-721-1326 (July).

Kota, S., F. Farias, W. Jeong, J.B. Kim, J.L. Bermudez, M. Clayton, W. Yan, and J. Haberl. 2016. Development of a reference building information model for thermal compliance testing—Part 1: Guidelines for generating thermal model input files. *ASHRAE Transactions* 122(1):256-266.

Kusuda, T., and J. Bean. 1981. Comparison of calculated hourly cooling load and indoor temperature with measured data for a high mass building tested in an environmental chamber. *ASHRAE Transactions* 87(1):1232-1240.

Lemmon, E.W., M.L. Huber, and M.O. McLinden. 2007. *NIST standard reference database 23: Reference fluid thermodynamic and transport properties—REFPROP*, v. 8.0. National Institute of Standards and Technology, Gaithersburg, MD.

Li, K.W., W.K. Lee, and J. Stanislo. 1986. Three-dimensional graphical representation of thermodynamic properties. *Proceedings of the 1986 ASME International Computers in Engineering Conference* 1.

Martocci, J. 2008. BACnet unplugged. *ASHRAE Journal* 50(6):42-46.

McGowan, J.J. 2002. *DDC's future*. www.automatedbuildings.com/news/jan01/articles/mcg/mcg.htm.

McQuiston, F.C., and J.D. Spitler. 1992. *Cooling and heating load calculation manual.* ASHRAE.

Mills, R.B. 1989. Why 3D graphics? In *Computer Aided Engineering*. Penton Publishing, Cleveland, OH.

Olgyay, V. 1963. *Design with climate: Bioclimatic approach to architectural regionalism*. Princeton University Press, Princeton, NJ.

Potter, C.D. 1987. *CAD in construction*. Penton Publishing, Cleveland, OH.

Rabl, A. 1988. Parameter estimation in buildings: Methods for dynamic analysis of measured energy use. *ASME Journal of Solar Energy, Engineering* 110.

Sinclair, K. 2002. *The componentization era is here!* www.automatedbuildings.com/news/mar01/articles/component/component.htm.

Sorrell, F., T. Luckenback, and T. Phelps. 1985. Validation of hourly building energy models for residential buildings. *ASHRAE Transactions* 91(2).

Spielvogel, L.G. 1975. Computer energy analysis for existing buildings. *ASHRAE Journal* 7(August):40.

Spitler, J.D. 2008. *Load calculation applications manual.* ASHRAE.

Tanenbaum, A.S. 1996. *Computer networks.* Prentice Hall, New York.

Yuill, G. 1985. Verification of the BLAST computer program for two houses. *ASHRAE Transactions* 91(2B):687-700.

FURTHER INTERNET RESOURCES

BACnet®
    See www.bacnet.org.

BACnet Manufacturers Association
    See www.bacnetassociation.org.

LonMark® Interoperability Association
    See www.lonmark.org.

Building Energy Software Tools Directory
    See www.buildingenergysoftwaretools.com.

Green Building XML
    See www.gbxml.org.

The preparation of this chapter is assigned to TC 1.5, Emerging Computer Applications.