CHAPTER 39

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 interactively over the Internet. 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 communication 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 advances in the business community have been adopted by the HVAC industry as de facto standards.

COMPUTER SYSTEM COMPONENTS AND TECHNOLOGIES

Because of rapid advances in computer technology, computers offer tremendous power at very low cost. The total cost of ownership of a personal computer is not limited to the cost of the computer hardware. Software and network configuration, 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), and hard disk storage capacity
- System compatibility and interoperability between vendors
- Ease of use and required training
- Data backup 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
- Web site support
- Software driver update support/reliability
- Cost/benefits comparison
- Information system infrastructure/interoperability requirements
- Technology obsolescence
- Total cost of ownership

Virtually all brand-name personal 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.

An information system comprised of computer networks depends on the ability of computers to communicate with each other in a standard architecture. Technology increases have resulted in computer systems that become obsolete in less than five years. Therefore, it is important to plan for compatibility with a future business computer architecture. 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, and HTTP, further described in the section on Networking Components. The combination of popular standards has resulted in network and Internet accessibility from local computers.

COMPUTER HARDWARE

Hardware is the physical equipment (electronics parts, cables, printed circuit boards, etc.) that provides the foundation for the software to run. Hardware processing power has increased dramatically, such that the average business system provides much more capacity than the average user needs. Specialized tasks, however, often require specialized hardware.

Mainframes are large, expensive computer systems that serve the majority of large-scale business and technical needs. Mainframe computers best serve large nationwide databases, weather prediction, and scientific modeling applications. They support many users simultaneously, and are usually accessed over a network from a personal computer (PC). More powerful mainframes are called **supercomputers**.

Personal computers (PCs) are desktop computers tailored to individual user needs, and provide much more convenient access to computing resources than the traditional mainframe. PCs are used in a wide variety of information-gathering, communication, organization, computation, and scheduling roles.

PC servers allow access to files and data on a network. PC servers are a special class of computers that support large amounts of memory, fast connection speed to the network, large disk storage for access of many files, and applications designed to be usable from other computer systems. Because system reliability is critical, there are additional features such as better construction, component redundancy, and removable hard drives.

Workstations are application-specific computers serving specialized needs such as computer-aided design (CAD) and manufacturing (CAM), product design and simulation, mapping geographic

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information system (GIS), or specialized graphics design. Workstations have greater processing power and graphical display capabilities than personal computers, and may also have other improvements found in PC servers.

Clusters are several PCs or workstations organized to work together. Clusters of PCs can approach the computing power of a mainframe at a fraction of the cost, if efficient application software is available. Clusters of workstations can provide more computing power than even the largest mainframe.

Minicomputers are medium-sized business computer systems that serve medium to large application needs. Minicomputers have been used to economically scale applications that have grown too large for PC servers. Many small business e-commerce applications have moved to the minicomputer platform.

A **web server** is a PC server, minicomputer, or mainframe that stores and distributes web-based information; it is typically used to distribute documents and other information across the Internet.

Laptop computers are smaller, battery-powered personal computers optimized for light weight and portability. Compared to a similarly priced personal computer, laptops are generally slower and have fewer features, though they generally include most basic features found in a desktop computer. A smaller, lighter laptop computer is called a **notebook**.

Palmtop computers serve a specialized niche, allowing access to some of the same information available from a laptop, but in a much smaller package. Palmtops may have no keys, or very small keys that are much smaller than the standard keyboard.

Personal digital assistants (PDAs) support limited functionality of laptop computers in a notecard-sized format. A typical interface method is a stylus with a graphical touch-sensitive screen; standard functions include a calendar, address book, e-mail, and a calculator. Options include synchronizing hardware to upload address lists or e-mail to a PC, and a modem for portable Internet access.

Calculators and organizers are available usually for fixed arithmetic functions and, on the high end, programmable applications. This hardware format is typically inexpensive and portable, but software is typically proprietary. Laptops and palmtops have challenged the advantages of calculators and organizers.

COMPUTER SOFTWARE

Software is computer instructions or data that can be stored electronically in storage hardware, such as random access memory (RAM), or secondary memory such as hard disk drives.

Software is often divided into two categories:

- *Systems software* includes the operating system and utilities associated with the operating system, such as file copying.
- *Applications software* includes the programs used to do the user's work, such as word processors, spreadsheets, or database. HVAC-specific programs belong to the applications software category.

Operating Systems

The operating system (OS) is the basic control program that allows execution and control of application software. Operating systems (system software) also provide a common environment for applications to use shared resources such as memory, secondary storage (e.g., hard disk storage), processing time, network access, the keyboard, graphic display environments, desktops, file services, and printer services. Application software must be selected first; that decision will typically limit the hardware computer platform and OS.

Utility Software

Utility programs perform a wide variety of organizing and data-handling operations such as copying files, printing files, file management, network analysis, disk size utilities, CPU speed tests, and other related operations. Most utilities perform one or two specific functions.

Compression Software. These utilities compress and archive data files in a standard format, such as ZIP. Compression utilities allow files and file systems to be compressed, making the transfer of information and files much more efficient without any loss of content or data. These utilities are valuable when file size is important, such as transmitting files over a limited-bandwidth communication system, and for archival purposes. A typical compression ratio for text files is 3:1. E-mail attachments are often compressed.

Antivirus Software. An important software package for most computer systems is antivirus software (see the section on E-mail, Viruses, and Hoaxes). Antivirus software detects, quarantines, repairs, and eliminates files that contain viruses. A computer virus may take various forms and is commonly attached invisibly to a word-processed or e-mailed document. Antivirus software is imperative when a computer is accessing Internet-based information.

Back-Up Software. The ability to recover from a massive failure such as a successful virus attack, accidental deletion of files, fire, hardware (especially hard disk) failure, and other inevitable disasters is extremely important. Typically, information service (IS) computers use a rotating digital tape back-up strategy that performs massive back-ups of network resources. Individual computers may not be included in these back-ups, so regularly scheduled back-ups must be performed. A relatively inexpensive way to back up small amounts of data is to store data files and documents in a compact disk recordable (CD-R) format, which allows roughly up to 700 MB of storage at low cost. Digital video disks (DVDs) promise roughly 10 times the storage capacity of CD-R. Tape back-up provides an extremely low cost per megabyte stored and is useful if quick access and retrieval of individual back-up files is not an issue. Back-ups should be stored in a secure location away from the computer system.

Application Software

Some useful application software includes that for the following needs:

Word Processing. Word processing applications are used for tasks that range from creating simple printable documents to providing products for advanced enterprise-level electronic distribution and publishing systems. Features may include automatic text layout, spellchecking, printing, index and table of contents generation, simple graphics, and the ability to save files in a variety of formats such as rich text format (RTF), hypertext markup language (HTML), plain text, or American Standard Code for Information Interchange (ASCII). Most word processors allow the user to view the output before printing.

Specification Writing. A useful extension to word processors is application software to create specifications for the consulting engineer. Features include ensuring selectable sections for creating desired features, and consistent naming of materials, specifications, and processes or sequences.

Specification software can save time by allowing the reuse of sections from a master specification, along with previously developed specification details, sometimes with small changes. Specification tools are most useful in situations that do not require completely new specifications from project to project.

Desktop Publishing. This is a specialized class of word processors with high-end, professional text and graphics layout features. Desktop publishing systems have been extended to incorporate professional-quality graphical images, many different styles of text and fonts, and special effects such as color fading, shadowing, and artistic effects. Using inexpensive, high-quality printers, the quality of output from desktop publishing software can be remarkable. In general, the limiting factor in the use of desktop publishing software is the time and training investment to use it efficiently.

Web Publishing. Word processors are best suited for printing documents on paper; web publishing tools are designed to format information and transfer the documents to web sites. In many regards, web publishing software is similar to word processing software, allowing text, graphics, and tables to be formatted for display. Unique extensions from web software include the ability to manage links, or connections within a related collection of documents.

Web publishing software saves information in HTML, a standard format used by web browsers. Web browsers can display information on many different screen resolution and sizes, which makes a standard layout of documents especially difficult.

Other features of web publishing software include tools to enforce consistency of web page format and style, lower resolution of pictures and graphics to reduce the loading time, and preview what the final web page will look like to the end user.

Standardized Web Document Formats. Created as a result of special formatting requirements for printing and display on web pages, this software converts word processing documents to a standard format. This standard format requires the use of a web browser software extension called a "plug-in," typically offered at no charge as a viewing tool. The viewing tool allows users to see and print the document in exactly the same format. The disadvantage of standardized formats is the inability to modify the information.

Spreadsheets. Spreadsheet applications allow the user to create tables for adding and subtracting columns of numbers in one complete view. Spreadsheets contain thousands of cells into which the user may enter labels, numbers, formulas, or even programs ("macros") to execute such functions as subroutines for a specific calculation, database sorting and searching, conversions, and other calculations. Automatic recalculations allow displayed information to be evaluated quickly. Spreadsheets are useful for importing and formatting data into a graphical display, trend analysis, and/or statistical computations. Users can input different variable values into a mathematical representation of the process or system, and evaluate the results immediately or save them as separate files of graphs for later analysis.

Databases. Database applications are designed to store, organize, and sort information in a specialized format optimized for speed and utility. Simple PC database applications are typically designed for single users, whereas database management systems (DBMSs) are designed for larger applications involving multiple-user access. DBMSs support security hierarchies, record and file locking, and mission-critical network-accessible applications such as financial and banking applications. The standard language for accessing the database information is structured query language (SQL).

Presentations. Software optimized for group presentations displays information on digital projection systems. Presentation software is able to present simple text and graphics in an attractive screen format package for seminars, demonstrations, and training. Additionally, most presentation software allows the creation of notes for the speaker to consult during the presentation, and slide handouts. Popular extensions to presentation software include sound effects and multimedia effects such as video and audio clips. Libraries of vendor and third-party graphics are available at extra charge or from the Internet.

Accounting. Accounting software for accounts receivable, accounts payable, payroll, and taxes is available for many hardware platforms. Many accounting software packages contain extra modules and applications that allow extensions for unique accounting requirements. Financial reports for projects can be easily generated from standard report packages. Large accounting systems can be integrated with databases and automatic tax-reporting functions. Individual accounts and corrections can be monitored and updated automatically. Large accounting systems also allow integration and reporting from individual employees via web browser applications.

Project Scheduling. Meeting project requirements and efficiently coordinating project resources are difficult tasks; project scheduling software helps solve these problems. Most project scheduling software is able to take resources (such as individual workers), length of task, percent allocation of resources, and task interdependencies, and present the information as a critical path method (CPM) chart or as a program evaluation and review technique (PERT) chart to evaluate the schedule. Many applications can perform resource leveling, resulting in an efficient allocation of resources to complete the project.

As project scheduling software is updated to include real data, the predicted completion date and the total amount of resources used (e.g., hours worked on individual tasks, material requirements) can be used as predictive record for future projects.

Management. Management software can review past and current data on inventory, accounting, purchasing, and project control, and predict future performance. As more data are accumulated, statistical analysis can predict performance with a specified level of confidence.

Much of the data required for these techniques may require access to standard industry data in industry-wide databases, financial forecasts, code standards, and demographic and other resources. In many cases, this information can be obtained on the Internet for a nominal fee.

Web Meetings. Similar to teleconferences, web meetings coordinate demonstrations and meetings over the Internet. Participants use a common web site to view and update a slide show presentation, with optional voice commentary handled either through traditional teleconferencing or through streaming audio or video feeds.

Graphics and Imaging. Graphics software packages readily produce images, *x-y* charts, graphs, pie charts, and custom graphics. Libraries of graphics and images exist for use in word processing, presentation, desktop publishing, and web page applications. Many graphics programs can produce output in numerous popular computer graphics formats such as Joint Photographic Experts Group (JPG), graphics interchange format (GIF), tagged information file format (TIFF), bitmap (BMP), and other standards. Specialty programs allow graphics files to be converted between graphics formats. Multimedia tools allow video and sound to be combined with traditional text and graphics.

Images require large amounts of data to be represented accurately. Graphics are usually stored in either bitmap or vector format. In **bitmap** (also known as **raster**) format, commonly used for picture and photo-oriented graphics, the image is decomposed into parts in a rectangular array represented by a pixel. Storage requires a bit (one-eighth of a byte) to store a black-and-white pixel (picture element), and several bits (in proportion to the number of colors of resolution) to store a color pixel. In **vector** representation, commonly used in CAD/CAM and architectural drawings, shapes are represented as connections between line segments. Although the output of bitmap images is simple on devices such as graphic printers, rescaling these images does not always produce satisfactory output. Conversions between formats give varying results. Bitmap images are frequently converted to JPG (typically for photographic images) and GIF (typically for simple drawings) file formats.

Web Browsers. Most Internet-enabled computers have web browsers that support text and graphical web page displays. The underlying language of the World Wide Web is HTML, and navigation is by clicking on links to access different computer systems and pages on the web.

Browsers are a preferred interface for accessing vastly different computer systems. Full-feature browsers also support Java® applets (small programs) and a host of extension applications that are available at nominal or no charge. These include streaming sound, streaming multimedia, and graphics formats other than GIF and JPG, which are directly supported by HTML. Some other available features include access to e-mail, file transfer protocol (FTP; for transferring files to and from servers over the Internet), chat rooms, newsgroups and forums, Telnet access to computers, and access to secure e-commerce sites that use encryption routines to protect sensitive data such as credit card information, bank account balances, and stock transfer information.

SOFTWARE AVAILABILITY

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.

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. Most off-the-shelf, shrink-wrapped software is nonreturnable once opened.

SOFTWARE LANGUAGES

Application software is written in a variety of computer languages. Most commercial software today is written in C++ or C to allow fast speed and efficient use of resources.

Visual Basic® is an extremely popular and easy-to-use graphical programming language for Windows® that has proprietary extensions of the original BASIC language. High-performance software modeling tools such as finite element analysis (FEA) and graphics modeling use Fortran and C.

Several modern languages, such as Java® and Smalltalk, use object-oriented programming. Java is a favored programming language for applications that run over computer networks such as the Internet. C++ mixes both traditional procedural C language programming and object-oriented extension concepts. The major disadvantage of Java and C++ is the high level of programming skill required to create programs.

Java is a powerful programming language and environment with extensions to support Internet, security, and multiplatform implementation. Java applets are small, secure, self-contained programs that need a host environment, such as a web browser, to run. Many new applications use standard web browsers with applets to create useful displays and interfaces. JavaBeans are modular components that provide users with standard modular and graphical interfaces of components. Enterprise JavaBeans (EJB) are server-based programs that allow interoperability and language standardization to be scalable and interchangeable between server vendors.

Relational system databases use structured query language (SQL). Object databases are still relatively new, but fully support the object-oriented paradigm of object references, instead of the traditional relational model.

CUSTOM PROGRAMMING

Using an existing software package is usually preferable to designing a custom application, which is much more expensive and potentially riskier, especially 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 because of 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.

INPUT/OUTPUT (I/O) DEVICES

Basic computer peripherals (e.g., monitor, keyboard, mouse, etc.) allow interaction with the computer and are sufficient for many applications. More advanced I/O capability is available through digital cameras, scanners, bar code readers, stylus pads, voice recognition devices, and fax machines. Common devices include the following.

Printer types include laser and ink-jet. Laser printers offer a lower cost per sheet, double-sided printing, faster throughput, and large storage capacity. Ink-jet printers offer color printing and lower initial cost but have a higher operating cost.

Digital cameras are useful for photographs and digital storage of images. These digitized images can be transmitted electronically and viewed or incorporated into web or traditional documents. PC video cameras allow a live image such as live conferencing to be viewed and recorded.

Scanners digitize printed photographs and images, and have a characteristic image quality expressed in dots per inch (dpi). The image files can be large and should preferably be stored using a compression format such as JPG. **Bar code readers** speed database input by converting a manual scan of a bar code to the alphanumeric input in a database field. **Stylus pads** combine the navigational functionality of a mouse with the ability to enter handwritten notes and sketches and run automated scripts based on movements on the pad.

Voice recognition software automatically converts speech to typed text. These programs take some tuning to learn the accent, diction, and idioms of the user. Many voice recognition software packages also enable automated scripts or macros to run on verbal commands.

Fax software emulates a printer driver. It allows the user to print a document to a target fax machine through a modem. It also allows the user to receive faxes as electronic documents. Other features include integration with electronic contact databases, templates for transmittal pages, and automated tracking of faxes sent and received.

HVAC SOFTWARE APPLICATIONS

Over the past decade, the use of computer software designing mechanical systems has increased. The advantages of software-assisted design over traditional manual methods include the following:

- Computers can better preserve design assumptions and document the design intent through consolidating and organizing resources (e.g., central databases, web sites with design documents)
- It is often faster and easier to modify assumptions used in a calculation and recalculate the results using a computer
- The computational speed of computers allows designers to tackle more difficult design problems and to use more accurate (but computationally intensive) methods
- Computers assist designers in analyzing design alternatives.

In the future, interoperable software design and application of expert systems could reduce the burden of design. Interoperable applications automatically pass design assumptions and calculation results between applications, reducing both the burden of user input and the opportunity for user error. Expert and rule-based systems could automate design standards to the point where simple system selection or distribution system sizing can be automated.

There is a wide variety of software used in the HVAC industry. This section covers applications that assist mechanical engineers in design, analysis, and specification of mechanical systems, including

- HVAC design software
- HVAC simulation software
- CAD/graphics software
- Miscellaneous utilities and applets

Much of this software is also used by HVAC equipment manufacturers to design their products, and by controls contractors to develop control systems.

In addition, sources for these applications and the fundamentals of interoperable computer applications for the HVAC&R industry are discussed.

The distinction between HVAC design and simulation is subtle. The convention used here is that design software is used for static analysis: evaluating equipment and distribution systems under a specific design condition. In contrast, HVAC simulation is used for dynamic system analysis over a range of time or operating conditions. Many applications provide both functions through a single interface.

HVAC DESIGN CALCULATIONS

HVAC design software includes programs for the following tasks:

- HVAC heating and cooling load calculations
- Duct system sizing and analysis
- Pipe system sizing and analysis
- Acoustical analysis
- Equipment selection

Although computers are now widely used in the design process, most programs perform analysis, not design, of a specified system. That is, the engineer proposes a design and the program calculates the consequences of that design. When the engineer can define alternatives, a program may aid design by analyzing the performance of the alternatives and then selecting the best according to predetermined criteria. Thus, a program to calculate the cooling load of a building requires specifications for the building and its systems; it then simulates that building's performance under certain conditions of weather, occupancy, and scheduling. Although most piping and duct design tools can size pipe or ductwork based on predetermined criteria, most engineers still decide duct dimensions, air quantities, duct routing, and so forth and use software to analyze the performance of that design.

Some interoperable software can pass values from one design phase to be used as inputs in the next. For example, a load program may be used to determine the design air quantities at the zone and space level. Through interoperability, this information can be preserved in the building model and used as an input for the duct sizing program. Interoperable software is further described in the section on Interoperable Computer Applications for the HVAC&R Industry.

Because computer programs perform repetitive calculations rapidly, the designer can explore a wide range of alternatives and use selection criteria based on annual energy costs or life-cycle costs.

Heat and Cooling Load Design

Calculating design thermal loads in a building is a necessary step in selecting HVAC equipment for virtually any building project. To ensure that heating equipment can maintain satisfactory building temperature under all conditions, peak heating loads are usually calculated for steady-state conditions without solar or internal heat gains. This relatively simple calculation can be performed by hand or with a computer.

Peak cooling loads are more transient than heating loads. Radiative heat transfer within a space and thermal storage cause thermal loads to lag behind instantaneous heat gains and losses. This lag can be important with cooling loads, because the peak is both reduced in magnitude and delayed in time compared to the heat gains that cause it. A further complication is that loads peak in different zones at different times (e.g., the solar load in a west-facing zone will peak in the afternoon, and an east-facing zone will usually peak in the morning). To properly account for thermal lag and the noncoincidence of zone loads, a computer program is generally required to calculate cooling loads for a multiple-zone system. These programs simulate loads for each hour of the day for every day of the year (or a representative subset of the days of the year), and report peak loads at both the zone and system level, recording the date and time of their occurrence. Because the same input data are used for heating and cooling loads, these programs report peak heating loads, as well.

Various calculation methods are used to account for the transience of cooling loads; the most common methods are described in detail in Chapters 28 and 29 of the 2001 *ASHRAE Handbook—Fundamentals*. The most accurate but computationally intensive method, the heat-balance method, is a fundamental calculation of heat transfer from all sources with the construction elements of the building (walls, floor, windows, skylights, furniture, ceiling, slab, and roof). Only the computational speed of present-day personal computers allows these calculations to be performed for large multizone buildings in a reasonable amount of time (ranging from several minutes to an hour or more). Several simplified methods or approximations of thermal lag are available to speed computation time, including the radiant time-series (RTS), transfer function (TFM), total equivalent temperature differential with time averaging (TETD/TA) and cooling load temperature differential with cooling load factors (CLTD/CLF) methods. These approximations are less accurate than the heat balance method, but can be sufficient if they are appropriately applied.

Both the TETD/TA and the TFM methods require a history of thermal gains and loads. Because histories are not initially known, they are assumed zero and the building under analysis is taken through a number of daily weather and occupancy cycles to establish a proper 24 h load profile. Thus, procedures required for the

TFM and TETD/TA methods involve so many individual calculations that noncomputerized calculations are highly impractical. The CLTD/CLF method, on the other hand, is meant to be a manual calculation method and can be implemented by a spreadsheet program. The CLTD and CLF tables presented in the 2001 *ASHRAE Handbook—Fundamentals* are, in fact, based on application of the TFM to certain geometries and building constructions. An automated version of TFM is preferred to CLTD/CLF because it is more accurate. The automated TETD/TA method, however, can provide a good approximation with significantly less computation than the TFM.

Characteristics of a Loads Program. In general, a loads program requires user input for most or all of the following:

- Full building description, including the construction and other heat transfer characteristics of the walls, roof, windows, and other building elements; size; orientation; geometry of the rooms, zones, and building; and possibly also shading geometries
- Sensible and latent internal loads from lights and equipment, and their corresponding operating schedules
- Sensible and latent internal loads from people
- Indoor and outdoor design conditions
- Geographic data such as latitude and elevation
- Ventilation requirements and amount of infiltration
- Number of zones per system and number of systems

With this input, loads programs calculate both the heating and cooling loads and perform a psychrometric analysis. Output typically includes peak room and zone loads, supply air quantities, and total system (coil) loads.

Selecting a Loads Program. Beyond general characteristics, such as hardware and software requirements, type of interface (icon-based, menu-driven versus command-driven), availability of manuals and support, and cost, some program-specific characteristics should be considered when selecting a loads program. The following are among items to be considered:

- Ease of use and compatibility with the existing operating system
- Type of building to be analyzed: residential versus commercial (residential-only loads programs tend to be simpler to use than more general-purpose programs meant for commercial and industrial use, but residential-only programs generally have limited abilities)
- Method of calculation for the cooling load (note that some programs support more than one method of calculation)
- Program limits on such items as number of systems, zones, rooms, and surfaces per room
- Sophistication of modeling techniques (e.g., capability of handling exterior or interior shading devices, tilted walls, daylighting, skylights, etc.)
- Units of input and output
- Program complexity (in general, the more sophisticated and flexible programs require more input and are somewhat more difficult to use than simpler programs)
- Capability of handling the system types under investigation
- Certification of the program for energy code compliance
- Ability to share data with other programs, such as CAD and energy analysis

Duct Design

Chapter 34 of the 2001 *ASHRAE Handbook—Fundamentals* describes several methods for duct design. Major considerations in duct design include the physical space required by the duct, cost of the ductwork and fittings, energy required to move air through the duct, acoustics, minimum velocities to maintain contaminants in suspension (fume exhaust), flexibility for future growth, zoning, and constructability. Duct software can help with the layout and analysis of new and/or existing distribution systems.

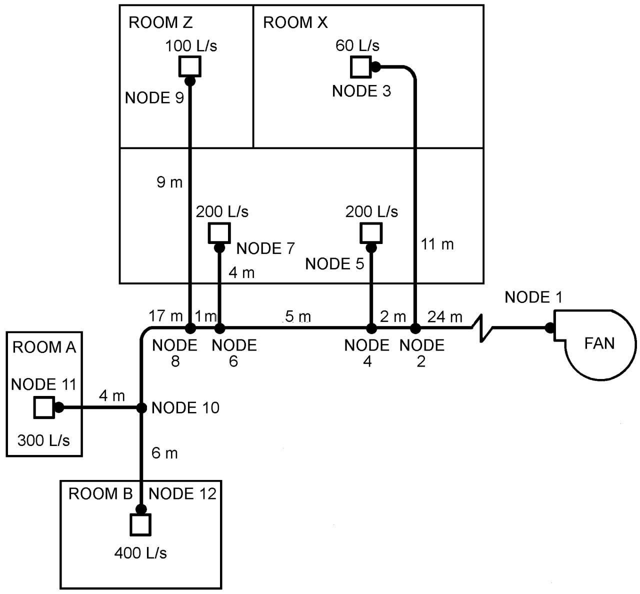

Fig. 1 Example of Duct System Node Designation

Duct design is more an art than a science, which complicates automation of design. Duct design programs and calculation methods are limited in their ability to (1) calculate actual operating pressures because of the impact of fan and duct system effects, and (2) take into consideration many unmeasurable factors in the process of laying out and sizing ducts (e.g., provision for space limitations, local duct construction preferences and practices, local labor and material costs, acoustics, and accommodating future remodeling).

Selecting and Using a Program. Duct design involves routing or laying out ductwork, selecting fittings, and sizing ducts. Computer programs can rapidly analyze design alternatives and determine critical paths in long and complicated distribution systems. Furthermore, programs and printouts can preserve the assumptions used in the design: any duct calculation requires accurate estimates of pressure losses in duct sections and the definition of the interrelations of velocity heads, static pressures, total pressures, and fitting losses.

The general computer procedure is to designate nodes (the beginning and end of duct sections) by number. Details about each node (e.g., divided flow fitting and terminal) and each section of duct between nodes (maximum velocity, flow rate, length, fitting codes, size limitation, insulation, and acoustic liner) are used as input data (Figure 1).

Characteristics of a duct design program include the following:

- Calculations for supply, return, and exhaust
- Sizing by constant friction, velocity reduction, static regain, and constant velocity methods
- Analysis of existing ducts
- Inclusion of fitting codes for a variety of common fittings
- Identification of the duct run with the highest pressure loss, and tabulation of all individual losses in each run
- Printout of all input data for verification
- Provision for error messages
- Calculation and printout of airflow for each duct section
- Printout of velocity, fitting pressure loss, duct pressure loss, and total static pressure change for each duct section
- Graphics showing schematic or line diagrams indicating duct size, shape, flow rate, and air temperature
- Calculation of system heat gain/loss and correction of temperatures and flow rates, including possible system resizing

- Specification of maximum velocities, size constraints, and insulation thicknesses
- Consideration of insulated or acoustically lined duct
- Bill of materials for sheet metal, insulation, and acoustic liner
- Acoustic calculations for each section
- File-sharing with other programs, such as spreadsheets and CAD

Because many duct design programs are available, the following factors should be considered in program selection:

- Maximum number of branches that can be calculated
- Maximum number of terminals that can be calculated
- Types of fittings that can be selected
- Number of different types of fittings that can be accommodated in each branch
- Ability of the program to balance pressure losses in branches
- Ability to handle two- and three-dimensional layouts
- Ability to size a double-duct system
- Ability to handle draw-through and blow-through systems
- Ability to prepare cost estimates
- Ability to calculate fan motor power
- Provision for determining acoustical requirements at each terminal
- Ability to update the fitting library

Optimization Techniques for Duct Sizing. For an optimized duct design, fan pressure and duct cross sections are selected by minimizing the life-cycle cost, which is an objective function that includes initial and energy costs. Many constraints, including constant pressure balancing, acoustic restrictions, and size limitations, must be satisfied. Duct optimization is a mathematical problem with a nonlinear objective function and many nonlinear constraints. The solution must be taken from a set of standard diameters and standard equipment. Numerical methods for duct optimization exist, such as the T method (Tsal et al. 1988), coordinate descent (Tsal and Chechik 1968), Lagrange multipliers (Kovarik 1971; Stoecker et al. 1971), dynamic programming (Tsal and Chechik 1968), and reduced gradient (Arkin and Shitzer 1979).

Piping Design

Many computer programs are available to size or calculate the flexibility of piping systems. Sizing programs normally size piping and estimate pump requirements based on velocity and pressure drop limits. Some consider heat gain or loss from piping sections. Several programs produce a bill of materials or cost estimates for the piping system. Piping flexibility programs perform stress and deflection analysis. Many piping design programs can account for thermal effects in pipe sizing, as well as deflections, stresses, and moments.

Numerous programs are available to analyze refrigerant piping layouts. These programs aid in design of properly sized pipes or in troubleshooting existing systems. Some programs are generic, using the physical properties of refrigerants along with system practices to give pipe sizes that may be used. Other programs "mix and match" evaporators and condensers from a particular manufacturer and recommend pipe sizes. See Chapter 2 of the 2002 *ASHRAE Handbook—Refrigeration* for specifics on refrigerant pipe sizing.

The general technique for computerizing piping design problems is similar to that for duct design. A typical piping problem in its nodal representation is shown in Figure 2.

Useful piping programs do the following:

- Provide sufficient design information
- Perform calculations for both open and closed systems
- Calculate flow, pipe size, and pressure drop in each section
- Handle three-dimensional piping systems
- Cover a wide selection of common valves and fittings, including specialized types (e.g., solenoid and pressure-regulating valves)
- Consider different piping materials such as steel, copper, and plastic by including generalized friction factor routines

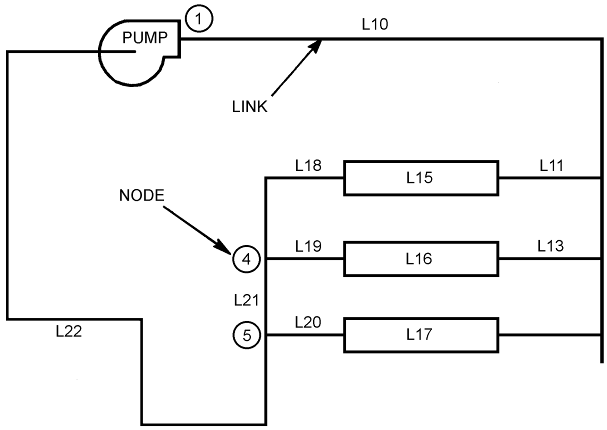

Fig. 2 Examples of Nodes for Piping System

- Accommodate liquids, gases, and steam by providing property information for a multiplicity of fluids
- Calculate pump capacity and head required for liquids
- Calculate available terminal pressure for nonreturn pipes
- Calculate required expansion tank size
- Estimate heat gain or loss for each portion of the system
- Prepare a cost estimate, including costs of pipe and insulation materials and associated labor
- Print out a bill of materials
- Calculate balance valve requirements
- Perform a pipe flexibility analysis
- Perform a pipe stress analysis
- Print out a graphic display of the system
- Allow customization of specific design parameters and conditions, such as maximum and minimum velocities, maximum pressure drops, condensing temperature, superheat temperature, and subcooling temperature
- Allow piping evaluation for off-design conditions
- Provide links to other programs, such as equipment simulation programs

Limiting factors to consider in piping program selection include the following:

- Maximum number of terminals the program can accommodate
- Maximum number of circuits the program can handle
- Maximum number of nodes each circuit can have
- Maximum number of nodes the program can handle
- Compressibility effects for gases and steam
- Provision for two-phase fluids

Acoustic Calculation

Chapter 47 summarizes sound generation and attenuation in HVAC systems. Applying these data and methodology often requires a large amount of computation. All sound-generation mechanisms and sound-transmission paths are potential candidates for analysis. Adding to the computational work load is the need to extend the analysis over, at a minimum, octave bands 1 through 8 (63 Hz through 8 kHz). A computer can save a great amount of time and difficulty in the analysis of any noise situation, but the HVAC system designer should be wary of using unfamiliar software.

Caution and critical acceptance of analytical results are necessary at all frequencies, but particularly at low frequencies. Not all manufacturers of equipment and sound control devices provide data below 125 Hz; in such cases, the HVAC designer conducting the analysis and the programmer developing the software must make experience-based assumptions for these critical low-frequency ranges.

The designer/analyst should be well satisfied if predictions are within 5 dB of field-measured results. In the low-frequency "rumble" regions, results within 10 dB are often as accurate as can be expected, particularly in areas of fan discharge. Conservative analysis and application of results is necessary, especially acoustically critical spaces.

Several easy-to-use acoustics programs are currently available, but they are often less detailed than custom programs developed by acoustic consultants for their own use. Acoustics programs are designed for comparative sound studies and allow the design of comparatively quiet systems. Acoustic analysis should address the following key areas of the HVAC system:

- Sound generation by HVAC equipment
- Sound attenuation and regeneration in duct elements
- Wall and floor sound attenuation
- Ceiling sound attenuation
- Sound breakout or break-in in ducts or casings
- Room absorption effect (relation of sound power criteria to sound pressure experienced)

Algorithm-based programs are preferred because they cover more situations (see Chapter 47); however, algorithms require assumptions. Basic algorithms, along with sound data from the acoustics laboratories of equipment manufacturers, are incorporated to various degrees in acoustics programs. The HVAC equipment sound levels in acoustics programs should come from the manufacturer and be based on measured data, because there is a wide variation in the sound generated by similar pieces of equipment. Some generic equipment sound generation data, which may be used as a last resort in the absence of specific measured data, are found in Chapter 47. Whenever possible, equipment sound power data by octave band (including 32 Hz and 63 Hz) should be obtained for the path under study. A good sound prediction program relates all performance data.

Many more specialized acoustics programs are also available. Various manufacturers provide equipment selection programs that not only select optimum equipment for a specific application, but also provide associated sound power data by octave bands. Data from these programs should be incorporated in the general acoustic analysis. For example, duct design programs may contain sound predictions for discharge airborne sound based on the discharge sound power of fans, noise generation/attenuation of duct fittings, attenuation and end reflections of VAV terminals, attenuation of ceiling tile, and room effect. VAV terminal selection programs generally contain subprograms that estimate the space NC level near the VAV unit in the occupied space. However, projected space NC levels alone may not be acceptable substitutes for octave-band data. The designer/analyst should be aware of assumptions, such as room effect, made by the manufacturer in presenting acoustical data.

Predictive acoustic software allows designers to look at HVAC-generated sound in a realistic, affordable time frame. HVAC-oriented acoustic consultants generally assist designers by providing cost-effective sound control ideas for sound-critical applications. A well-executed analysis of the various components and sound paths enables the designer to assess the relative importance of each and to direct corrective measures, where necessary, to the most critical areas. However, computer-generated results should supplement the designer's skills, not replace them.

Equipment Selection and Simulation

Equipment-related computer applications include programs for equipment selection, equipment optimization, and equipment simulation.

Equipment selection programs are basically computerized catalogs. The program locates an existing equipment model that satisfies the entered criteria. The output is a model number, performance data, and sometimes alternative selections.

Equipment optimization programs display all possible equipment alternatives and let the user establish ranges of performance data or first cost to narrow the selection. The user continues to narrow performance ranges until the best selection is found. The performance data used to optimize selections vary by product family.

Equipment simulation programs calculate the full- and part-load performance of specific equipment over time, generally one year. The calculated performance is matched against an equipment load profile to determine energy requirements. Utility rate structures and related economic data are then used to project equipment operating cost, life-cycle cost, and comparative payback. Before accepting output from an equipment simulation program, the user must understand the assumptions made, especially concerning load profile and weather.

Some advantages of equipment programs include the following:

- High speed and accuracy of the selection procedure
- Pertinent data presented in an orderly fashion
- More consistent selections than with manual procedures
- More extensive selection capability
- Multiple or alternative solutions
- Small changes in specifications or operating parameters easily and quickly evaluated
- Data-sharing with other programs, such as spreadsheets and CAD

Simulation programs have the advantages of (1) projecting part-load performance quickly and accurately, (2) establishing minimum part-load performance, and (3) projecting operating costs and offering payback-associated higher-performance product options.

There are programs for nearly every type of HVAC equipment, and industry standards apply to the selection of many types. The more common programs and their optimization parameters include the following:

Air distribution units	Pressure drop, first cost, sound, throw
Air-handling units, rooftop units	Power, first cost, sound, filtration, footprint, heating and cooling capacity
Boilers	First cost, efficiency, stack losses
Cooling towers	First cost, design capacity, power, flow rate, air temperatures
Chillers	Power input, condenser head, evaporator head, capacity, first cost, compressor size, evaporator size, condenser size
Coils	Capacity, first cost, fluid pressure drop, air pressure drop, rows, fin spacing
Fan coils	Capacity, first cost, sound, power
Fans	Volume flow, power, sound, first cost, minimum volume flow
Heat recovery equipment	Capacity, first cost, air pressure drop, water pressure drop (if used), effectiveness
Pumps	Capacity, head, impeller size, first cost, power
Air terminal units (variable and constant volume flow)	Volume flow rate, air pressure drop, sound, first cost

Some extensive selection programs have evolved. For example, coil selection programs can select steam, hot-water, chilled-water, and refrigerant (direct-expansion) coils. Generally, they select coils according to procedures in ARI *Standards* 410 and 430.

Chiller and refrigeration equipment selection programs can choose optimal equipment based on factors such as lowest first cost, highest efficiency, best load factor, and best life-cycle performance. In addition, some manufacturers offer modular equipment for customization of their product. This type of equipment is ideal for computerized selection.

However, equipment selection programs have limitations. The logic of most manufacturers' programs is proprietary and not available to the user. All programs incorporate built-in approximations or assumptions, some of which may not be known to the user. Equipment selection programs should be qualified before use.

HVAC SIMULATION

Energy Simulation

Unlike peak load calculation programs, building energy simulation programs integrate loads over time (usually a year), consider the systems serving the loads, and calculate the energy required by the equipment to support the system. Most energy programs simulate the performance of already designed systems, although programs are now available that make selections formerly left to the designer, such as equipment sizes, system air volume, and fan power. Energy programs are necessary for making decisions about building energy use and, along with life-cycle costing routines, quantify the effect of proposed energy conservation measures during the design phase. In new building design, energy programs help determine the appropriate type and size of building systems and components; they can also be used to explore the effects of design tradeoffs and evaluate the benefits of innovative control strategies and the efficiency of new equipment.

Energy programs that track building energy use accurately can help determine whether a building is operating efficiently or wastefully. They have also been used to allocate costs from a central heating/cooling plant among customers of the plant. However, such programs must be adequately calibrated to measured data from the building under consideration.

Characteristics of Building Energy Simulation. Most programs simulate a wide range of buildings, mechanical equipment, and control options. However, computational results differ substantially across programs. For example, the shading effect from overhangs, side projections, and adjacent buildings frequently affects a building's energy consumption; however, the diverse approaches to load calculation result in a wide range of answers.

The choice of weather data also influences the load calculation. Depending on the requirements of each program, various weather data are used:

- Typical hourly data for one year only, from averaged weather data
- Typical hourly data for one year, as well as design conditions for typical design days
- Reduced data, commonly a typical day or days per month for the year
- Typical reduced data, nonserial or bin format
- Actual hourly data, recorded on site or nearby, for analysis where the simulation is being compared to actual utility billing data or measured hourly data

Simulation programs differ significantly in the methods they use to simulate the mass effects of buildings, ground, and furniture. How accurate these methods are and how well they delay peak heating and cooling can lead to significant uncertainty in predicting building heating and cooling needs, sizing equipment to meet those loads, and predicting system energy needs.

Both air-side and energy conversion simulations are required to handle the wide variations among central heating, ventilation, and air-conditioning systems. To properly estimate energy use, simulations must be performed for each combination of system design, operating scheme, and control sequence.

Simulation Techniques. Two methods are used in computer simulation of energy systems: the fixed schematic technique and the component relation technique.

The **fixed-schematic-with-options technique**, the first and most prevalent method, involves writing a calculation procedure that defines a given set of systems. The schematic is then fixed, with the user's options usually limited to equipment performance characteristics, fuel types, and the choice of certain components.

The **component relation technique** is organized around components rather than systems. Each component is described mathematically and placed in a library. User input includes the definition of the schematic, as well as equipment characteristics and capacities. Once all components have been identified and a mathematical model for each has been formulated, they may be connected and information may be transferred between them. Although its generality leads to certain inefficiencies, the component relation technique does offer versatility in defining system configurations.

Selecting an Energy Program. In selecting an energy analysis program, factors such as cost, availability, ease of use, technical support, and accuracy are important. However, the fundamental consideration is whether the program will do what is required of it. It should be sensitive to the parameters of concern, and its output should include necessary data. For other considerations, see Chapter 31 of the 2001 *ASHRAE Handbook—Fundamentals*.

Time can be saved if the initial input file for an energy program can also be used for load calculations. Some programs interface directly with computer-aided design (CAD) files, greatly reducing the time needed to create an energy program input file.

Comparisons of Energy Programs. Because energy analysis programs use different calculation methods, results vary significantly. Many comparisons, verifications, and validations of simulation programs have been made and reported (see the Bibliography). Conclusions from these reports can be summarized as follows:

- Results obtained by using several programs on the same building range from good agreement to no agreement at all. The degree of agreement depends on interpretations by the user and the ability of the programs to model the building.
- Several people using several programs on the same building will probably not agree on the results of an energy analysis.
- The same person using different programs on the same building may or may not find good agreement, depending on the complexity of the building and its systems and on the ability of the programs to model specific conditions in that building.
- *Forward* computer simulation programs, which calculate the performance of a building given a set of descriptive inputs, weather conditions, and occupancy conditions, are best suited for design.
- Calibrating hourly forward computer simulation programs is possible, but can require considerable effort for a moderately complex commercial office building. Details on scheduled use, equipment set points, and even certain on-site measurements may be necessary for a closely calibrated model. Special-purpose graphic plots are useful in calibrating a simulation program with data from monthly, daily, or hourly measurements.
- *Inverse*, *empirical*, or *system parameter identification* models may also be useful in determining the characteristics of building energy usage. Such models can determine relevant building parameters from a given set of actual performance data. This is the inverse of the traditional building modeling approach, hence the name.

Energy Programs to Model Existing Buildings. Computer energy analysis of existing buildings can accommodate complex situations; evaluate the energy effects of many alternatives, such as changes in control settings, occupancy, and equipment performance; and predict relative magnitudes of energy use. There are many programs available, varying widely in cost, degree of complexity, and ease of use.

A general input-data acquisition procedure should be followed in computer energy analysis of existing buildings. First, **energy consumption data** must be obtained for a one- to two-year period. For electricity, these data usually consist of metered electrical energy consumption and demand on at least a month-by-month basis. For natural gas, the data are in a similar form and are almost always on a monthly basis. For both electricity and natural gas, it is helpful to record the dates when the meters were read; these dates are important in weather normalization for determining average billing period temperatures. For other types of fuel, such as oil and coal, the only data available may be delivery amounts and dates.

Unless fuel use is metered or measured daily or monthly, consumption for any specific period shorter than one season or year is difficult to determine. Data should be converted to per-day usage or adjusted to account for differences in length of metering periods. The data tell how much energy went into the building on a gross basis. Unless extensive submetering is used, it is nearly impossible to determine when and how that energy was used and what it was used for. It may be necessary to install such meters to determine energy use.

The **thermal and electricity usage characteristics** of a building and its energy-consuming systems as a time-varying function of ambient conditions and occupancy must also be determined. Most computer programs can use as much detailed information about the building and its mechanical and electrical system as is available. Where the energy implications of these details are significant, it is worth the effort of obtaining them. Testing fan systems for air quantities, pressures, control set points, and actions can provide valuable information on deviations from design conditions. Test information on pumps can also be useful.

Data on **building occupancy** are among the most difficult to obtain. Because most energy analysis programs simulate the building on an hourly basis for a one-year period, it is necessary to know how the building is used for each of those hours. Frequent observation of the building during days, nights, and weekends shows which energy-consuming systems are being used and to what degree. Measured, submetered hourly data for at least one week are needed to begin to understand weekday/weekend schedule-dependent loads.

Weather data, usually one year of hour-by-hour weather data, are necessary for simulation (see Chapter 27 of the 2001 *ASHRAE Handbook—Fundamentals*). The actual weather data for the year in which energy consumption data were recorded significantly improves simulation of an existing building. Where the energy-consuming nature of the building is related more to internal than to external loads, selection of weather data is less important; however, for residential buildings or buildings with large outside air loads, the selection of weather data can significantly affect results. The purpose of the simulation should also be considered when choosing weather data: either specific-year data, data representative of long-term averages, or data showing temperature extremes may be needed, depending on the goal of the simulation.

Usually the results of the first computer runs will not agree with actual metered energy consumption data. The following are possible reasons for this discrepancy:

- Insufficient understanding of energy-consuming systems that create the greatest use
- Inaccurate information on occupancy and time of building use
- Inappropriate design information on air quantities, set points, and control sequences

The input building description must be adjusted and trial runs continued until the results approximate actual energy use. Matching the metered energy consumption precisely is difficult; in any month, results within 10% are considered adequate.

The following techniques for calibrating a simulation program to measured data from a building should be considered:

- Matching submetered loads or 24 h day profiles of simulated whole-building electric loads to measured data
- Matching *x-y* scatter plots of simulated daily whole-building thermal loads versus average daily temperature to measured data
- Matching simulated monthly energy use and demand profiles to utility billing data

Having a simulation of the building as it is being used permits subsequent computer runs to evaluate the energy effects of various alternatives or modifications. The evaluation may be accomplished simply by changing the input parameters and running the program again. The effect of various alternatives may then be compared and an appropriate one selected.

Computational Flow Dynamics

Computational fluid dynamics (CFD) is a technique for simulation, study, analysis, and prediction of fluid flow and heat transfer in well-defined, bounded spaces. It is based on equations (Navier-Stokes, thermal energy, and species equations, with the appropriate equation of state) that govern the physical behavior of a flow/thermal system, under the premise that mass, momentum, thermal energy, and species concentration are conserved locally and globally within the model.

Usually these equations are in the form of nonlinear partial differential equations relating velocities, pressure, temperature, and some scalar variables to space directions and time. Initial and boundary conditions are specified for each domain, and numerical methods such as finite difference, finite volume, or finite element analysis are utilized to solve these equations. The domain (typically space) is divided (discretized) into cells or elements, the nodal points are defined, then equations are solved for each discrete cell. After solving these equations, the dependent variables (velocities, pressure, temperature, and scalar) are made available at the nodes.

CFD analysis can be applied to a variety of tasks, including location of airflow inlets/outlets in a space, velocities required for system performance, flow pattern determination, temperature distribution in space, and smoke movement and build-up in a space with fire.

HVAC GRAPHICS, CAD, AND BUILDING DATA MODELS

Computer-Aided Design

Computer graphics of buildings and their systems help coordinate interdisciplinary designs and simplify modifications. CAD (referring to computer-aided drafting at times and to computer-aided design at other times) is a subset of CADD (computer-aided design and drafting). CADD encompasses the creation of **building data models** and the storing and use of attributes of graphic elements, such as automated area takeoff or the storage of design characteristics in a database. Drafting, or the creation of construction documents, is quickly becoming a mere by-product of the design process. The distinction between engineering and drafting in engineering firms is decreasing as design and production work become unified. In this section, CADD refers to all aspects of design.

Building data models express not only true dimensions, but also how different elements are connected and where they are located. It is easy to extract lengths, areas, and volumes, as well as the orientation and connectedness (topology) of building parts from computerized drawings of buildings. Drawings can be changed easily and, in most cases, do not require redrawing construction documents. Building walls or ductwork, for example, can be added, removed, enlarged, reduced, and relocated. The user can rotate an entire building on the site plan without redrawing the building or destroying the previous drawing.

CAD systems automate (1) material and cost estimating, (2) design and analysis of HVAC systems, (3) visualization and interference checking, and even (4) manufacturing of HVAC components such as ductwork. These systems are now customized to HVAC applications; for instance, double- and single-line duct layout can be re-represented with a single command and automatically generate three-dimensional (3D) building data models.

Computer-generated drawings of building parts can be linked to nongraphic characteristics, which can be extracted for reports, schedules, and specifications. For instance, an architectural designer can draw wall partitions and windows, and then have the computer automatically tabulate the number and size of windows, the areas and lengths of walls, and the areas and volumes of rooms and zones. Similarly, the building data model can store information for later use in reports, schedules, design procedures, or drawing notes. For example, the airflow, voltage, weight, manufacturer, model number, cost, and other data about a fan displayed on a drawing can be stored and associated with the fan in the data model. The link between the graphics and attributes makes it possible to review the characteristics of any item or to generate schedules of items in a certain area on a drawing. Conversely, the graphics-to-data links allow the designer to enhance graphic items having a particular characteristic by searching for that characteristic in the data files and then making the associated graphics brighter, flashing, bolder, or different-colored in the display.

Computer-generated data models can also help the designer visualize the building and its systems and check for interferences, such as structure and ductwork occupying the same space. Some software packages now perform automatic interference checking. Layering features also help an HVAC designer coordinate designs with other disciplines. Mistakes in design can be corrected even before the drawings are plotted to eliminate costly field rework or, worse, at-fault litigation. For complex projects, interference software applications are available that assist in managing interferences throughout the building data model.

HVAC system models and associated data can be used by building owners and maintenance personnel for ongoing facilities management, strategic planning, and maintenance. For instance, an air-handling unit can be associated with a preventative maintenance schedule in a separate facility management application. Models are useful for computer-aided manufacturing such as duct construction. The 3D building data model can also aid in developing sections and details for building drawings. CAD programs can also automate cross-referencing of drawings, drawing notations, and building documents.

In addition to the concept of the single-building data model, the Internet is has greatly influenced engineering workflows. As bandwidth continues to widen, the speed of the Internet has allowed engineering firms to expand their clients, partners, and services worldwide. Software applications are available that allow users to design projects and share building model data globally over the Internet, and can be used for simple viewing and redlining as well. Project managers can view all aspects of the design process live and redline drawings simply by using a web browser.

Computer Graphics and Modeling

Computer graphics programs may be used to create and manipulate pictorial information. Information can be assimilated more easily when presented as graphical displays, diagrams, and models. Historically, building scale models has improved the design engineer's understanding and analysis of early prototype designs. The psychrometric chart has also been invaluable to HVAC engineers for many years.

Combining alphanumerics (text) with computer graphics lets the design engineer quickly evaluate design alternatives. Computers can simulate design problems with three-dimensional color images that can predict the performance of mechanical systems before they are constructed. Simulation graphics software is also used to evaluate design conditions that cannot ordinarily be tested with scale models because of high costs or time constraints. Product manufacturability and economic feasibility may thus be determined without constructing a working prototype. Whereas historically only a few dozen scale-model tests could be performed before full-scale manufacturing, combined computer and scale-model testing allows hundreds or thousands of tests to be performed, improving reliability in product design. Graphic modeling and simulation of complex fluid flow fields are also used to simulate airflow fields in unidirectional cleanrooms, and may eventually make cleanroom mock-ups obsolete (Busnaina et al. 1988). Computer models of particle trajectories, transport mechanisms, and contamination propagation are also commercially available (Busnaina 1987).

Integrated CADD and expert systems can help the building designer and planner with construction design drawings and with construction simulation for planning and scheduling complex building construction scenarios (Potter 1987).

A simple, helpful tool for the HVAC engineer is graphic representation of **thermodynamic properties and thermodynamic cycle analysis**. These programs may be as simple as computer-generated psychrometric charts with cross-hair cursor retrieval of properties and computer display magnification of chart areas for easier data retrieval. More complex software can graphically represent thermodynamic cyclic paths overlaid on two- or three-dimensional thermodynamic property graphs. With simultaneous graphic display of the calculated results of Carnot efficiency and COP, the user can understand more readily the cycle fundamentals and the practicality of the cycle synthesis (Abtahi et al. 1986).

Typical **piping and duct system simulation** software produces large amounts of data to be analyzed. Pictorially enhanced simulation output of piping system curves, pump curves, and load curves speeds the sizing and selection process. Hypothetical scenarios with numeric/graphic output increase the designer's understanding of the system and help avoid design problems that may otherwise become apparent only after installation (Chen 1988). Graphic-assisted fan and duct system design and analysis programs are also available (Mills 1989).

Airflow analysis of flow patterns and air streamlines is done by solving fundamental equations of fluid mechanics. Finite-element and finite-volume modeling techniques are used to produce two- or three-dimensional pictorial-assisted displays, with velocity vectors and velocity pressures at individual nodes solved and numerically displayed.

An example of pictorial output is Figure 5 in Chapter 16, where calculated airflow streamlines have been overlaid on a graphic of the cleanroom. With this display, the cleanroom designer can see potential problems in the configuration, such as the circular flow pattern in the lower left and right.

Major features and benefits associated with most computer flow models include the following:

- Two- or three-dimensional modeling of simple cleanroom configurations
- Modeling of both laminar and turbulent airflows
- CAD of air inlets and outlets of varying sizes and of room construction features
- Allowance for varying boundary conditions associated with walls, floors, and ceilings
- Pictorial display of aerodynamic effects of process equipment, workbenches, and people
- Prediction of specific airflow patterns in all or part of a cleanroom
- Reduced costs of design verification for new cleanrooms
- Graphical representation of flow streamlines and velocity vectors to assist in flow analysis

A graphical representation of simulated particle trajectories and propagation is shown in Figure 6 of Chapter 16. For this kind of graphic output, the user inputs a concentrated particle contamination and the program simulates the propagation of particle populations. In this example, the circles represent particle sources, and the diameter is a function of the concentration present. Such simulations help the cleanroom designer determine protective barrier placement.

Although research shows excellent correlation between flow modeling done by computer and in simple mock-ups, modeling software should not be considered a panacea for design; simulation of flow around complex shapes is still being developed, as are improved simulations of low-Reynolds-number flow.

Simulations range from two-dimensional and black and white to three-dimensional, color, and fully animated. Three-dimensional color outputs are often used not only for attractive presentations, but to increase user productivity (Mills 1989).

HVAC UTILITIES

Utility programs and modules are calculation tools that can be used both alone and integrated into other design tools.

Unit Conversion Programs

Many small utilities automatically convert between different sets of measurement units. Many of these are available as freeware or shareware. Chapter 37 of the 2001 *ASHRAE Handbook—Fundamentals* provides factors for unit conversions between SI and I-P units.

Psychrometric Utilities

Chapter 6 of the 2001 *ASHRAE Handbook—Fundamentals* provides equations to calculate psychrometric properties. Most of the utilities and Visual Basic® functions that are available to automate these calculations will determine psychrometric properties from any two of the properties and a barometric pressure. Some will also calculate entering and leaving properties from entering state-point(s) and a defined process (e.g., mixing of air streams, dehumidification), and plot to a psychrometric chart. Charting can be performed by scanning a psychrometric chart and determining the *x* and *y* axes by using the linear properties of dry-bulb temperature and humidity ratio.

Thermal Comfort Modules

An ASHRAE utility (ASHRAE 1997) calculates the predicted mean vote (PMV) for thermal comfort from the inputs for clothing, metabolic rate, mean radiant temperature, air speed, dry-bulb temperature, and relative humidity. This utility uses the calculations presented in ASHRAE *Standard* 55-1992.

Refrigeration Properties and Design

The program REFPROP (NIST; http://www.boulder.nist.gov/) allows the user to examine thermodynamic and transport properties for 39 pure refrigerants and blends. It may be used in an interactive mode. Because source code is included, it may also be used as part of a program that requires refrigerant properties. Other refrigerant property programs are also available from sources such as universities. Programs should be able to address the following refrigerant properties:

- Enthalpy
- Entropy
- Viscosity
- Thermal conductivity

Ventilation

Many ventilation programs are available to help designers meet the requirements of ASHRAE *Standard* 62, Ventilation for Acceptable Indoor Air Quality. As with any computer program, users should evaluate any program's technical capabilities, such as

- Ventilation requirements by application
- Application of the Multiple Space equation in *Standard* 62
- Use of ventilation effectiveness
- Application for spaces with intermittent or variable occupancy

In addition to technical capabilities, the units of input and output and the ability to interface with programs for input or output should also be examined.

SOURCES OF HVAC SOFTWARE

Many applications have been developed as the result of ASHRAE-funded research, ranging from database retrieval for use in HVAC&R calculations to demonstration versions of advanced tools.

The ASHRAE web site (www.ashrae.org) and the ASHRAE Online Bookstore are good sources for obtaining this software, and provide information about these programs and their system requirements, as well as other sources of HVAC-related software.

INTEROPERABLE COMPUTER APPLICATIONS FOR THE HVAC&R INDUSTRY

HVAC&R computer applications have historically been standalone tools that require manual reentry of data to accomplish multidisciplinary analysis. In most projects, these data must then be manually transcribed for use in other professional software, for work such as HVAC calculations and design, cost estimating, building energy performance simulation, and energy code compliance checking. This process requires time and resources. Furthermore, error detection and correction can be just as resource consuming; undetected errors can lead to serious problems. Any changes to the design require corresponding changes in transcription for other applications. Each data element in a building design may typically be independently recreated seven times in the course of design. Much of this information may be lost and/or outdated later in the building life cycle during construction, renovation, and facility maintenance.

The goal of automatically sharing data between different tools is becoming possible because of software interoperability, the ability to share the same information among software applications used by practitioners performing different industry tasks. National and international efforts to develop standardized data models that allow software interoperability are well under way. A key product of these efforts is the Industry Foundation Classes (IFC) data model developed by the International Alliance for Interoperability (IAI). Members of the IAI, such as ASHRAE, work to develop cross-platform and cross-application communication standards.

Interoperability also requires that software vendors incorporate standard data models in their software applications. As shown in Figure 3, this can be done either by directly accessing and updating an IFC data file or by indirect access through an IFC-compliant data server. Several CAD tools now have implementations based on the evolving IFC data model standard, allowing building geometry input in these tools to be easily shared with other IFC-compliant tools. Nongeometric building data (e.g., construction material properties, HVAC&R equipment characteristics) are also included in the IFC data model. In addition to CAD tools, many other IFC-based HVAC&R software applications are available. Current information on state-of-the-art software interoperability is available at the web site addresses listed in the Bibliography.

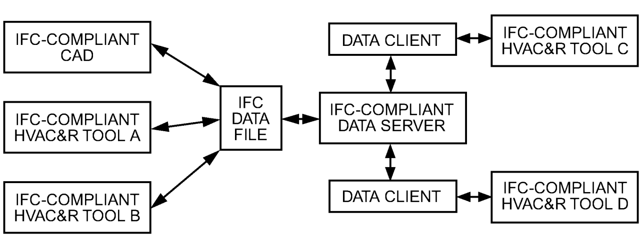

Fig. 3 Software Interoperability Based on IFC Data Model Standard

NETWORKING COMPONENTS

Computers use resources that are commonly arranged into networks comprised of hardware and software components. Hardware network components include the following:

- Hubs
- Switches
- Routers
- Bridges
- Repeaters

Software network components usually take one of two forms: (1) dynamic link libraries (DLLs) to control network hardware, or (2) applications to communicate between computers according to adopted networking standards (e.g., IEEE 802.3 Ethernet).

Numerous computer network configurations exist for intra-, inter-, and extra-office data communication. Some common examples include

- Local area networks (LANs)
- Wide area networks (WANs)
- Metropolitan area networks (MANs)
- Intranet
- Extranet
- Internet

Figure 4 is a diagram of large business system architecture with Internet connections. The system has a large number of personal computers connected via Ethernet to a central wiring closet device called a hub. This hub simplifies the wiring infrastructure by allowing centralized wiring termination for modular utility connections to individual computers. The firewall, or computer security barrier, protects against unauthorized access from the outside Internet to individual nodes inside the firewall. Users may connect to the Internet either through a corporate router or indirectly from home through an Internet service provider (ISP), which may charge a fee for the service. Higher-bandwidth connections typically cost more as speed increases.

LAN PROTOCOLS

The Ethernet protocol is the most widely used and accepted local area network (LAN) standards, and is used extensively in industry. Because of its pervasive acceptance in industry, HVAC building automation protocols such as BACnet® and LonWorks® allow their protocols to use Ethernet in their physical layer. Ethernet is a multi-access, packet-switching network where each node can request access to the network on an equal basis with any other node. Ethernet uses the collision sense, multiple access/collision detect (CSMA/CD) technique: if two nodes transmit at the same time, a collision occurs; both nodes then wait a random period of time and try again. This allows efficient allocation of bandwidth based on need.

An Ethernet LAN can use different media, such as the following:

- 10Base5, also known as Thick Net, which uses the large coaxial cable RG-11
- 10Base2, also known as Thin Net, which uses the smaller coaxial cable RG-58
- Fiber-optic cable
- 10Base-T (Twisted Pair), the most popular type, which has a wiring limitation length of 30 m and is typically used in centralized wiring systems.

A faster version of Ethernet, called 100Base-T or Fast Ethernet, supports data transfer rates of 100 Mbps; however, the fastest version, Gigabit Ethernet, supports data rates of 1000 Mbps (1 Gbps).

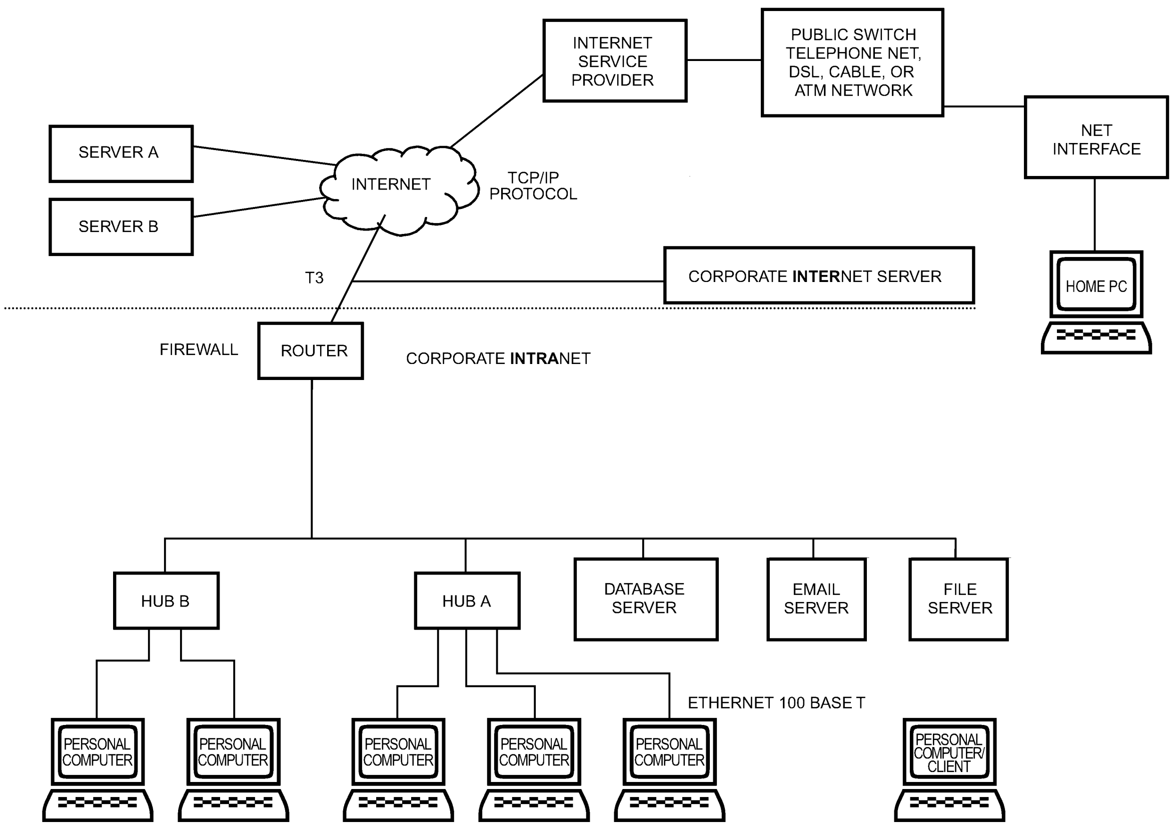

Fig. 4 Example of Business System Architecture

TRANSMISSION CONTROL PROTOCOL/ INTERNET PROTOCOL

Transmission control protocol/internet protocol (TCP/IP) is a set of protocols that allow computers to communicate with each other. TCP/IP is the language of the Internet, and is also used in local networks, intranets, and extranets. As communication protocols such as TCP/IP have gained acceptance, availability of components based on these protocols has increased and driven networking costs down.

WIRELESS SERVICE

One of several immediately applicable new technologies is wireless connections for computers and equipment (e.g., to the Internet or to a LAN). Wireless communications to remote sensors can provide a low-cost solution where the cost of running conventional wiring is prohibitive or inappropriate.

Wireless monitoring components include a wireless transmitter and a web site. The transmitter is mounted on or near the equipment being monitored. The web site determines what alerts are sent to whom, and the method of delivery (e.g., e-mail, pager, telephone). Alert messages specify the condition that triggered the alert and the location, make, model, and serial number of the equipment. Also, field service technicians can inspect service procedures, service request, and maintenance from a remote computer at the job site to determine repair history on a piece of equipment.

Issues such as reliability, battery replacement alerts, maintenance, and reliability due to electromagnetic noise and interference should be considered when using wireless communications.

TELEPHONY STANDARDS

Regular analog phone service offers limited bandwidth and can support analog phone modems up to 56 kilobits per second (kbps). Digital phone standards include digital subscriber line (DSL), which can support bandwidth to 640 kbps but is limited to a 3050 m wire length from the telephone switching office. Cable modems provide high-speed access from traditional cable TV service companies. Cable networks generally have download speeds roughly between 500 kbps and 2 Mbps, but are often limited to about 128 kbps upload speed.

T1 and T3 are high-speed digital communication lines used by main communications trunks between servers, or for access to the Internet from an Internet service provider or company connection line. T1 connection speed is a maximum of 1.5 Mbps; T3 maximum speed is 44.736 Mbps. Asynchronous transfer mode (ATM) digital service provides high-speed communication at a typical maximum data rate of 155 Mbps.

FIREWALLS

Firewalls (computer security barriers), frequently used to prevent outside individuals from accessing internal, proprietary networked resources, can be designed to block certain messages from coming into or leaving the network. Firewalls are typically implemented in a high-speed router, and can efficiently block all communication to a specific IP address. All messages that enter and leave the intranet pass through the firewall, which examines each message and halts progress of illegal communications. Firewalls are an essential part of corporate computer security systems.

MONITORING AND CONTROL

A control system performs two primary functions: monitoring (also referred to as data acquisition or data gathering) and control (also referred to as device control). A control consists of a set of measured (monitored) parameters, a set of controlled parameters, and a control function that translates the measurement data into control signals applied to controlled parameters.

Supervisory control includes (1) **total system monitoring** (functions such as alarm reporting, energy measurement and calculation, logs, and trend reports) and (2) **overall control** (functions such as manual overrides, optimizing modification or discharge local loop set points, optimizing start-stop of subsystems, and controlled interaction between subsystems).

Types of supervisory control, depending on focus, 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.

INTEROPERABILITY

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 Networking 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 (ASHRAE *Standard* 135). As a result, the BACnet protocol may be used by head-end computers, general-purpose direct digital controllers, and application-specific or unitary controllers.

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 Standards Organization/Open Systems Interconnection) model. The application layer and a simple network layer are defined in the BACnet standard.

The **physical layer** provides a means of connecting devices and transmitting the electronic signals that convey the data.

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 that will be 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 building that is very far away. This long-distance communication is typically done through telephone networks. Using the Internet is becoming a popular, low-cost alternative to phones.

DIRECT DIGITAL CONTROL (DDC) APPLICATIONS

Building management systems use standard workstation technology to connect or view system information. Standardization of building and vendor control protocol will allow future systems to access BACnet® and LonWorks® systems. Although there are many approaches to communicating building information, the web-browser-based client/server approach is becoming a standard interface.

Graphical representation of data from automation systems (e.g., operating conditions, trend data) is effective for enhancing operation and corrective action.

Direct digital control (DDC) allows precise and repeatable control using vendor hardware and software platforms. Many vendors allow access to DDC and set-point parameters, or are supporting common application standards such as distributed component object model (DCOM) ActiveX® and Enterprise JavaBeans®/common object request broker architecture (EJB/CORBA). Purchasing outside standards from companies specializing in certain components allows HVAC workstation providers to use common components for analysis, trending, and graphical presentation.

CONTROL COMPONENTIZATION

HVAC manufacturers use DDC microprocessors to create powerful, low-cost controls and feature-rich equipment. In the past, many of the 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.

In the past, because all major HVAC equipment required some type of control system, control points were duplicated. Acceptance 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's testing.

As the functionality of component control increases and associated cost decreases, component-level interaction makes building-wide system integration less critical.

INTERNET-ENABLED BUILDING AUTOMATION SYSTEMS

With Internet-enabled building automation systems, additional information outside the traditional control system (e.g., weather data, real-time energy data, pricing rates, manufacturers' equipment data) can be combined with real-time equipment data to create valuable analysis information. Commercial applications allow device integration to view real-time data, command equipment, and trend data. Users can manage energy consumption and costs, correct comfort problems, and solve equipment issues from distributed locations. Access control systems are available through the Internet using existing Internet standards such as TCP/IP and HTTP/XML.

CONVERGENCE OF INFORMATION SYSTEMS AND INFORMATION TECHNOLOGY

As the information system (IS) and information technology (IT) industry has advanced, so have applications that can be used in building automation. Internet browser technology is a standard application, allowing information to be shared across nontraditional computer boundaries.

Because there is such demand in business for IT products, expertise and knowledge formerly reserved for IT applications can be applied to, for instance, user interface and building automation applications. A critical concern about integrating IT systems and building automation is information security. Security standards developed by the online commerce and banking industry could be a model for future development.

Web-based building controls that use the IT approach should create an open, interoperable structure for control automation systems. Implementing common field-bus standards and integration with web browsers can be helpful for legacy system support. Rapid adoption of the Internet and standardization efforts in the field bus and building automation protocols have made developing a single standard for both Internet and control a goal for many vendors.

Combining building automation with Internet functionality will provide functionality in a user-friendly form.

INTERNET AND APPLICATIONS

The Internet originated in 1969 as an experimental project of the Advanced Research Project Agency (ARPA), and was called ARPANET. From its inception, the network was designed to be a decentralized, self-maintaining series of redundant links between computers and computer networks, capable of rapidly transmitting communications without direct human involvement or control, and with the automatic ability to reroute communications if one or more individual links were damaged or otherwise unavailable. Among other goals, this redundancy of linked computers was designed to allow vital research and communications to continue even if portions of the network were damaged by a war or other catastrophic event.

Messages between computers on the Internet do not necessarily travel entirely along the same path. The Internet uses packet-switching communication protocols that allow individual messages to be subdivided into smaller packets These are then sent independently to the destination and automatically reassembled by the receiving computer. Although all packets of a given message often travel along the same path to the destination, if computers along the route become overloaded, packets can be rerouted to less loaded computers.

No single entity—academic, corporate, governmental, or nonprofit—administers the Internet. It exists and functions because hundreds of thousands of separate operators of computers and computer networks independently decided to use common data transfer protocols to exchange communications and information with other computers. No centralized storage location, control point, or communications channel exists for the Internet, and no single entity can control all of the information conveyed on the Internet.

Internet Communication Methods

The most common methods of communications on the Internet (as well as within the major on-line services) can be grouped into the following categories and are described in the following sections:

- One-to-one messaging (such as e-mail)
- One-to-many messaging (such as mailing list servers)
- Distributed message databases (such as USENET news groups)
- Real-time communication (such as Internet Relay Chat)
- Real-time remote computer use (such as Telnet)
- Remote information retrieval (such as ftp, gopher, and the World Wide Web)

Most of these methods of communication can be used to transmit text, data, computer programs, sound, visual images (i.e., pictures), and moving video images.

Servers

Network servers are fast becoming an important part of building automation and computer services systems. A web page runs on a generic web server. Files available for central storage and shared resources among users of a network are referred to as a file server. FTP servers allow users outside a company to store and manage large files such as drawing and construction documents. Mail servers are central storage servers that provide e-mail services to users. Database servers provide core database functionality, and can be added to application servers to access specific application services.

E-mail

Electronic mail (e-mail) is an extremely useful communications tool for use with local area networks, wide area networks, and the Internet. Using e-mail software, a message can be sent to individuals or to groups. Unlike postal mail, simple e-mail generally is not "sealed" or secure, and can be accessed or viewed on intermediate computers between the sender and recipient unless the message is encrypted. Modern e-mail software can attach graphics and executable programs, as well. These features should be used with caution because of the large network resources required to support the file transfer.

Computer Viruses, Worms, and Trojan Horses. Computer viruses are programs that replicate themselves and typically do damage to the host system; they are frequently received through e-mail attachments. A **worm** is a self-contained program that spreads working copies of itself to other computer systems, typically through network connections. A **Trojan horse** is a program that performs undocumented activities not desired by the program user.

Antivirus software is vital to maintaining system security. Some PC operating systems are more vulnerable to viruses and worms than others.

Some newer e-mail programs automatically execute script files attached to e-mail; this leaves the user open to viruses and other types of attack. As a precaution, e-mail programs that automatically execute script files should not be used, or, if no other program is available, automatic script execution should be turned off. Only attachments from reputable or trusted sources should be opened, and then only after scanning the attachment with antivirus software.

Hoaxes. A common problem associated with e-mail is the hoax or chain letter. A hoax is commonly spread as a warning about serious consequences of a new virus, offers of free money or prizes, or dubious information about a person, product, or organization. A common request from the hoax is to send it to everyone you know, in effect overloading the system with useless information. Although hoaxes and chain letters do not damage the host computer, they tax network resources, spread misinformation, and distract users from real work. Users should not pass hoaxes along, but should simply delete the message. Legitimate warnings about viruses come from IT staff or antivirus vendors. Individual hoaxes can be investigated through web sites devoted to hoaxes and virus myths (e.g., Lawrence Livermore National Laboratory 2002).

Mailing Lists

The Internet also contains automatic mailing list services (e.g., LISTSERV) that allow communication about particular subjects of interest to a group of people. Users can subscribe to a mailing list on a particular topic of interest to them. The subscriber can submit messages on the topic to the mailing list server that are forwarded, either automatically or through a human moderator overseeing the list, to the e-mail accounts of all list subscribers. A recipient can reply to the message and have the reply also distributed to everyone on the mailing list. Most mailing lists automatically forward all incoming messages to all mailing list subscribers (i.e., they are unmoderated).

Distributed Message Databases

Distributed message databases, such as USENET newsgroups, are similar to mailing lists but differ in how communications are transmitted. User-sponsored newsgroups are among the most popular and widespread applications of Internet services, and cover all imaginable topics of interest. Like mailing lists, newsgroups are open discussions and exchanges on particular topics. Users, however, need not subscribe to the discussion mailing list in advance, but can access the database at any time. Some newsgroups are moderated, but most are open.

Real-Time Communication

Internet users can also engage in an immediate dialogue, in real time, with other people on the Internet, ranging from one-to-one communications to Internet Relay Chat (IRC), which allows two or more to type messages to each other that almost immediately appear on the receivers' computer screens. IRC is analogous to a telephone party line, using a computer and keyboard rather than a telephone. With IRC, however, at any one time there are thousands of different party lines available, with collectively tens of thousands of users discussing a huge range of subjects. Moreover, a user can create a new party line to discuss a different topic at any time. Some IRC conversations are moderated or have channel operators. Commercial online services often have their own chat systems to allow their members to converse.

Real-Time Remote Computer Use

Another method to access and control remote computers in real time is using Telnet, the main Internet protocol for connecting remote computers. For example, using Telnet, a researcher can use the computing power of a supercomputer located at a different university. A student can use Telnet to connect to a remote library to access the library's online catalog program.

Remote Information Retrieval

The most well-known use of the Internet is searching for and retrieving information located on remote computers. The three primary methods to locate and retrieve information on the Internet are ftp, Gopher, and HTTP (the World Wide Web).

A simple method, **file transfer protocol** (ftp) allows the user to transfer files between the local computer and a remote computer. The program and format named **Gopher** guides a search through the resources available on a remote computer.

World Wide Web. The World Wide Web (WWW) serves as the platform for a global, online store of knowledge, containing information from diverse sources and accessible to Internet users around the world. Though information on the web is contained in individual computers, the fact that each of these computers is connected to the Internet allows all of the information to become part of a single body of knowledge. It is currently the most advanced information system developed on the Internet, and encompasses most information in previous networked information systems such as ftp, Gopher, wide-area information server (WAIS) protocol (used to search indexed databases on remote servers), and USENET.

Basic Operation. The WWW is a series of documents stored in different computers all over the Internet. An essential element of the web is that each document has an address (rather like a telephone number).

Many organizations now have home pages on the web, which, through links from the home page, guide the user to information about or relevant to that organization.

Links may also take the user from the original web site to another web site on another computer connected to the Internet. These links from one computer to another, from one document to another across the Internet, are what unify the web into a single body of knowledge, and what makes the web unique.

Publishing. The WWW allows people and organizations to communicate easily and quickly. Information is published on the web; this process requires only a computer connected to the Internet and running WWW server software. The computer can be anything from an inexpensive personal computer to several state-of-the-art computers filling a small building. Many web publishers choose instead to lease disk storage space from a company with the necessary facilities, eliminating the need to own any equipment.

Information to be published on the web must be formatted according to web standards, which ensure that all users who want to view the material will be able to do so.

Web page design can significantly affect user satisfaction. Web pages with content limited to one screen tend be easier to use than long web pages that require scrolling. Web pages with large graphics files or that require special software to view the page may discourage low-bandwidth-connection users (e.g., internet access over regular analog phone lines) because of long waits. Maintaining and updating web content is important: regular changes encourage repeat users. Web pages that give current information available nowhere else create value for users and encourage new and repeat visitors. However, care must be taken to obtain written permission for use of copyrighted material. Web sites can be open to all Internet users, or closed (creating an intranet), accessible only to those with advance authorization. Many publishers choose to keep their sites open to give their information the widest potential audience.

Searching the Web. Systems known as **search engines** allow users of the web to search by category or by key words for particular information. The engine then searches the web and presents a list linked to sites that contain the search term(s). Users can then follow individual links, browsing through the information on each site, until the desired material is found. There are also web-based directories maintained by humans that can often give more precise results for a search in a particular area.

Search engines results can be narrowed by adding more key words: for example, a search for the word HVAC may end up with a list several hundred pages long, but a narrower search for HVAC VAV could narrow the focus.

Common Standards. The web links disparate information on Internet-linked computers by using a common information storage format called **hypertext markup language (HTML)** and a common language for the exchange of web documents, **hypertext transfer protocol (HTTP)**. HTML documents can contain text, images, sound, animation, moving video, and links to other resources. Although the information itself may be in many different formats and stored on computers that are not otherwise compatible, these web standards provide a basic set of standards that allow communication and exchange of information.

Many specialized programs exist to create and edit HTML files. Like HTML, **extensible markup language (XML)**, is a subset of the standard generalized markup language (SGML) protocol. XML applies the same document presentation principles of HTML to data interchange beyond simply displaying the data. XML separates data content from its presentation. This allows for different visual renditions of the same message, for displays on different devices.

Supervisory Groups. No single authority controls the entire Internet, but it is guided by the Internet Society (ISOC). ISOC is a voluntary membership organization intended to promote global information exchange through the Internet (Krol and Hoffman 1996). The Internet Architecture Board (IAB) defines Internet communication standards. The IAB also keeps track of information that must remain unique. For example, each computer on the Internet has a unique 32-bit address. The IAB does not actually assign the addresses, but it makes the rules about how to assign them (Krol and Hoffman 1996).

Collaborative Design

The Internet is revolutionizing how project teams collaborate. Interactions, such as sharing or jointly developing drawings or documents or designing software, can now take place efficiently with collaborators around the world.

Collaborative design raises many coordination issues. Methods of sharing data, such as distributed databases, revision and developmental accounting, and security concerns associated with the transmission of design information must be carefully considered.

SECURITY ISSUES

Computer security requires sound planning and continuous maintenance and monitoring. Mail servers can scan for viruses before users open e-mail, and individual virus software loaded on individual machines serves as a second layer of protection (see also the section on Computer Viruses, Worms, and Trojan Horses). Always save attached files to a safe directory and scan with antivirus software before using. Typically, IS and IT staff have a dedicated support person and strategy to maintain security.

A critical area for computer security is user names and passwords. Many systems require frequent changes of passwords with minimum length, number, case, and other requirements. Passwords should never be released to anyone.

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FURTHER INTERNET RESOURCES

BACnet Manufacturers Association: www.bacnetassociation.org
LONMARK Interoperability Association: www.lonmark.org