Title

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Publication Date

1984-07-01

LBL-17898

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

To be presented at the ACEEE 1984 Summer Study on Energy Efficiency in Buildings, Santa Cruz, CA, August 14-22, 1984

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Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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LBL-17898

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This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Solar Heat Technologies, Active Heating and Cooling Division of the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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ABSTRACT

The application of innovative design and modern computer-based HVAC controls presents many opportunities for energy conservation in both new and older commercial buildings. New computer technology is rapidly entering the market place to help control energy use. Many things are needed for successful energy-efficient building operation: good design of the building, the HVAC system, and the controls; installation during construction of the system and controls as designed; careful commissioning to bring the building to full operational status; and education of operation and maintenance personnel on how the building should be controlled so that they can refine and improve the building operation.

Traditionally, there have been two major feedback mechanisms in the operation of a commercial building: the occupants complain to the maintenance personnel about comfort conditions; and management, who pays the energy bills, complains to the maintenance personnel about the cost. Because the space conditions are adjusted to minimize occupant complaints, heating, ventilating and air conditioning (HVAC) equipment can preform poorly for years and no one may notice. Only when "conserving energy" becomes an important management goal is the real operation of the HVAC equipment examined.

Experiences with several new "state of the art" office buildings will be discussed. It is important to close the feedback loop from the actual building operation back to the engineering and design community by examining problems in new and retrofit buildings after occupancy.

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INTRODUCTION

As the cost of operating buildings has increased since the oil embargo of 1973, the architecture and engineering community has developed many innovative approaches to reducing the energy consumption in new and retrofit commercial buildings. Sophisticated new computer technology is rapidly entering the market that offers the potential to greatly improve the ability of building operators to manage and limit energy use while maintaining comfort conditions.

However, more than new computer hardware and good design of both the building and the HVAC system and controls is needed for effective control to achieve energy conservation. The space conditioning system and controls must be installed as designed and the temptation to cut corners and save money on the mechanical system and controls must be restrained. The heating ventilating and air conditioning systems must be carefully commissioned to bring the building to full operational status. The operation and maintenance personnel should be trained on the building operation philosophy and on the new control features of the building.

There are two major feedback mechanisms in the operation of a commercial building: the occupants complain to the maintenance personnel about comfort conditions; and management, who pays the energy bills, complains to the maintenance personnel about the cost. The maintenance personnel try to minimize complaints from the occupants and from management. Because the space conditions are adjusted to minimize occupant complaints, heating, ventilating and air conditioning (HVAC) equipment can perform poorly for years and no one may notice. Only when "conserving energy" becomes an important management goal is the real operation of the HVAC equipment examined.

Innovative designs and modern computer-based HVAC control systems require feed-forward from the architect/engineer to the operating personnel as to how the building should be operated. They also require feed-back from operating buildings to the design community as to what really works in practice.

DESIGN

The emphasis on energy conservation has stimulated much creativity in the design of new commercial buildings as represented by: the Bateson California State Office Building in Sacramento, CA; the two Enerplex Buildings in Princeton, New Jersey; and the Lockheed Building in Sunnyvale, CA.

The annual site energy use of the Enerplex buildings is expected to be below 400 MJ/m^2-yr (35 $kBtu/ft^2$-yr) compared to a typical pre-1973 office building energy use of 3,000 MJ/m^2-yr (250 $kBtu/ft^2$-yr).[1]

The site energy use of the Bateson building is expected to be of the order of 360 MJ/m^2-yr (30 $kBtu/ft^2$-yr) compared to the 1977 standard for new Federal office buildings of 660 MJ/m^2-yr (55 $kBtu/ft^2$-yr). [2]

The site energy use of the Lockheed building is expected to be 230 MJ/m^2-yr (19 $kBtu/ft^2$-yr) excluding energy used by computer equipment.[3]

These three "state of the art" office buildings represent a range of energy conserving features that are now being considered in new building design.

The 25,000 m^2 (267,000 ft^2) Bateson Building in Sacramento features a large central atrium with skylights with sun louvers, destratification fans, and power vents to remove heat. There are two rockbeds which are cooled at night and used to cool the building during the day. Direct evaporative cooling (air washers) can be used to help cool the rockbeds or to cool the outdoor air supply. Outdoor air can be brought in at night to cool down the building.

The 56,000 m^2 (600,000 ft^2) Lockheed Building in Sunnyvale features a large central atrium that also serves as an exhaust plenum and large open plan zones served from low static pressure diffusers. The major office space opens directly on the atrium space. The atrium provides daylight to the spaces adjacent to the atrium, and has power exhaust at the top to minimize heat gain. The building also features deep daylighting with a 5.5 m (18 ft) height between floors to achieve deep penetration of daylight into the space and with 3.7 m (12 ft) interior light shelves on the building perimeter. To reduce impact of the solar gains on the mechanical system, the space above the light

[1] L. N. Norford, A. Rabl, and R. H. Socolow, "Measurement of Performance of Solar-Heated Office Buildings," Report PU/CESS 159, Center for Energy and Environmental Studies, Princeton University, Jan 1984.

[2] Sim VanderRyn, "Preliminary Design and Performance Analysis for: NEW STATE OFFICE BUILDING, Site No. 1," Office of the State Architect, Deparment of General Services, State of California, March 1, 1977.

[3] Lee S. Windheim, Robert J. Riegel, Kyle V. Davy, and Michael Shanus, "Case Study: Lockheed Building 157, Deep Daylighting/Innovative Lighting Concepts for A Large Office Building," in Proceedings of the International Daylighting Conference, Phoenix, AZ, February 1983.

shelves serves as a return air plenum. Because the return air temperature will exceed the outdoor air temperature for most of the operating hours, the economizer cycle will operate the building on outside air.

The 12,000 m^2 (130,000 ft^2) Enerplex North Building in Princeton features a large atrium with fans to distribute air through underground concrete pipes or through the double envelope to warm the building shell in winter and to minimize conduction losses. Additional heating is provided by electrical resistance heating elements. In the winter a large sprayed pond accumulates ice for use with summer cooling. Summer operation features nocturnal cooling, and venting of the atrium. Daylighting of the building is accomplished through the atrium or through a light shelf.

The 12,000 m^2 (130,000 ft^2) Enerplex South Building in Princeton features heating by direct gain south wall with movable sun shades, an unconditioned north-facing atrium solar heated through skylights and vented in the summer to prevent overheating. Penetration of daylight into the space is by means of transom windows on the south wall and a light slot, a long narrow cavity that penetrates from the roof to the ground floor. The building is heated and cooled using an electric heat pump from 11 ^oC (52 ^oF) water from an underground aquafer.

Typically, some of the energy conserving measures are in the structure of the building itself with the use of double envelopes, overhangs, atriums, light shelves, or light slots. Portions of the building, such as the atrium, may be largely unconditioned and may experience temperature swings. However, the principal occupied spaces will be maintained within traditional comfort limits.

Other innovative features depend on how the building will be operated. These include the use of night ventilation, rockbeds for heating or cooling, evaporative cooling (air washers), etc. Air handling systems and thermal mass will be coupled with a control strategy to cool the building at night. Air from the atrium may be circulated through a rockbed, or around a double skin to reduce conduction losses through the building envelop, or the atrium may be vented with fans to remove heat.

The design of the heating ventilating and air conditioning system to maintain comfort conditions, must be integrated with the various features of building operation through the controls. These innovative buildings have many different modes of operation which can place stringent design requirements on the building temperature control system, so that the different modes which can operate simultaneously do not place conflicting demands on equipment. The successful implementation of these features requires effective and reliable control system operation.

The implementation of control can be by means of traditional pneumatic or electric controls and time clocks, as in the case of the Enerplex buildings; pneumatic and relay control supervised by a computer that initiates different modes of operation, as in the Bateson building; or by means of more direct computer control, as in the Lockheed building.

The implementation of the control strategies can be by means of traditional pneumatic or electric control, pneumatic control with supervisory energy management computer, or through direct digital computer control. New computer technology is rapidly entering the market place to greatly increase the capability to control energy use in buildings.

The application of computer control in buildings has three aspects: local loop function where the computer assumes direct digital control of specific equipment such as chillers, or air handlers; supervisory function where the computer oversees the system operation resetting temperatures, and turning on and off equipment according to schedule or changing building requirements; and management function where the computer reports information about the status of the system, trends in energy consumption and peak demand, etc.

CONSTRUCTION

The heating and cooling system is one of the last parts of the building to be completed. There is a great temptation during construction to cut corners to save money. Contractors may suggest modifications to the building owner that are at cross-purposes with the intent of the building designer. These modifications are accepted by the building owner over the strong objections of the architect/engineer.

In one case, the cooling system was specified with a low static pressure delivery system with a long slot diffuser extending across the open office space. The original design used low static pressure (0.08 inches water gauge) on the cold air supply which would minimize the fan energy required. The design called for fan rooms on each floor of the building. During construction the mechanical contractor convinced the owner that considerable cost could be saved if the individual fan rooms on each floor were replaced with a single fan room on the ground floor. The additional space gained was fitted out as traditional offices served by separate VAV systems operated at a moderate static pressure (2.5 inches water gauge). This required the entire fan system to be redesigned at the higher static pressure. Thus, to gain some additional office space, much of the fan energy savings were lost, and there was a considerable increase in fan noise.

In another case, key applications software and interface hardware to vary the temperature of the cold supply air in response to changing building load was deleted to save money. Even though the field controls were in place and the documentation assured the operators that the cold supply air temperatures would be readjusted every ten minutes, the interface boards necessary to assure operation of the pneumatic system in the event of computer failure, and the applications software were never purchased. As a consequence, a maintenance engineer had to spend hours every week manually adjusting the ten air handling system supply air temperatures in response to changing building load conditions.

During the 1970's, the Army, Navy, and Air Force purchased many computer-based energy management systems, for their large facilities with a "brick and mortar" mentality. The necessary hardware from major vendors was delivered to the facilities and installed. The facilities personnel were left with the task of making the systems work. The frustration encountered in bringing space-age technology to facilities energy management led to the development of the "Tri-service specification" for energy monitoring and control systems.[4]

COMMISSIONING

The pressure for early occupancy of new buildings is almost irresistible. At the end of a project that has been in the planning for as long as 4 years, the excitement as completion draws near is intense and there is great pressure to get the building cleaned up, to get the contractors out, and to move revenue producing tenants into the building. The building owners often accept the building prematurely. In any new or renovated building it is important to test the HVAC system thoroughly before acceptance of the system and occupancy of the building. In an innovative building it is crucial.

In one case tenants were moved into the third floor offices while they were still gluing carpet on the first floor. The balancing of the air handling system in the building was hasty and incomplete, so that ventilation of the building was inadequate. The building experienced severe air quality problems which were blamed on the building.

If computer technology is involved in the control system, the operating personnel should have formal hands-on factory training provided by the vendor. To accomplish this, up to ten days of training of key operating people should be specified and called out in the construction contract. After training, the operating people should participate in the commissioning of the building, and should perform a 30-day final acceptance test of the computer control system to verify operation.

In one case, the plant facilities people were not allowed in the building until after it was accepted for occupancy. The operating engineering staff assembled documentation of the control systems and operating strategies for the building, but they had only half the information. They had no information or training on the computer control system that was to initiate the innovative building operating features. Upon occupancy they had responsibility for the building but no training.

The availability of the computer to operate the system greatly broadens the range of building operation strategies available to the designer.

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[4] "Energy Monitoring and Control Systems," (Technical Manual TM5-815-2/AFM88-36/NAVFAC DM-4.9), Department of the Army, the Air Force, and the Navy, Washington, DC, September 1981. Tri-Service Specification

However, more than new control hardware such as computers are needed to implement effective control for energy conservation. The new control hardware must be successfully integrated with the fans, chillers, air handling equipment, and space conditioning equipment. Each of the major subsystems must be brought to full operational status. The controls have to be designed and installed correctly, and properly adjusted and calibrated.

Proper commission of the computer control system is crucial. Every computer control point should be inspected and verified as to the actual location of equipment in the field to the readout from the computer and signed off both by the agents of the owner and vendor. Mis-placed or mis-wired sensors, contractors, or actuators can cause great frustration and operational problems. Each software application program should be run to verify its proper operation according to specification and a field acceptance test should be run to verify the software in normal building operation. This should be done before final acceptance.

Not all building systems will operate initially. There must be a phased commissioning of the different building systems. First, the local control loops must be brought into operation. In one building an innovative dead-band thermostat proved difficult to adjust, which led to occupant complaints. In the same building the linkage on variable air volume system dampers tended to jam, making the boxes uncontrollable. Subsequently, the linkages were modified by operating personnel. If the fan controls, variable air volume systems, and thermostats are not working, there is no point in trying to get the computer to control the building. Once the local loops have been verified they can be brought under central computer control.

Next, the supervisory control functions of the host computer system must be initiated, verifying the operation of each mode of operation of the building, for instance night ventilation, or rockbed cooling, and then verifying that the computer software selects the proper mode of operation. It is important to verify that different modes that may operate simultaneously do not place conflicting demands on the hardware. Finally, the management functions, the trend logging, energy demand tracking, and energy consumption functions must be implemented and verified.

OPERATION

The operating personnel need to be involved with the building operating strategy long before they assume responsibility for the day to day operation. They should have a thorough understanding of the intentions of the design architect/engineer as to how the building should be operated.

As the operating personnel become familiar with the building operation during the first year of occupancy, there is a chance to improve the building performance by tuning. While there may be many wrong ways to control a building, there is also no unique right way. There may be different control strategies available, for instance, to achieve night cool down, or morning warm up. The operating people can begin to "fly" the building by trying different strategies and observing the resulting energy usage and comfort conditions.

Traditionally, there has been two major feedback mechanisms in the operation of a commercial building: the occupants complain to the maintenance personnel about comfort conditions; and management, who pays the energy bills, complains to the maintenance personnel about the operating costs. The maintenance personnel try to minimize complaints from the occupants and from management. Because the space conditions are adjusted to minimize occupant complaints, heating, ventilating and air conditioning (HVAC) equipment can perform poorly for years and no one may notice. Too often the work of the operating and maintenance personnel is taken for granted. Attempts to maintain and upgrade equipment are frustrated by limited staff and budgets. Only when "conserving energy" and reducing operating costs becomes an important management goal is the real operation of the HVAC equipment examined and the necessary resources allocated to the operating personnel.

SUMMARY

Innovative building design and new control technology are presenting new opportunities for energy efficient building operation. For successful operation, it is necessary to have good feed-forward from the design operating concept for the building to the operating personnel in the occupied and functioning building. It is important to close the feedback loop from the actual building operation back to the engineering and design community by examining problems in new and retrofit buildings after occupancy. With good design, good specification, good control, good construction, good commissioning, and trained operating personnel, it is possible to achieve smooth operation and significant energy conservation.

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