# Identification and Quantification of the Impact of Improper Operation of Midsize Minnesota Office Buildings on Energy Use: A Seven Building Case Study

Peter Herzog, The Herzog/Wheeler & Associates
Lance LaVine, University of Minnesota

This three year study analyzes the impact of building operations on energy use in seven office buildings. These buildings were all constructed after 1980 and range in size from 50,000 to 250,000 square feet. Three of the buildings employ heat pumps, three variable air volume systems, one is on a district steam system and one has a cool storage system. Approximately half were owner occupied and half were leased space. The objectives of the study were to determine (1) the level of energy savings that might be attributed to improved building operations; (2) if there was a pattern to operation malfunctions that might simplify identification of significant operation energy losses; and (3) if a relatively simple, cost-effective procedure could be developed to identify and correct operation malfunctions. HVAC, lighting and control systems were monitored in each building for a period of two weeks during each climatic season. Results demonstrate a conservatively derived average potential utility cost saving of 15 percent in these buildings. Operation malfunctions, which contribute to unwarranted utility costs, are detailed in terms of specific equipment and control problems. Potential savings, garnered by correcting these problems, are allocated in terms of end uses, fuel type and occurrence during occupied or unoccupied hours. Operation malfunctions are aggregated to construction, equipment, control and operation causes. The protocol that was developed for this study suggests a platform for development of a cost effective approach to monitoring and correcting operations malfunctions in midsize buildings as well as suggesting a possible approach to a cost effective commissioning procedures for midsize buildings.

## Study Objectives

This study addresses three major issues concerning the relationship of building operations to energy conservation. The first of these is an attempt to determine the general level of impact that improved operation procedures might have on energy conservation. Though there is general agreement that a significant relationship exists between operation and energy use in buildings, that relationship had not been quantified nor examined in detail in our region. Secondly, if in fact these saving prove to be significant enough to warrant further investigation, it would prove helpful to determine if there were any general patterns of building malfunction that would confine monitoring to specific sites or times thus simplifying the procedure of identifying operation problems. If no such patterns were found to exist, the problem of developing an identification protocol for operation problems in buildings might prove to be so complex as to preclude the cost effectiveness of such identification. Finally, if both of the previous objectives were to be met, then the actual implementation of malfunction identification protocol would be dependent on development of a cost effective procedure that could be used in a wide range of buildings. The general goal of this three-year study, thus, was to both determine the magnitude of potential energy savings that might be associated with improved building operation and to create a cost effective protocol to identify operation problems in buildings so that they might be corrected.

## Study Subjects

Office buildings were selected as study subjects because they constitute a major portion of the non-residential building stock in Minnesota and because this study paralleled an energy conservation design study of this same building type. Seven office buildings were selected from a broad data base that had been prepared by a local electric utility. These seven buildings generally represent the characteristics of current office building design standards in the Minneapolis/St. Paul metropolitan area. All of the buildings were constructed after 1980. Study subjects ranged in size from 67,000 to 320,000 square feet (Figure 1). Three of the buildings employed heat pumps while four were VAV systems. Six of the buildings were heated by a gas boiler and one by a direct steam system. Four of these buildings utilized D.X. cooling systems, three used evaporative cooling, and one a central chiller. One of the buildings (Building 6) also employed an ice storage

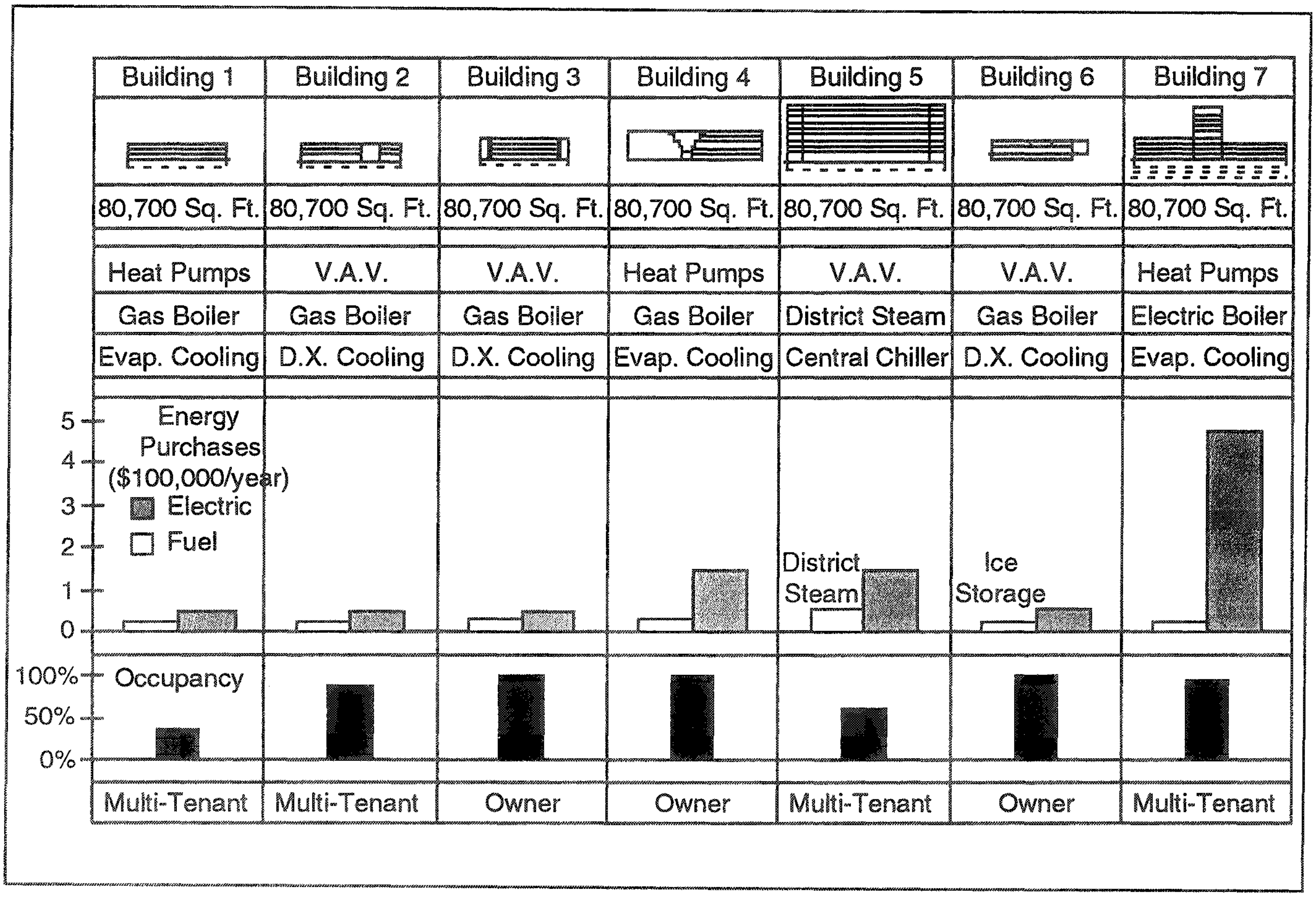

*Figure 1. Building Characteristics*

evaporative cooling, and one a central chiller. One of the buildings (Building 6) also employed an ice storage system. The three owner-occupied buildings of the study were 100 percent occupied while the four multi-tenant buildings of the study were 40, 60, 80 and 90 percent occupied.

## Study Method

The research method employed in this work was designed to determine both the amount of energy that might be saved through improved operations and the operation variables that such saving might be associated with (Figure 2). Utility costs (metered energy input) were documented for each building for at least two years prior to the test. The energy consuming systems in each building were identified from construction documents and verified in a site visit. A schematic diagram of these systems was then developed for each building with projected energy uses based on the specified energy use and schedule of major system components. The key operating variables for each system were determined from construction documents and from site interviews with building operation personnel. These preliminary energy use allocations and definitions of key operating variables were then used to devise a monitoring plan for each building. Monitoring was confined to those subsystems with great enough annual energy expenditures to warrant examination. Actual monitoring of selected systems was carried out for at least a two-week period during each climatic season of the year.

Results of this monitoring procedure were rectified with utility bills to create an "Actual Annual Energy Cost" model. Deviations from how the building was intended to be operated were then noted, and energy savings which would emanate from correcting unintended operation were quantified. These deviations were then subtracted from the actual energy expenditures of the building to identify the amount of energy the building would have consumed if operated in accordance with original design intentions. This allocation of energy by end use was called the "Design Annual Energy Cost" model. In this way only measures which could be operationally corrected were taken credit for in the identification of improved energy consumption that could be attributed to operation. It is

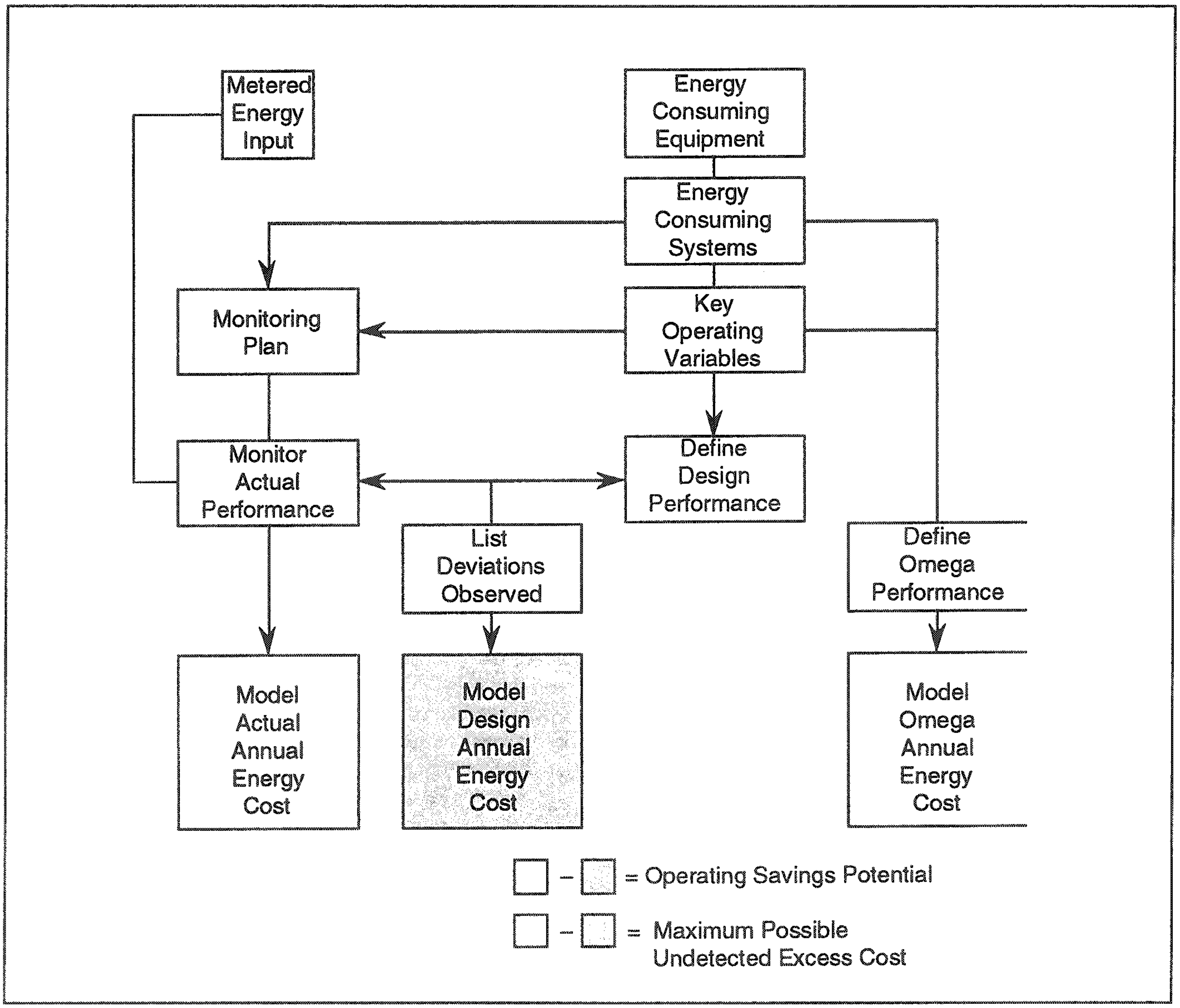

*Figure 2. Research Methods*

important to note that the definition of intended operation of buildings that formed the basis of this measure emanated from the owners and operations staff of these buildings. No attempt was made to consider how these buildings ought to be operated in order to achieve maximum energy savings due to improved building operation. The definition of savings that might be assigned to improved operation of these buildings is thus an inherently conservative measure in that it accepts current operating intention and only takes credit for savings that would accrue to identified and possible corrections in operation procedures that were consistent with the intentions of owners and operators of the buildings.

Finally, a projection was made that attempted to quantify the greatest potential impact that identified malfunctions might have if operation errors went unidentified and uncorrected. The contention of this model was that because operating personnel of study buildings had no way of identifying operation malfunctions, there was no reason not to assume that these malfunctions might, under appropriate circumstances, grow worse. This model, termed the "Omega Annual Energy Cost" model, is hence a worst case projection of the potential energy costs of current operation malfunction in each study building if the operation of this system was allowed to deteriorate to its lowest possible unnoticed level. These three models are then compared to identify both energy savings that might be gained through correction of existing operation malfunction and to characterize the possible worst case risk if these malfunctions were to go unattended.

## Study Results

Reports are available which document specific operation issues in each of the seven case study office buildings in detail. These reports specify the characteristics of each of these buildings in detail; document building gas and electrical utility costs for two years; describe the organization of personnel used to operate the building and their associated operations responsibilities in terms of key operating variables; calculate the actual energy use of the buildings by end use; describe the nature of each operation malfunction; quantify the energy impact of each malfunction; project the possible impact of that malfunction to determine possible worst case energy losses; identify whether this malfunction occurred during hours in which the building was occupied or unoccupied; quantify of potential dollar savings that might be credited to corrected operation procedures; and document the results of a follow-up meeting conducted three months after study findings were reported to building owners and operation personnel to determine the extent of action that had been taken to correct reported operation malfunctions.

This summary of the data developed concerning operation malfunctions in the seven building case studies addresses the three issues that were raised to initiate this study.

1. *Are there significant energy savings that might be associated with improved building operation?*

An average savings of 15.4 percent of the existing utility costs of these buildings could be realized if they were operated in accordance with their design and operation intent (Figure 3). This savings is not premised on assuming ideal operation of buildings or any changes in equipment. It is simply the dollar savings that might be attributed to operation of these buildings if, in fact, they were operated in accordance with their own specified intentions. These savings ranged from 8 to 21 percent.

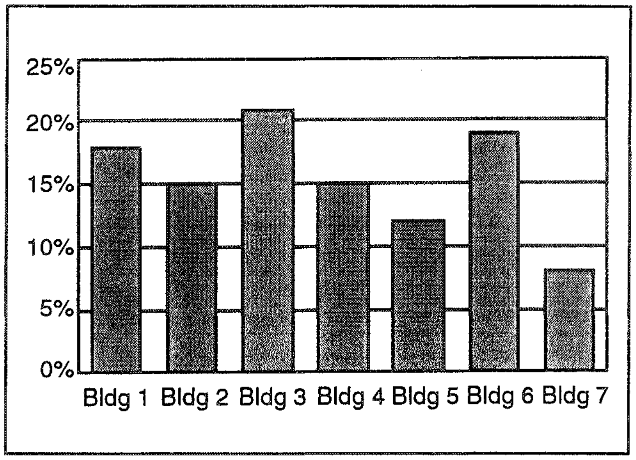

*Figure 3. Dollar Savings Associated with Improved Operation*

The major operation problem in Building 1 was excessive cycling of hot water boilers. In Building 2, simultaneous firing of all five units of the modular boiler, lights left on during unoccupied hours, a snow melt coil that cycled on when there was no snow, and office equipment that was left on during unoccupied hours accounted for the majority of operating energy losses. In Building 3 these losses were due primarily to an improper reset schedule for the perimeter radiation, cooling compressors and condenser fans that operated when not required, and air handling equipment that operated 45 hours per week when the building was unoccupied. In Building 4 these problems consisted primarily of a kitchen makeup air unit that was continuously left on, office equipment that was left on during unoccupied hours, and short cycling times in the continuous operation of heat pumps. 50 percent of the office equipment in Building 5 was left on during unoccupied hours as well as having chillers and air handling units that operated 60 percent more than anticipated. In Building 6, simultaneous heating and cooling occurred because of inappropriate control of perimeter radiation, lighting and office equipment were left on during unoccupied hours, and excessive cooling energy was consumed because of failure of the economizer cycle. Building 7 wasted the least operation energy--8 percent. The waste was due to office equipment that was left on during unoccupied hours and heat pumps that operated continuously. Thus while some operation problems--lights and equipment left on during unoccupied hours--were found in a majority of the buildings, others--inappropriate boulder and reset operation , snow melt, and air handling schedules--were unique to particular buildings.

All buildings were managed and operated by personnel who considered themselves to be leaders in office building management. Few of the operation malfunctions were suspected by this personnel before the study findings were made known to them. Each was surprised at the number and magnitude of the impact of these operation malfunctions, though they generally understood the nature of such problems once they were identified in the study.

2. *Is there a pattern of significant operation problems in office buildings?*

The objective of this portion of the study was to attempt to limit the potential monitoring sites required to identify operation malfunctions with significant energy saving impacts. This search was based on the assumption that energy conservation strategies that attempt to capture the first 80 percent of savings from a procedure are normally more cost effective than those that attempt to capture the final 20 percent of such savings. The goal of this portion of the study was thus to cream potential operation savings by identifying systems with major energy saving potentials and to identify common malfunctions within these systems. Though this procedure leaves the question of maximum saving potential unanswered, it does attempt to identify those potential operation savings which might be most economically achieved.

Patterns of operation malfunction are, in part, dependent on the kind of mechanical systems a building employs. The seven office buildings of this study employed two different kinds of mechanical systems. In the four variable air volume buildings, 80 percent of energy used is consumed by five building systems: air handling; chilling; electric lights; office equipment; and perimeter radiation (Figure 4). The most frequent operation problems associated with these buildings are excess operation during unoccupied hours and failed variable air volume control in air handlers; excess air handling unit operation during unoccupied hours and failed mixed air control; excessively high outdoor reset control setting in perimeter heating; and lights and office equipment that are not turned off during unoccupied hours.

In heat pump buildings, five systems account for 77 percent of annual energy use: heat pumps, the core circulation pump, lighting, office equipment, and boilers (Figure 5). The most common operation problems in those buildings were excess operation of pumps during unoccupied hours; inability of heat pumps to achieve design temperature differential; and excess cycling of these

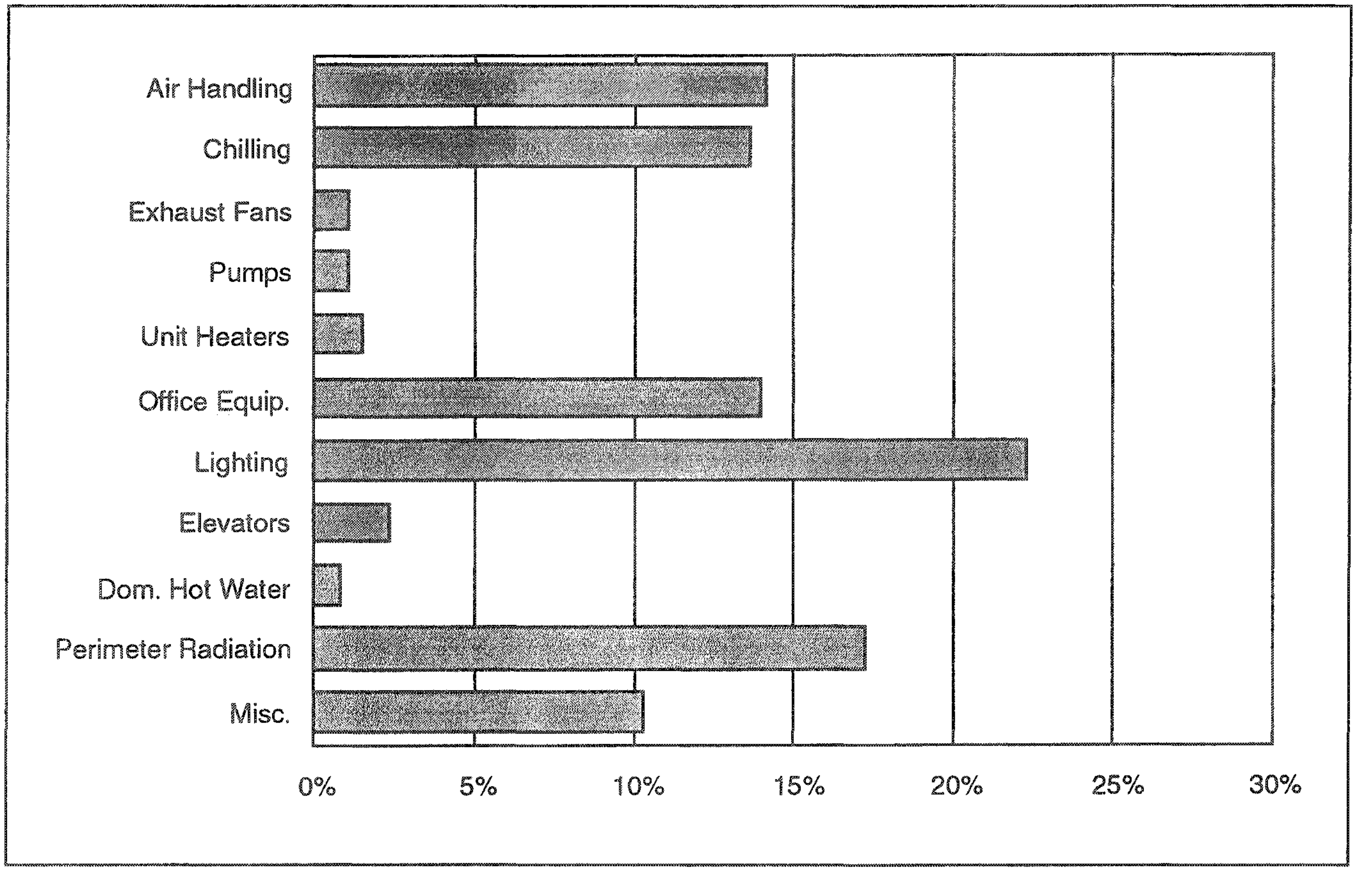

*Figure 4. VAV Energy Dollars Consumption*

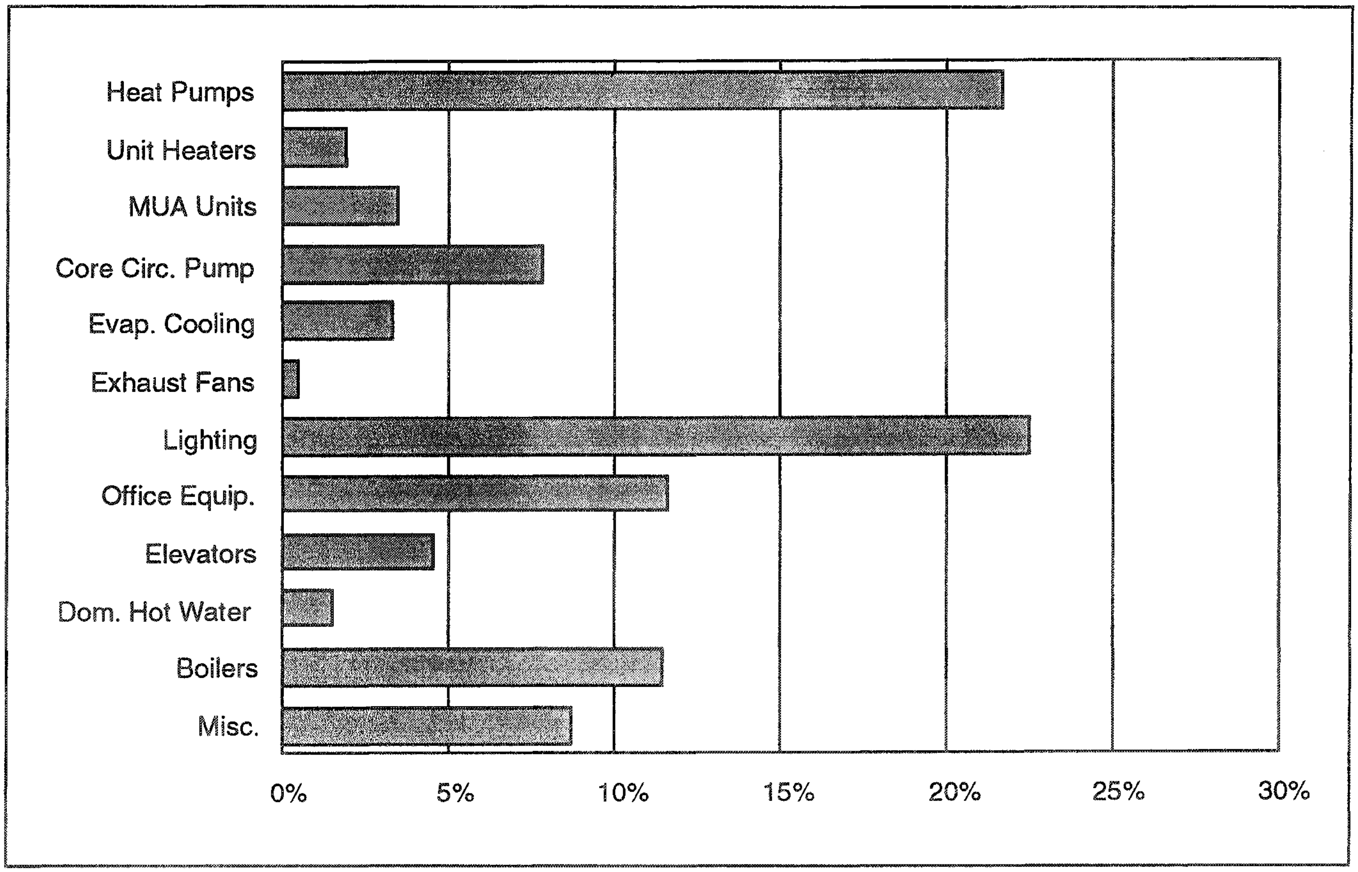

*Figure 5. Heat Pump Energy Dollars Consumption*

pumps. Again, lights and office equipment left on during unoccupied hours constituted significant operation problems.

The point of this analysis is that in both VAV and heat pump office buildings, 80 percent of energy consumed is used by a very limited number of systems whose operating variables are relatively simple to determine and hence might be fairly easily monitored. In variable air volume buildings, air handling units need to be monitored to confirm programmed schedules and settings of the optimum start/stop function. Cooling compressors and condenser fans need to be monitored to confirm operating schedules, discharge air temperature settings, and the outdoor economizer changeover setpoint temperature. Office equipment and lights should be monitored simply to determine if they are turned off when they should be. Perimeter radiation reset schedules and boiler efficiencies need to be checked.

In heat pump buildings, heat pump hour of operation, cycling rates, ran rate, thermostat settings, and core loop water temperatures need to be monitored. Lighting and office equipment should be checked as in variable air volume buildings and makeup air units need their operation schedules checked. While the specific set of operating variables that are appropriate to determine the operational efficiency of office buildings would not hold true for all building types using the same method that identified them in office buildings.

A second pattern that arose from this work was a function of when malfunctions in operation tended to occur. Though only an average of 30 percent of energy expenditures occurred in these buildings during unoccupied hours, approximately 80 percent of waste of energy due to malfunction occurred during this period (Figures 6 and 7).

This data presents an interesting pattern for two reasons. First, it implies that correction of operation problems in office buildings is likely to have little impact on tenant comfort. Changes in operation procedures that might impact tenant perceptions of comfort and hence satisfaction with their environment is a major concern of building owners and operators. This study suggests that correction of 80 percent of operation problems would not place tenant satisfaction at risk in office buildings. Secondly, it suggests that operation of equipment during unoccupied

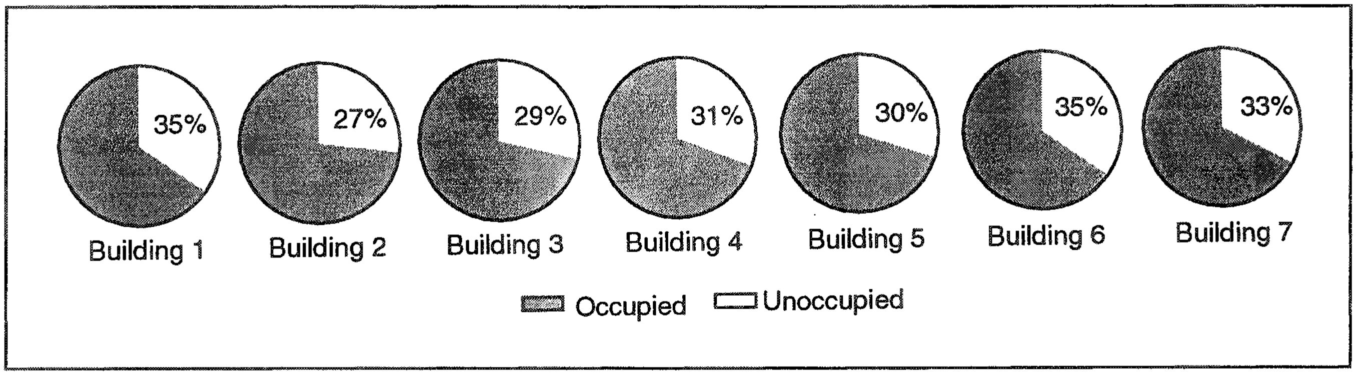

*Figure 6. Energy Use During Unoccupied Hours*

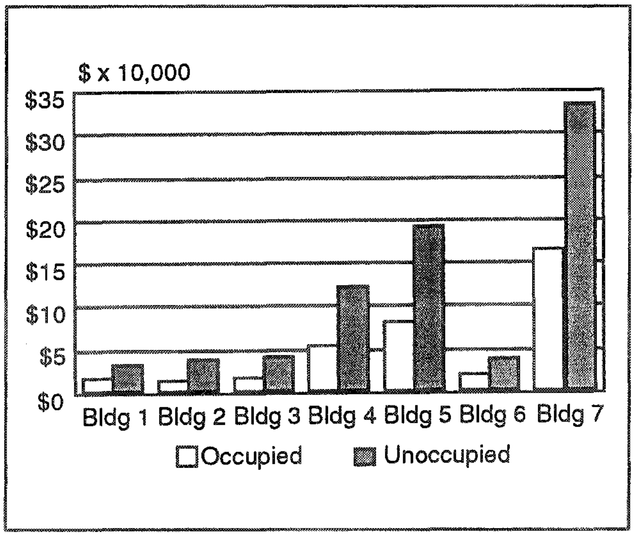

*Figure 7. Excess Energy Use*

hours can easily go astray because there is no one in the building to take note of these malfunctions. Such malfunctions are frequently masked by EMS systems, time clocks, and equipment settings that are simply assumed to work. None of the buildings studied utilized even the most rudimentary of systems to check on whether or not these assumptions were, in fact, true. As buildings grow older, original operation procedures are overlaid with a progressively more complex maze of tactical adjustments that are intended to satisfy specific tenant needs and complaints. As these modifications accumulate, original operating intent, even if originally clear, degrades. When problems of misinstallation of equipment and initial calibration of this equipment are added to the problem of degradation of the clarity of operation procedures over time, it is surprising that buildings perform as well as they do. Because the least attention is paid to these problems during unoccupied hours, it is not surprising that the majority of energy waste due to operation malfunction occurs during this period.

The last pattern of operation malfunction that was derived from this analysis concerns the cause of operation malfunction that occurred in these buildings. Nearly half of energy loss due to inappropriate operation (45 percent) was due to occupant or operation behavior or decisions; 29 percent of this loss was due to control or equipment failure; 22 percent was due to equipment installation errors; and finally, 4 percent of these losses were due to known operation deviations that had come to be accepted for a variety of reasons (Figure 8). This distribution of losses suggests that no single attack on operation problems will be effective. The ability of operating personnel and building occupants to make wise decisions requires attention as does a detailed survey to determine that equipment is installed and operating correctly. An effective vehicle for improving operations in buildings therefore should pay equal attention to human and mechanical systems.

3. *Can a non-intrusive, transferable, and cost effective procedure be developed to identify operation malfunctions so that they might be corrected?*

The protocol developed for this study as a research procedure could be translated into an operating procedure with some relatively simple modifications. A key to the success of this study was the use of credit card size monitoring probes that record temperature and electrical current data without being directly connected to a central information storage device. The use of these non-intrusive, independent data gatherers allows quick and easily moved installation of monitoring devices. This flexibility is critical to adapting to the wide range of equipment and operating conditions found in buildings. Downloading of the information from these probes is facilitated by software that allows it to be immediately

| | Installation Error | Inappropriate Occupant or Operator Behavior or Decisions | Control or Equipment Error | Know Deviation in Operation | Total Excess Energy Dollars |
|---|---|---|---|---|---|
| Building 1 | 03% | 94% | 03% | | $8,644 |
| Building 2 | 34% | 55% | 11% | | $8,331 |
| Building 3 | 35% | 24% | 09% | 32% | $12,969 |
| Building 4 | 24% | 54% | 22% | | $26,295 |
| Building 5 | 28% | 15% | 55% | 02% | $32,389 |
| Building 6 | 30% | 60% | 10% | | $12,053 |
| Building 7 | 11% | 51% | 35% | 03% | $39,905 |
| **Total Excess** | **$31,016** | **$62,461** | **$41,114** | **$5,995** | **$140,586** |
| **% of Total Excess Dollars** | **22%** | **45%** | **29%** | **04%** | **100%** |

*Figure 8. Percent of Excess Energy Dollars by Cause*

graphed and analyzed. Neither these probes nor their attendant software are prohibitively expensive. Together they provide a vehicle that might be used by a wide range of personnel to determine how buildings are actually being operated.

The procedure outlined in this study is transferable from a research to an operating procedure primarily because of its conceptual simplicity. While a number of decisions within this protocol require an informed viewpoint and some experience with this system, the overall conceptual organization of this process is readily accessible. The development of a system schematic requires that an overview of system objectives and operating characteristics be developed. Assigning energy use to each system is a fraction of readily available information and provides a good initial sense of where the building in question uses most of its energy. Limited operating variables associated with each of these systems allows for simplified selection of monitoring sites. Comparison of anticipated with actual energy expenditures in each of these systems readily identifies questions concerning operational efficiency. In short, this procedure is consistent with common sense.

Finally, this procedure has proven to be quite cost effective. The cost of analyzing the operational efficiency of the seven office buildings of this study was approximately $13,500 per building. This cost included $3500 to write a report that could be published. The actual cost of this procedure then is probably somewhere between $10,000--$12,000 for a 100,000 square-foot office building. Operation savings identified in this study ranged from $8,331 to $39,905 and averaged $20,084. The average simple payback of this procedure is thus .67 year. While other building types might cost more to analyze due to more complex mechanical systems and issues, the cost of the operations study in each of the study buildings would be repaid in under a year if appropriate corrective measures were taken.

## Conclusions

As building mechanical, lighting, and control systems become more complex, it would be absurd to assume that increased sophistication in equipment and controls will not require a more rigorous system of surveillance to assure that they perform as specified. Such vigilance is both technically possible and economically feasible. The protocol described in this paper provides a relatively inexpensive and simple alternative to more elaborate procedures. Its objective is to create a cost-effective tool that might be used in the market place as a way to identify operation problems in existing buildings or perhaps provide a foundation for a commissioning process for new buildings. Efforts are currently underway to explore both of these possibilities.

## Bibliography

"Office Building Operations Case Study Reports," Herzog/Wheeler & Associates, Lance LaVine and Bob Lorenzen, Minnesota Building Research Center, 1991.