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Analysis of Savings Due to Multiple Energy Retrofits in a Large Office Building

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EXECUTIVE SUMMARY

S.1 OBJECTIVE AND SCOPE

The objective of this analysis was to characterize the benefits of the individual energy conservation measures that were applied to an existing large office building. The measures included those for lighting; those for the heating, ventilation, and air conditioning (HVAC) systems; and an energy management and control system (EMCS). The purpose was to improve our understanding of the impacts of the individual measures in contrast to the entire group of measures that were installed during a building improvement project.

The scope of the study was primarily analytical; it used an hourly building simulation model to estimate the benefits. Input parameters for this model were adjusted so that the calculated results matched closely with the available monthly electrical billing data. Supplemental building energy use data were collected and used to improve the adjustment of these parameters. The benefits of the individual measures were then calculated using the matched model.

S.2 UNITED UNIONS BUILDING AND MEASURES

The structure selected for this study was the all-electric United Unions building located at 1700 New York Avenue in Washington, D.C. It is a seven-story office building, having about 170,000 sqft conditioned floor area, plus a three level basement garage. This building was first completed and occupied in 1973, and the energy conservation measures were installed during the renovation of the building in 1988. The energy savings realized through these improvements averaged about 200 MWh per month, with total demand savings of 600 kW for the middle summer months. The total construction cost was about \$700,000, while the energy cost savings are about \$160,000 per year.

The lighting measures consisted of installing improved reflectors in the fluorescent fixtures, which permitted partial delamping, and replacing many of the incandescent lamps

with self-ballasted fluorescent fixtures. We estimated that the original peak lighting power level was reduced from 3 W/sqft to 1.6 W/sqft and that the peak plug-in office equipment power level remained at about 0.8 W/sqft.

The HVAC system measures consisted of disconnecting unneeded electric resistance heaters, converting the constant-speed dual-duct air handling systems to variable-air-volume (VAV) systems, equipping supply air fan motors with variable-frequency drives, reactivating a deactivated economizer, and adding an EMCS to provide enthalpy control for the economizer and to optimize the HVAC system running times. After these measures were installed, the fan energy consumption was reduced to about 50% of the design value for most of the operating time.

In addition to the installation of the energy conservation measures, the original gray-tinted building windows were replaced with bronze-tinted windows during the building renovation for structural reasons. The impact of changing the color of the window tinting was small, but the reduced air infiltration around the replacement windows was estimated to have lowered the building energy consumption about 0.5%.

S.3 MODELING APPROACH AND AVAILABLE DATA

Evaluation of the energy and cost savings for the conservation measures was performed using the DOE-2.1D building computer simulation model. Recognizing that models such as DOE-2.1D are approximations of the true building physical behavior, historical energy use data were used to adjust the model input parameters to gain confidence in this approach. The data used were the monthly billing statements that included the building energy consumption, peak power demand and cost, and hourly energy data obtained in this study through the building EMCS. Billing data for a year-long period in 1986–1987 were used for the pre-retrofitted building and data for the year 1989 for the post-retrofitted building. The weather data used for the adjustment of the model parameters were those measured at the nearby Washington National Airport, supplemented by 1992 hourly data collected through the building EMCS.

The input parameters were adjusted so that the simulations closely matched the pre-retrofit and post-retrofit monthly billing data and the 1992 hourly energy use data. The selection of the most appropriate parameter values is strongly dependent on the user's knowledge and experience. For the billing periods, the matched model predictions agreed closely with the monthly energy consumption, peak demand, and energy cost data. For the hourly data, a reasonably good simulation agreement was obtained for one week that the HVAC systems were operated in the normal night and weekend shutdown mode. However, the agreement was somewhat lower for the previous week, when the systems were operated continuously. The predicted peak loads, in particular, were about 10% to 15% lower than the measured values during each workday. The reasons for these differences were not resolved.

The building air infiltration had to be increased to match the winter load data. This adjustment apparently was necessary because of a significant stack effect during the cold weather periods. A first order approximation of this effect was made by specifying the stack air infiltration rates. Time and budget did not permit further investigation. The effects of this parameter, however, should be investigated in more detail in future analyses of taller buildings.

S.4 RETROFIT MEASURES BENEFITS

The savings realized by the installation of the energy conservation measures were normalized using the matched DOE-2.1D program with Washington, D.C. (Dulles Airport) Typical Meteorological Year (TMY) weather data and the 1989 Potomac Electric Power Company rate schedule.

The normalized annual energy consumption resulting from the installation of the measures in the United Unions building decreased from 7,036 MWh to 4,449 MWh, a 37% savings, as shown in Fig. S.1. The monthly savings ranged from 200 to 240 MWh. Also, there were significant reductions in the peak power demand, particularly in the summer when the utility rates are higher. The resulting impact on the energy costs is shown in Fig. S.2. A savings of \$163,000, about 35% of the original energy cost, can be realized each year. The monthly savings were greater during the summer when the energy rates

and the demand charges are high. The monthly savings for July and August were each about \$20,000, or 40% of the original amount. The demand charges accounted for slightly less than half of the energy costs, and during the summer, they were reduced about 40% by the conservation measures.

The estimated components of the annual building energy consumption are listed on a per-square-foot basis in Table S.1. Before the building was retrofitted, the total electrical energy consumption was considerably higher than the average for the office buildings in the area. After it was retrofitted, the energy consumption was about that for an average office building.

Fig. S.1. Normalized monthly energy consumption before and after the installation of energy conservation measures.

Fig. S.2. Monthly billing charges before and after the installation of the energy conservation measures.

Lighting was the largest energy consumer before and after the conservation measures were installed. The second largest consumer was the circulating air system fans. For both components, there were large energy savings following the installation of the measures.

Table S.2 is an overall breakdown of the annual energy and cost savings for the individual measures. Of the 37% energy savings, the lighting measures accounted for 17%, just under half of the total. Reducing the lighting fixture power led to 18% savings, but the thermal interaction created higher heating equipment demand, lowering the

Table S.1. Estimated components of the United Nations building electricity consumption before and after installation of energy conservation measures (170,000 sqft floor area)				
	Before Retrofit		After Retrofit	
<u>Electricity consumption</u>	<u>kWh/sqft·yr (Btu/sqft·yr)</u>		<u>kWh/sqft·yr (Btu/sqft·yr)</u>	
Total	41.4	(141,300)	26.2	(89,300)
Lighting	19.7	(67,300)	12.3	(42,000)
Office equipment	4.4	(15,000)	4.4	(15,000)
Elevators	0.5	(1,730)	0.5	(1,730)
Heating	3.1	(10,500)	2.7	(9,350)
DHW heating	0.1	(400)	0.1	(400)
Cooling	4.3	(14,640)	2.1	(8,200)
Fans	8.7	(29,650)	3.7	(12,700)
HVAC auxiliaries	0.6	(2,160)	0.3	(920)
<u>Peak demand</u>	<u>W/sqft (Btu/hr·sqft)</u>		<u>W/sqft (Btu/hr·sqft)</u>	
Winter	10.2	(34.8)	7.9	(27.0)
Summer	9.5	(32.3)	5.8	(19.8)

Table S.2. Summary of the annual energy conservation measure savings for the United Nations building.				
	Energy (GWh)	Energy savings (%)	Energy, cost (\$)	Cost, savings (%)
Before measures	7.04		464,000	
After measures	4.45		301,000	
Total savings	2.59	37	163,000	35
Lighting savings				
Total	1.21	17	79,000	17
Reduced power	1.26	18	74,000	16
Other loads	- 0.05	- 1	5,000	1
HVAC system savings				
Total	1.38	20	84,000	18
Variable-air-volume	0.21	3	4,000	1
Reduced htg cap	0.12	2	14,000	3
Fan speed control	0.47	7	34,000	7
Economizer	0.56	8	32,000	7

savings by 1%. The remaining 20% savings were due to the HVAC system improvements. Converting the constant-volume HVAC systems to VAV systems saved 3%, disconnecting the excess electric heating capacity saved 2%, adding frequency

control to the fan motors (speed control) saved 7%, and activating the economizer with the new EMCS saved 8%. Because of the large savings, the speed control feature is generally included in the retrofit package when a constant-volume air system is converted to a VAV system.

For the associated cost savings, lighting and HVAC system measures each accounted for about half of the total 35% savings. The lighting measures reduced pre-retrofit energy costs about 17%. Reduction of the lighting fixture power led to a 16% cost savings, and the thermal interaction added another 1% savings. The reason that the interactions resulted in cost savings is that they decreased HVAC system cooling loads when the utility rates were high and increased system heating loads when the utility rates were low.

For the HVAC system measures, the components of the 18% cost savings were converting to a VAV system, 2%; disconnecting excess heating element capacity, 2%; adding fan motor speed control, 7%; and reactivating the economizer, 7%. The percentage of the total cost savings associated with the HVAC systems was slightly lower than the percentage of the total energy savings because HVAC system measures do not reduce the peak demand and time-of-use energy loads as much as they reduce total energy consumption.

The United Unions building HVAC systems normally are operated in a time-schedule mode, which involves shutting down the systems when the building is not being used for business during nights, weekends and holidays. Prior to installing the EMCS, this was done manually, and the systems were started 2 to 4 hours before occupancy to allow the building air temperatures to reach the desired level at the start of the daily operation. After the building was retrofitted, the EMCS was programmed to optimize (minimize) the HVAC systems operating times. We estimated the annual energy savings realized by using the time-schedule mode, compared with a continuous-operation mode, to be 2.34 GWh for the pre-retrofitted building and 1.03 GWh for the post-retrofitted building. These values represent about 25% and 19% energy reductions.

The associated cost savings using the time-schedule mode operation of the HVAC systems were calculated to be \$49,000, about 10%, for the pre-retrofitted building, and \$2,600, about 1%, for the post-retrofitted building. We have reasons to question the low calculated savings for the retrofitted building. However, the calculated lower peak power demands and peak time-of-use energy for the systems operating in the continuous mode and the high charges for these items resulted in the limited cost savings.

The savings associated with using the EMCS instead of manual switching to control the HVAC systems startup and shutdown times was estimated to be about 1%. The DOE-2.1D model used to estimate these savings is only approximate, and it is possible that the savings could be higher, say 3%.

S.5. CONCLUSIONS

The results of this study highlight the importance of installing major energy conservation measures in existing large commercial buildings for saving large amounts of energy and reducing peak electric demands. The simulations with the DOE-2.1D model, adjusted to match the measured data, have allowed a better understanding of the energy, demand, and cost impacts of the specific measures. The selection of appropriate parameter values for a matched model having many variables, such as DOE-2.1D, is strongly dependent on the user's knowledge and experience. One parameter worthy of further study is air infiltration into the building, since it surfaced as a significant variable for taller buildings.

About half of the savings resulted from the lighting system measures. These measures are particularly important during the summer, where the heat generated at the lighting fixtures adds to the building cooling load. Although the office equipment loads were not changed in the simulations, their contributions can be very significant because of recent trends toward the increased use of such equipment.

The remaining half of the savings resulted from the measures applied to the HVAC systems. The importance of matching the HVAC air flow rates to those required for adding heat to or extracting it from the conditioned spaces is reiterated. Converting the

constant-volume dual-duct systems to VAV systems with variable-frequency drives for the circulating air fan motors led to about a 9% savings. There were small (about 2%) savings from the elimination of the excess heating capacity. Most of the energy savings obtained by reactivating the air economizer were realized during the heating season because the dampers were partially open prior to its reactivation. There was a large reduction in the summer peak energy demand for the same reason. This emphasizes the importance of keeping the economizer dampers in good working condition.

The analysis showed that shutting down the HVAC systems on nights and weekends saves about 20% of the energy that would be consumed if the systems operated continuously. The calculated cost saving is only about 1%, however. The lower calculated peak demand and peak time-of-use energy loads for the continuously running systems, and the high associated charges for these items, led to the low savings. The calculation model was not sufficient to predict the exact magnitude of the savings, but calculated trends appear to be reasonable.

The effectiveness of using the EMCS to optimize the HVAC system startup and shutdown times appears to be small for this particular situation. The precision of the DOE-2.1D model used to estimate the savings for this measure is limited, but the savings appears to be in the range of 1% to 3%. This does not imply that one should abandon the EMCS concept; it was effective in controlling the reactivated economizer. This does imply that one must consider the benefits, the initial cost, and the maintenance cost of the EMCS before investing in the system. The results here reinforce findings of other studies that simple EMCS functions provide most of the energy savings benefits and that many EMCSs should have simpler designs.

ANALYSIS OF SAVINGS DUE TO MULTIPLE ENERGY RETROFITTS IN A LARGE OFFICE BUILDING

H.A. McLain
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ABSTRACT

This study characterizes the benefits of individual energy conservation measures that were applied to the existing 170,000 sqft United Unions office building in Washington, D.C. The measures included those for lighting; those for heating, ventilation, and air conditioning (HVAC) systems; and an energy management and control system (EMCS). The study was primarily analytical, using the DOE-2.1D model with input parameters adjusted so that the calculated results matched closely with the available monthly and short-term hourly data.

Installation of the measures reduced the annual energy consumption of the building from 7,040 to 4,450 MWh. The annual cost savings are estimated to be \$163,000. The total project cost was about \$700,000, which implies a payback time of slightly over 4 years. About half of the energy and cost savings were from the lighting system measures. The remaining half of the savings were from the improvements made to the existing HVAC systems. These included disconnecting unneeded resistance heaters, converting from a constant-volume dual-duct systems to variable-air-volume dual-duct systems with variable-frequency drives for the supply fan motors, and reactivating the existing economizer. The utility rate schedule for the building has high demand and peak time-of-use energy charges, and they were found to be very important factors in the cost savings.

The EMCS offered a large benefit by providing a more reliable control for the reactivated economizer and a limited benefit by optimizing the startup and shutdown times of the HVAC systems. This reinforces the findings of other studies that simple

EMCSs provide most of the energy saving benefits and that many EMCSs should have simpler designs.

1. INTRODUCTION

1.1 OBJECTIVE AND SCOPE

The objective of this analysis was to characterize the benefits of the individual energy conservation measures that were applied to an existing large office building. The applied measures included those for lighting; those for the heating, ventilation, and air conditioning (HVAC) systems; and an energy management and control system (EMCS). The purpose was to improve our understanding of the impacts of the individual measures in contrast to the entire group of measures that were installed during a building improvement project.

When this study was initiated, the intent was to examine the potential energy consumption, demand, and cost savings from an EMCS installed to control an HVAC system. The office building selected for this study is located in Washington, D.C., and it was completed and occupied in 1973. The building improvement project was done in 1988. In the course of this study, it became apparent that all the energy conservation measures, in addition to the EMCS, were of interest. Thus, the study was expanded to evaluate their impacts.

The scope of the study was primarily analytical; it used an hourly building simulation model to estimate the benefits. Input parameters for this model were adjusted so that the calculated results matched closely with the available monthly electrical billing data. Hourly building energy use data were also collected and used to improve the adjustment of these parameters. The benefits of the individual measures were then calculated using the matched model.

This report documents the results of this analysis, covering the energy, electricity demand, and cost savings for the individual measures. The cost savings are based on the actual utility rate structure for the building. The report includes the description of the building, the installed measures, the available recorded data, the methodology to estimate the savings, and the values of the savings.

1.2 BACKGROUND

The Existing Buildings Research program of the Office of Building Technologies, within the Conservation and Renewable Energy Program of the U.S. Department of Energy, has directed its effort, over the past several years, to advancing the capabilities for improved delivery of energy efficiency technologies to residential and commercial buildings. This analysis is part of that effort. Commercial buildings energy use is about 16% of total U.S. primary energy consumption, according to Energy Information Administration 1990 data. About 70% of the primary energy being used for commercial buildings is in the form of electricity. This represents nearly one-third of the total electrical energy consumed in the country (EIA 1993). Thus, reducing electricity use in this sector is an important part of achieving improved overall energy efficiency of the U.S. building stock.

For the nation, about 40% of the total electricity used in commercial buildings is for lighting, 25% for cooling, 20% for heating, and the remaining 15% for other demands, such as office and other plug-in equipment (BNL 1991). Efforts to improve the energy efficiency of these electricity-based systems provide important opportunities to support national goals related to improvements in energy efficiency and reduced environmental emissions.

Commercial buildings tend to have low electrical load factors because of their use schedules, which result in high energy consumption during the occupied (peak) periods and much lower consumption during the unoccupied periods. Many electrical utility rate schedules include demand and time-of-use charges to reflect the actual cost of generating electricity and encourage electricity conservation during these periods.

1.3 UNITED UNIONS BUILDING

Building codes, such as ASHRAE 90.1 (ASHRAE 1989b), have been developed to set energy conservation standards for the construction of new buildings. There is, however, a large inventory of existing commercial buildings in the United States. These buildings are usually refurbished during their lifetimes because of the changing use and

demands or because of the availability of new technology. Several projects installing energy conservation measures in existing office buildings have been described by Abel (1992). One of these, the United Unions building, was the structure chosen for this study. It is an all-electric building located in Washington, D.C.

Prior to the building improvement project, the building had high electricity consumption and costs. The conservation measures that were included in the improvement project were window replacement, lighting fixture improvements, HVAC systems improvements, and a new EMCS. The project was very successful, resulting in substantially lower electricity use and cost and an immediate positive cash flow for the financing package. Electricity consumption was reduced about 200 MWh per month, and the annual electricity cost was reduced about \$160,000 per year (Powell 1988).

As for many buildings, the measures were all installed during a single building renovation project. Our interest was to sort out the existing data to gain an understanding of the effectiveness of the individual measures. Historical data that were available were the monthly energy billing data before and after the measures were installed and the Washington National Airport hourly weather data.

The impacts of the individual measures were estimated using the DOE-2.1D building simulation program (LBL 1981, 1989). Input data parameters for this program were adjusted so that the predicted energy use and costs matched closely with the available energy, power, and cost data. The matched model was then used to calculate the effectiveness of the individual measures.

1.4 REPORT ORGANIZATION

This report is organized in eight sections plus an abstract, executive summary, and appendices. This section provides the objective of the study, gives a brief background of energy use in commercial buildings, and introduces the selection of United Unions building and the analytical methodology. Section 2 describes the building and the HVAC systems, as well as the energy conservation measures installed in 1988. The available data are also described in Sect. 2. The approach used for the analysis is described in

more detail in Sect 3. The adjustment of the input parameters for the building simulation model is described in Sect. 4. Section 5 addresses the incremental benefits from the individual retrofit measures, showing energy and peak demand reductions as well as cost savings. These results are then summarized and discussed in Sect. 6. The conclusions of this study are given in Sect. 7. The references are listed in Sect. 8. The appendices include the utility rate schedules for the United Unions building, ambient air temperatures during a September 1992 special test period, and listings of the matched DOE-2.D input data files for the building in both the pre-retrofit and post-retrofit configurations.

2. UNITED UNIONS BUILDING AND RETROFIT MEASURES

The United Unions building selected for this study is located at 1700 New York Avenue in Washington, D.C. It is an all-electric office building that uses electricity for its heating and cooling needs, as well as for lighting and office equipment. This building was first completed and occupied in 1973. It was then retrofitted with new windows, lighting improvements, HVAC improvements, and an EMCS in 1988 under the direction of the National Energy Management Institute (NEMI). The energy savings realized through these improvements averaged about 200 MWh per month, with total demand savings of 600 kW off the summer peak, as illustrated in Fig. 2.1. The total construction cost was about \$700,000, while the energy cost savings are about \$160,000 per year (Powell 1988).

NEMI first became involved in the United Unions building project in early 1986, when a preliminary analysis demonstrated a higher-than-average energy use for the building, about 130,000 Btu/sqft·yr compared with a target of about 85,000 Btu/sqft·yr for an efficient structure of this type in Washington, D.C. Furthermore, NEMI's analysis

Fig. 2.1. Monthly billing electrical energy consumption and peak demand for the United Unions building before and after installation of conservation measures.

showed that the peak summer loads were excessive and there was a potential for reducing the total energy use by more than 30%. In June of 1987, the building management committee decided to launch a retrofit program through NEMI's Total Energy Management Program. The program consisted of a detailed technical/financial study followed by the installation of the measures. The study presented several opportunities to save energy and reduce demand costs in the building, while improving comfort and general occupant satisfaction. The technical scope of the study report was approved by the United Unions building committee, and the retrofit project proceeded in 1988.

2.1 BUILDING DESCRIPTION

The United Unions building is a seven story office building, roughly rectangular in plan, with a conditioned area of 170,000 sqft and a three level underground garage. Of the conditioned space, 85% is for offices, 10% is for circulation, and 5% is for restaurants, a fitness club, and other amenities.

The building is oriented due north and has nearly identical facades on all sides. Primary access to the building is from the north through the first floor, and the secondary access is from the south through the ground floor. The lobbies on the first and ground floors are interconnected via a large stairway in the middle of the floors. There is little exterior shading of the building except for

Fig. 2.2. Southwest view of the United Unions building, Washington, D.C.

an adjacent building located 13 ft away from the east exterior wall (Figs. 2.2 and 2.3).

2.1.1 Design and Construction

The building design has a typical floor plan consisting of an interior zone and four perimeter zones in the four orientations. The interior zone includes core space for vertical circulation and other building services. The building is constructed with a structural steel frame and concrete floors and roof. Floor-to-floor height is 10 ft 6 in. and floor-to-ceiling height is 9 ft. Ceilings are suspended acoustical tiles, and there are no return air ceiling plenums. Precast concrete exterior cladding of 7 ft by 10 ft 6 in. by 4 in. thick is used

Fig. 2.3. Northeast view of the United Nations building, Washington, D.C.

for the vertical enclosure of the building. The windows are 1/4 in. double panes with tinted glazing. They were replaced during the renovation project because of structural problems with the original windows. A gray color glass was used for the original glazing and a bronze color glass was used for the replacement glazing. The impact on energy use of changing the glazing color is estimated to be very small (ASHRAE 1989a; LBL 1988). Interior building partitions are frame walls with gypsum board on each side. Heat transfer coefficients (U-values) of the building envelope are 0.282 Btu/h·sqft·°F for exterior walls, 0.125 Btu/h·sqft·°F for roof, and 0.370 Btu/h·sqft·°F for windows.

2.1.2 Occupancy and Use

There are a total of 450 work-stations in the building offices. For the simulations, we estimated that the building occupancy varied from 15 people during nights and weekends to 520 people during the peak office hours. We also estimated that the peak office lighting and equipment power densities were originally 3.0 W/sqft and 0.8 W/sqft,

respectively. Nominal office hours are between 8:00 a.m. and 5:00 p.m., Monday through Friday, and between 8:00 a.m. and 3:00 p.m. on Saturday. The occupancy, lighting, and office equipment operating schedule profiles were estimated from discussions with the building occupants and comparison with supplemental hourly energy use data recorded for this study in 1992. For weekdays, the transition between minimum and normal daily building use occurs during about 2-5 hours at the beginning and end of the occupancy schedules. For example, the daily occupancy transition starts at 6:00 a.m. and reaches full occupancy level at 8:00 a.m. The occupants start to leave at 5:00 p.m. and the building reaches the minimum occupancy level by 10:00 p.m. during the weekdays.

2.2 LIGHTING

2.2.1 Original Lighting

As originally built, most of the lighting for the building was provided by unique 6-lamp, 30-W-per-lamp, 3 x 3 ft fluorescent fixtures. In addition, about 500 incandescent and flood lamps, having wattages of 60 to 300 per lamp, were used. The lighting system was controlled locally and manually, and the original peak lighting power level was estimated to be about 3 W/sqft.

2.2.2 Retrofitted Lighting

In the retrofit project, 2,329 of the 6-lamp fluorescent fixtures were fitted with custom silver film reflectors. They improved the light output of fixtures so significantly that two, and in many cases four, of the lamps were removed from each fixture, and the inactive ballasts were disconnected. The required light levels between 60-80 fc were still maintained following this removal, while lighting energy demand was reduced by more than 225 kW. In addition, many of the 60- to 300-W incandescent and flood lamps were replaced with combinations of self-ballasted 5- to 13-W compact fluorescent lamps, which saved an additional 25 kW (Powell 1988; Abel 1992). We estimated that these changes reduced the peak lighting power level from about 3.0 W/sqft to about 1.6 W/sqft.

2.3 HVAC SYSTEMS

2.3.1 Original Installation

The United Unions building has four dual duct air handling systems that distribute heating and cooling air to four vertical zones. Each system has a 50-hp supply air fan and two 30-hp return air fans. As built, the systems provided constant-volume air flow to each conditioned zone in the building. The supply air temperature to each zone was controlled by mixing the hot and cold air streams in a mixing box located in that zone. Electric resistance heating coils are used to heat the hot deck air, and chilled water coils are used to cool the cold deck air. Two 370-ton centrifugal chillers, backed up by a third 120-ton reciprocating chiller, provide the chilled water. A fourth 80-ton heat recovery chiller provided the winter building core cooling and make-up air preheating. The chilled water loop has a 50 hp-pump to circulate the water.

Fig. 2.4. Primary HVAC equipment in the United Unions building.

An air economizer was originally installed, but the unit was allowed to become deactivated. We estimated that before the building was renovated, the economizer dampers were fixed in a position such that it provided about 20% continuous ventilation air when the circulating air system was operating.

Before the HVAC systems were modified, they were manually shut down nights and Sundays at fixed times to save energy. They were started at about 5:00 a.m. (3:00 a.m. Mondays) and were shut down at about 8:00 p.m. weekdays and about 3:00 p.m. Saturdays.

2.3.2 HVAC System Improvements

In the upgrade of the building HVAC systems, 251 dual-duct mixing boxes in the perimeter zones were replaced with new variable-air-volume (VAV) control boxes. The new boxes have dampers to vary the amount of cool or warm air delivered to the spaces depending on the zone loads. Controls for the new boxes were designed to prevent supplying heating and cooling air to each space simultaneously. The existing zone pneumatic thermostats were refurbished to improve local comfort control. The overall result was improved temperature control with lower circulating air flow rates and significantly lower fan power requirements (Powell 1988).

To reduce the fan power requirements further, variable-frequency motor drives, controlled by static pressure sensors in the supply duct, were installed to regulate the speed of each of the four 50-hp main air supply fans. The eight parallel 30-hp return air fans were controlled by return duct static pressure sensors. Back-draft dampers and controls were installed at each return fan to avoid recirculation. Because of reduced energy demands after the building was renovated, it was found that four of the eight 30-hp return air fans could be shut off, even under the peak load conditions. Also, the main 50-hp supply fans seldom operated above 85% of their design speed — consuming only about half as much energy as before. These HVAC improvements accounted for 150 kW in monthly demand reduction (Abel 1992; Powell 1988).

Some of the hot deck heating elements for the air supplied to the interior zones of the building were not required to meet the interior zone heating loads, and they were disconnected. A 7.5-hp auxiliary pump was added to the chilled water loop, it can be used instead of a 50-hp main circulating pump when the building cooling loads are minimal.

2.3.3 EMCS Installation

A new EMCS was installed to monitor and optimize the HVAC systems operation. Connected to the EMCS are 56 pneumatic control points and 32 sensor points, a personal computer interface, and a modem. This unit is used to optimize the startup and

shutdown times of the systems, the operation of the four chillers and the cooling towers, control of the building energy demand, and load shedding (if necessary). It is also used to control the repaired air economizer, which was connected to the unit (Abel 1992, Powell 1988). Differences in the measured indoor and outdoor air enthalpies are used in controlling the outdoor air admitted by the economizer, and the minimum air makeup meets the ventilation rates specified by ASHRAE Standard 62-1981 (ASHRAE 1981).

Among the indirect benefits of an EMCS are the ability to monitor the HVAC systems, fine-tune equipment operation and maintenance management, generate data bases of the building energy use, and installing alarms to identify potential and actual problems relating to the occupants' thermal comfort and the HVAC equipment. The ability to access the status of the HVAC equipment operation from one location allows the operators to identify any problems and take appropriate actions more quickly.

The term "EMCS" is somewhat amorphous, since HVAC system controls can range from very simple devices to very large complex systems. The simplest can be a thermostat and a timeclock for controlling the operation of an HVAC system. For many years, pneumatic systems have been used to control building HVAC equipment. The development of low-cost electronics and microprocessors has favored the installation of more integrated and complex EMCSs in buildings during recent years. They are finding increasing use, particularly in large buildings and military bases. Part of the incentive for installing these systems is to respond to the power demand charges being imposed by many electric utilities (ACEC 1984; Burns 1987; Piette 1991)

The benefits of an EMCS must be weighed against the cost of installing and maintaining the system. The initial cost can vary from \$100 – \$2,000 for simple thermostat-timeclock systems to \$1,000 – \$1,000,000 for complex integrated systems. Use of simpler systems with standard components can help to minimize costs. There has been a learning curve with the use of EMCSs. The ability to understand and control power demands is a great benefit in many situations. However, there have been cases where the effectiveness of the EMCS has been limited. Among the problems have been high initial maintenance costs, systems not being maintained because of high costs or misunderstandings, lack of communication between the system designer and operator,

and the lack of knowledge by the designer of what is really needed (Gettings 1988; Piette 1991).

A particularly valuable feature of EMCSs is that they can be used, or modified to be used, for collecting and storing data about the building behavior and use. Hourly building energy use and ambient weather data were collected for this study using the building EMCS. EMCSs are not always designed with this capability in mind, however, so this feature can be limited for some buildings or installations. There is no standard format for recording the data, access to the data is sometimes difficult, and it is important that the sensing elements are maintained to ensure correct readings. The collected data can be of great help in analyzing building energy behavior and the effectiveness of energy conservation measures. The data also can be used to help the energy user develop strategies for reducing building demand and peak time-of-use charges. Moreover, analyses of data collected from EMCSs have identified excessive energy consumption due to poor control and malfunction of the operating equipment in many situations. (Claridge 1993; Gettings 1988; Heinmeier 1992; Herzog 1992.)

3. MODELING APPROACH AND AVAILABLE DATA

Ideally, the best method to determine the energy savings from retrofit measures is to monitor the building's energy use before and after the installation of each measure and model the impact empirically, but this process is time-consuming and expensive. Moreover, energy use in an existing building is a function of ambient weather conditions and building occupancy and use, which can be different before and the measures are installed. These differences can, at times, mask the effectiveness of the individual measures.

An alternative is to use a computer simulation model of the building to evaluate the energy savings. This was the approach used in this study. These models, however, are approximations of the true physical behavior and frequently, as for this study, data on detailed building activity level are limited. To gain confidence in the models, historical energy use data are used to adjust the model input parameters so that the predicted and historical data match closely. Although there are still uncertainties associated with this procedure, as discussed by Kaplan (1992) and by Koran (1992), it has been used successfully to predict the importance of and trends associated with the different conservation measures (Hunn 1992, Bou-Saada 1993).

3.1 AVAILABLE DATA

3.1.1 Monthly Billing Data

When this study was initiated, monthly billing data were the only building energy use data available. These data included both the electrical energy consumption and the peak demand load for each billing month. The data for a year-long period during 1986-1987, before the conservation measures were installed, and for 1989 after they were installed were presented in Fig. 2.1.

3.1.2 Hourly Data

The monthly billing data were supplemented by recording the hourly whole-building energy consumption using the EMCS sensors from May through October 1992. Hourly ambient air temperature and relative humidity data were also collected at the building using the EMCS. These data helped to build an empirical knowledge of the building's operating dynamics and energy performance. This knowledge was particularly important in developing building activity (internal load) schedules and evaluating the EMCS performance. A special test was conducted during the week of September 13, 1992, during which the building HVAC systems were operated 24 hr each day for 7 days, to obtain hourly building energy use data when the systems were not shut down at nights and on weekends.

3.1.3 Load Profiles

The daily load profiles were very informative in determining the occupancy and use of the building, as well as the operation of the HVAC systems. The EMCS was used to optimize the startup times of the HVAC systems, minimizing operation of the systems before occupancy, necessary to bring the building to the desired temperature. Profiles of the United Nations building electrical energy consumption for each day of the week are presented in Figs. 3.1 through 3.7. These plots were developed from the 1992 hourly data base, and each figure has a representative day for May/June, August, and October.

Fig. 3.1 shows the energy consumption profiles for Sundays. The building is occupied at its minimum level then, the HVAC systems are not in an operational mode, and the lighting and equipment power levels are at their minimum for security and maintenance purposes. Hourly energy consumption levels are

Fig. 3.1. Sunday energy use profiles (1992).

maintained at about 240 kW. It was also observed that the HVAC systems appear to start briefly at 7:00 a.m. and that they either soon satisfy the load or are turned off by the control system.

Fig. 3.2 shows the energy consumption profiles for Mondays. The building occupancy and use schedules are about the same Mondays through Fridays. The EMCS usually starts the HVAC systems earlier on Mondays than on the other days of the week because of the greater amount of thermal energy accumulated in the

Fig. 3.2. Monday energy use profiles (1992).

building mass during the longer weekend shutdown times. The EMCS also starts the system at different hours depending upon the season of the year. During the warmer summer nights and weekends, the building heats up to higher temperatures when the HVAC systems are off. Then, the systems needed to be started earlier to remove the additional heat before the building is occupied. The systems were started at 3:00 a.m. in May and August, and at 5:00 a.m. in October. The peak demand in August was higher than in May and October because of the higher summer cooling load. It was about 1,050 kW in August and about 900 kW in May and October. The HVAC systems are operated until 8:00 p.m., when the building occupancy is dropping rapidly.

The energy consumption profiles for Tuesday are shown in Fig 3.3. They show that the HVAC systems were started at 4:00 a.m. in August, 5:00 a.m. in June, and 6:00 a.m. in October, about 1 to 2 hours later than on Mondays. This reduction is due to the smaller thermal mass effect during the weekday nights. The HVAC systems were shut off at 8:00 p.m., as they were on Mondays. The consumption pattern is fairly identical to that on Mondays except for the startup time. The earlier startup time and higher peak demand for August were again observed.

Fig. 3.4 shows the Wednesday energy consumption profiles. The system is started by the EMCS at 5:00 a.m. in all three months, 1 to 2 hours later than the startup time on Tuesdays. As the building is operated with normal weekday schedules, the startup time is reduced to 2 hours before occupancy. The peak demand is maintained at around 1,000 kW. As usual, the system is stopped at 8:00 p.m., which represents 14 hours of building operation.

The energy use profiles for Thursdays are very similar to those for Wednesdays (Figs. 3.4 and 3.5). The HVAC systems are again started at 5:00 a.m. in all three months. The daily peak demand is a little smaller, about 900 kW.

The profiles for Fridays are shown in Fig. 3.6. The May, August, and October profiles become more identical toward the end of the week. The pattern of energy consumption and the building operation on

Wednesdays, Thursdays, and Fridays are almost identical except for the start times. However, on Fridays, the HVAC systems are started at 6:00 a.m. and are shut down at

Fig. 3.3. Tuesday energy use profiles (1992).

Fig. 3.4. Wednesday energy use profiles (1992).

Fig. 3.5. Thursday energy use profiles (1992).

8:00 p.m. This indicates an hour's running time before the occupants begin to arrive at 7:00 a.m., which is 1 hour less than the analogous running times on Wednesdays and Thursdays. The profiles show almost the same daily peak demand of 900 kW as for Thursdays.

Fig. 3.6. Friday energy use profiles (1992).

The Saturday energy use profiles, shown in Fig. 3.7, are lower than those for the weekdays because of the reduced occupancy and building operation schedules on that day. The occupants start to arrive at 7:00 a.m. and most of them are gone by 3:00 p.m. The systems are started about an hour before the

Fig. 3.7. Saturday energy use profiles (1992).

occupants arrive at 6 a.m., and are shut down at their departure, at about 3:00 p.m. The daily peak energy use reaches about 700 kW for the first hour of system operation and stabilizes around 550 kW during the remaining hours.

3.1.4 Weather Data

Hourly weather data for the Washington National Airport, available from the National Climatic Data Center, were used together with the historical energy use data to adjust the simulation model parameters. This airport is located about 3 miles southwest of the United Nations building. These data were supplemented by hourly ambient air temperature and relative humidity data collected from the building EMCS during May through October 1992. For weather normalization, in evaluating the impacts of the

individual conservation measures, the Typical Meteorological Year (TMY) weather data for Washington, D.C. (Dulles Airport) were used.

3.2 SIMULATION MODEL

The simulation model selected for the analysis of the United Unions building was the DOE-2.1D Building Energy Analysis Program (LBL 1981, 1989). This is an hourly simulation model that has been used extensively for energy analyses of buildings. The program uses the transfer function method to calculate the dynamic thermal behavior of the building.

The DOE-2.1D program is structured to run in four sequential steps, called LOADS, SYSTEMS, PLANT, and ECONOMICS. The building energy loads are calculated in LOADS assuming fixed interior space temperatures. These loads are used together with the HVAC systems controls and characteristics in SYSTEMS to predict the actual space temperatures and heat added to or extracted from the spaces. These data are subsequently used in PLANT to estimate the fuel and electricity requirements for the primary HVAC equipment and for the whole building. The costs of supplying this energy are finally calculated in ECONOMICS.

The building data input file for the program consists of a series of keywords and commands called the Building Description Language (BDL). The input is divided into the four parts of the program listed above. Input files for the United Unions building are listed in Appendix C. Separate files were developed for the building before and after the conservation measures were installed. The differences in these files are primarily in the lighting loads and in the configuration and operation of the HVAC systems.

The DOE-2.1D program uses these input data plus hourly data from a separate weather file to calculate the building energy use and costs. Because the billing periods for the United Unions building were not the same as the calendar months, a separate computer program was written to calculate the energy charges from the DOE-2.1D predicted hourly building energy consumption values.

3.3 ENERGY SAVINGS CALCULATIONS

The input files for the simulation program were initially developed from building survey data that included building occupancy, functional areas, envelope construction, HVAC systems, controls, zoning, lighting systems, and office equipment. The calculated results using these files were compared with the measured data. The input parameters were then adjusted so that there was a good match between the calculated and the measured energy use. This was done for the building in both the pre-retrofit and post-retrofit configurations. Details of the building dynamic behavior and the adjustment of the input parameters are discussed in Sect. 4.

The resulting model was then used to evaluate the significance of each retrofit measure and to determine the level of effectiveness among the retrofit measures. Incremental benefits were determined for the lighting, HVAC, and EMCS measures. The cost savings associated with each energy conservation measure were then calculated using the Potomac Electric Power Company (PEPCO) 1989 electric rate schedule for the building (Appendix A). Some calculations were done using PEPCO's 1992 rate schedule, and these results are so identified.

4. ADJUSTMENT OF THE MODEL PARAMETERS

As stated in Section 3, input files for the simulation program were initially developed from survey data for the building that included occupancy, functional areas, envelope construction, HVAC systems, controls, zoning, lighting systems, and office equipment. Information for the building published by Abel (1992) and by Powell (1988) were used also. The internal load schedules in the initial input files were derived from those published in the documents supporting the development of the building energy conservation guidelines (PNL 1983).

The input parameters were adjusted so that the simulations closely matched the 1986–1987 pre-retrofit and 1989 post-retrofit monthly billing data, and the 1992 hourly energy use data. The parameters were first changed to match the monthly billing energy consumption, peak demand, and energy costs. The hourly data were used to adjust the building's internal load and HVAC systems schedules. This procedure was repeated until there was a reasonable match between the simulations and all the data. Separate DOE-2.1D input files were developed for the building in its pre-retrofit and post retrofit configurations. These files are listed in Appendix C.

For the parameter adjustment simulations, the Washington National Airport hourly weather data were used for the respective time periods. For the 1992 hourly simulations, the ambient air temperature and humidity data measured using the building EMCS were used in place of the airport data.

4.1 ADJUSTED PARAMETERS

The process used to adjust the parameters was to find inconsistencies between the simulated results and the monitored data, and then determine what model input parameters were causing the inconsistencies. This was done in this study by writing Fortran programs to extract and process the DOE-2.1D program hourly data. These processed data together with the measured data were imported into a spreadsheet, where they were compared and graphed. The model parameters were then changed and

it was run again to obtain new output data, which were again compared with the measured data. Bronson (1992) outlined a similar method using hourly measured data and three-dimensional plots to adjust the model parameters. This iterative procedure is more an art than a science, and engineering judgement is required for the selection of the parameters to be modified.

A number of the adjusted parameters for the building in its pre-retrofit configuration are listed in Table 4.1. Further details of the assumptions are given in the DOE-2 input file listing, presented in Appendix C. To fit the measured data, it was estimated that the building had 520 occupants, a 3.0 W/sqft lighting load, and a 0.8 W/sqft office equipment load.

The HVAC system was a dual-duct, constant-speed system with electric resistance heaters in the hot decks. The capacities of these heaters were estimated from the peak building electrical load data. For the simulations, cooling is provided by two 370 ton-chillers, rejecting heat to cooling towers having a total rated capacity 25% greater than the total chiller capacity. The air circulation rates in the building were assumed to be 7 air changes per hour (ACH) in the interior zones and 10 ACH in the perimeter zones. The economizer was not operational during the 1986–1987 pre-retrofit period, and a 20% fixed ventilation air flow was estimated. The HVAC systems were started and shut down at specified times during the week. Basically, they were operational during working hours and off during the remaining hours.

To match the winter load data, the building air infiltration was increased. There appeared to be a significant stack effect during the winter months. This was not modeled directly. A first order approximation of this was made, however, by specifying a stack air infiltration rate, as shown in Table 4.1.

The changes that were made in the adjusted simulation parameters after the energy conservation measures were installed in the United Nations building are listed in Table 4.2. The changes were in the lighting power and in the HVAC system. The pre-retrofit gray plate glass and the post-retrofit bronze plate glass were represented as the

Table 4.1. Selected parameters assumed for simulating the United Unions building in its pre-retrofit configuration

Internal loads

Occupants: 520
 Lighting: 3.0 W/sqft
 Office equipment: 0.8 W/sqft

Air infiltration

Wind induced: 0.3 air change per hour (ACH) at 10 mph windspeed

Stack: 1.3 ACH

Schedule (multipliers)

Period	Occupied	Unoccupied
Through Feb 28	0.75	1.00
Apr 30	0.65	0.90
Sep 30	0.05	0.25
Nov 30	0.35	0.50
Dec 31	0.75	1.00

HVAC equipment

Type: Dual-duct system

Heating equipment: Electric resistance heaters in hot decks.
 260 kW capacity for building interior zones
 350 kW capacity for building perimeter zones

Cooling equipment: Two 370-ton (4.44 MBtu/h) centrifugal chillers
 Four 2.80 MBtu/h cooling towers
 Four 50-hp supply fans
 Eight 30-hp return fans

HVAC system characteristics

Circulating air flow rate: 7 ACH (1.05 cfm/sqft) for building interior zones
 10 ACH (1.50 cfm/sqft) for building perimeter zones

HVAC system control

Temperature setpoints: 72°F for heating
 76°F for cooling

Fan control: Constant speed

Ventilation air: 20% of circulating supply air

System operation: On at specified times Monday through Saturday
 Off nights, Sundays and holidays

same type of window in the simulations, since their properties are very similar (ASHRAE 1989a; LBL 1988). Basically, the change in windows did not have much influence on the change in the energy use, although the new windows were apparently structurally superior.

Table 4.2. Changes in the selected parameters for simulating the United Unions building in its post-retrofit configuration

Internal loads

Lighting: 1.6 W/sqft

Air infiltration

Wind induced: 0.3 air change per hour (ACH) at 10 mph windspeed

Stack: 1.3 ACH

Schedule (multipliers)

Period	Occupied	Unoccupied
Through Apr 30	0.65	0.90
Sep 30	0.05	0.25
Nov 30	0.35	0.50
Dec 31	0.75	1.00

HVAC equipment

Type: Dual-duct variable-air-volume system

Heating equipment: Electric resistance heaters in hot decks.

100 kW capacity for building interior zones

350 kW capacity for building perimeter zones

HVAC system control

Minimum air flow rate fraction: 0.5

Fan control: Variable-frequency motor drives

Ventilation air: Enthalpy economizer controlled

Minimum supply air fraction: 0.03

Maximum supply air fraction: 0.50

System operation: EMCS* optimum controlled start times Monday through Saturdays.

Off nights, Sundays, and holidays

*EMCS = Energy Management and Control System

In the post-retrofit simulations, the power required for lighting was reduced from 3.0 W/sqft to 1.6 W/sqft. All the other internal loads were taken to be unaffected. There appeared to be some reduction in the air infiltration in the winter. This was simulated in the model by empirically reducing the infiltration rates for the months of January and February. The HVAC system was converted to a dual-duct variable-air-volume (VAV) system. The hot deck electrical heater capacity for the interior zones was reduced from 260 kW to 100 kW, since many of these heaters were disconnected during the building alterations. The air economizer was reactivated and connected to the EMCS. The

ventilation air flow rate through this unit was specified to vary from 0.03 to 0.50 of the maximum circulating air flow rate.

Both the supply air and return air fans were specified to have variable-frequency motor drives in the simulations. This is an approximation, since in reality, the return air fans were turned on and off using a static pressure-activated control. The DOE-2 default curve for calculating variable speed motor power, shown in Fig. 4.1, was used for calculating the fan energy consumption.

Fig. 4.1. DOE-2 default curve for variable-speed motor powered fan energy input.

Source: DOE-2 Reference Manual

The EMCS-optimized HVAC startup times were approximated in the simulations by the DOE-2.1D optimum fan start algorithm (LBL 1989). In this algorithm, the system start time is delayed until the run time matches what is needed to achieve the desired space temperatures at the beginning of the working day. In DOE-2.1D, it is done on an hourly basis, whereas in the building it is done on shorter time increments (10 min or less).

4.2 BILLING PERIOD COMPARISONS

The billing period data used for the model calibration were for the June 1986 – May 1987 period for the building in its pre-retrofit configuration, and for the 1989 calendar year for the building in its post-retrofit configuration. Separate simulations were run for the calendar years 1986 and 1987, and appropriate data were extracted for comparisons. In this study, the first day and the final day of each billing month were those for the actual billing month.

Plots of the predicted and measured monthly billing electricity consumptions and peak demands for the 1986-1987 time period are presented in Figs. 4.2a and 4.2b. The agreement between the simulation and the measurements cases is good. For the energy use data, Fig. 4.2a, the agreement is within 5%, except for February and March, where it is within 8%. For the peak energy demand, Fig. 4.2b, the agreement is again within 5%, except for the 10% difference in November. The larger differences occur in the winter when the utility electricity rates for the building are lower (Appendix A). It should be noted that the actual billing peak demand values are for 30-min time intervals, while the predicted values are for 1-hr time intervals. One would expect the billing demands to be slightly higher than the calculated values, although there were insufficient data to confirm this.

Figs. 4.3a and 4.3b are analogous plots for the United Unions building during the calendar year 1989. Again, the agreement between the simulation

Fig. 4.2a. Simulated and measured billing period electricity consumption during the pre-retrofit years 1986-1987.

Fig. 4.2b. Simulated and measured billing peak electricity demand during the pre-retrofit years 1986-1987.

Fig. 4.3a. Simulated and measured billing period electricity consumption during the post-retrofit year 1989.

and the measurements is good. The monthly energy consumption values, Fig. 4.3a, are within 6%, except for April, where there is an 11% difference. For the peak energy demand, Fig. 4.3b, the agreement is within 5% except for February, April, November and December. The differences for these months varies from 9% to 19%. Again, these higher differences are during the winter season, when the utility rates are lower.

Fig. 4.3b. Simulated and measured billing peak electricity demand during the post-retrofit year 1989.

The 1989 electrical energy billing costs for the building were calculated using the DOE-2.1D program-predicted hourly energy consumption and the 1989 PEPCO electrical rate schedule (Appendix A). These results are plotted together with the actual billing charges in Fig. 4.3c. The simulated charges are within 4% of the actual charges during the summer months and within 9% of the actual charges during the winter.

Fig. 4.3c. Simulated and actual building energy costs during the post-retrofit year 1989.

4.3. HOURLY DATA COMPARISONS

Hourly data used in the calibration of the simulation model were those obtained during September 1992. A comparison of the simulated and measured building electrical consumption data for the week of September 20 through September 26 is presented in Fig. 4.4. The building was being used and operated under normal post-retrofit conditions during this week. The overall agreement is reasonably good. For the week, the total

simulated electricity consumption is within 0.5% agreement with the measured total. The daily total ranges from 6% underprediction on Tuesday to 6% overprediction on Wednesday. The minimum load during the nights and weekends is about 250 kW. The peak measured hourly consumption for the week was about 980 kWh on Tuesday, which was about 8% higher than the

predicted peak value for Tuesday. The predicted peak hourly consumption for this week was about 925 kWh on Wednesday, which is about 7% higher than the measured value for that day.

Fig. 4.4. Simulated and measured hourly energy consumption profiles for the week Sept. 20 through Sept. 26, 1992. (Normal HVAC systems operation.)

Fig. 4.5 is an analogous plot for the week of September 13 through September 19, 1992. For this week, the operation of the HVAC systems was altered for testing purposes. The systems were operated continuously with no time-of-day temperature setback/setup control.

Fig. 4.5. Simulated and measured hourly energy consumption profiles for the week Sept. 13 through Sept. 19, 1992. (Continuous HVAC systems operation.)

The measured and the predicted total energy

consumption for the week agreed within 1.5%. The daily totals were within 7% agreement. However, the predicted peak hour energy consumption values for this week were lower than the measured values, as shown in Fig. 4.5. The measured peak load was about 990 kWh on Wednesday. The predicted value was about 18% lower. On the other weekdays, the predicted peak load was about 10 to 14% lower than the measured

values. The minimum load for the week was about 500 kW, which is about two times that observed during the normal operation of HVAC systems (Fig. 4.4).

Attempts to improve the agreement between the measured and predicted peak loads during the week of continuous HVAC system operation were limited. Increasing the office equipment load from 0.8 W/sqft to 1.0 W/sqft resulted in slightly better agreement. In that case, the predicted daily peak loads were within 9% to 12% of the measured values. However when using the 1.0 W/sqft equipment load for the monthly billing period simulations, there was less agreement with the measured data there was using the 0.8 W/sqft equipment load.

Many reasons can be conjectured why the predicted peak hourly loads are lower than the measured peak loads for the week of September 13 through September 19. Among these are the occupancy and internal load schedules, the building thermal capacitance, air infiltration, and the HVAC systems' operating characteristic parameters (Braun 1990).

The fact that the measured peak hourly loads are about the same for both the weeks with and without the continuous operation of the HVAC systems was surprising. Generally, it has been found that the peak loads in office buildings similar to the United Unions building are higher because the systems being shut down when the building is essentially unoccupied. This effect is particularly noticeable on Mondays after the systems were shut down during the weekends (Braun 1990). Moreover, the United Unions building occupants complained of being cold during the week of the continuous HVAC operation. This suggests that the building internal surfaces were cooler during that week, which can contribute to thermal discomfort. Whether or not there were some other heat sources turned on during this week was not known.

The ambient air temperatures during the week of this test were mild. As shown in Appendix B, they ranged from the mid 60s to the low 70s during the nights and the mid 70s to the low 80s during the days (deg F). The effect of the running the systems continuously might have been more revealing during mid-summer, when the ambient air temperatures are high.

Because of the uncertainties associated with the test and the assumptions used in the simulation model, investigation of the reasons for differences in the peak loads during the week of continuous HVAC systems operation were not investigated further. This is, of course, an engineering judgement, weighing the time required to achieve better agreement with the data and the accuracy required for the project. A good match of the hourly data profiles for the following week, where the HVAC systems' operation was controlled by the EMCS, was obtained, however.

4.4 MODEL SUFFICIENCY

We believe that the matched DOE-2.1D model was sufficient to estimate the impact of the individual energy conservation measures. The agreement between the predicted and measured pre-retrofit and post-retrofit billing data is very good, within 5% for most of the billing periods. There was also good agreement between the model and measured hourly energy use profiles for the week that was analyzed, where normal building EMCS control was used. The match of the profiles for the week where the HVAC systems were operated continuously was not quite as good as we desired, but we believe that the model is sufficient to predict the trends of the impact of this type of operation.

5. RETROFIT MEASURES BENEFITS

An energy retrofit measure is, by definition, intended to reduce the use of some forms of energy from what it would otherwise have been. Whether the energy retrofit measure is worthwhile depends both on the reduction in energy use and on the comparison between the value of that reduction and the cost of the retrofit. Frequently, as for the United Unions building, all the energy measures are installed simultaneously. Moreover, the ambient weather conditions differ when measuring the building energy use before and after the building is retrofitted. Thus, the DOE-2.1D simulation program, adjusted to match the measured data, was used to estimate the benefits of the individual measures using a common set of building operating and weather conditions. The weather data used to evaluate the individual measures were the TMY data for Washington, D.C. (Dulles Airport), as stated in Sect. 3.1.4.

In this section, the normalized total benefits of the retrofit measures for the United Unions building are presented first. Next, the estimated benefits of individual lighting and HVAC systems measures are presented. Finally, the results of the simulations comparing the time-of-day operation with the continuous operation of the HVAC systems are presented. The benefits of the measures were evaluated based on (1) energy reduction, (2) peak energy demand reduction, and (3) cost savings.

It was assumed that there was no change in the building energy use associated with the replacement of the windows, as discussed in Sect. 4.1. For evaluation of the other retrofit measures, it was assumed that the outside air infiltration for the pre-retrofitted building is the same as that for the post-retrofitted building. The errors introduced by this assumption are estimated to be about 0.5% lower energy use than the expected actual use and 0.3% lower energy cost for the pre-retrofitted building.

The PEPCO 1989 electricity rate schedule was used for most of the simulations. The 1992 rate schedule was used in a few of the calculations for comparison purposes, and the results are annotated where it was used. These schedules are listed in Appendix A, and they have both time-of-day and peak demand charges. The dates of the billing

periods for all the calculations were assumed to be the same as those printed on the 1989 billing statements. The dates for the 1992 billing periods probably are slightly different, but 1989 dates are sufficient in this study. Also, the peak demands were calculated for 1-h time intervals, whereas the billing peak demands were for 30-min time intervals. This results in slightly lower calculated cost savings for the measures.

5.1 OVERALL BENEFITS

5.1.1 Energy and Peak Demand Savings

The normalized overall energy savings resulting from the installation of the energy conservation measures in the United Nations building are shown in Fig. 5.1a. The annual electricity consumption is changed from 7,036 MWh to 4,449 MWh, which is a saving of 2,587 MWh, or 37% of the original value. The monthly savings range from 200 to 240 MWh. Moreover, there are significant reductions in the peak demand power, as shown in Fig. 5.1b. The reduction of the peak demand power is the greatest in the summer, when the utility demand charges are higher (Appendix A). In July, the peak demand is reduced from 1610 kW to 990 kW, for a saving of 39%.

Fig. 5.1a. Normalized monthly energy consumption before and after then installation of energy conservation measures.

Fig. 5.1b. Normalized monthly peak power demand before and after the installation of the energy conservation measures.

5.1.2 Component Energy Use

The total and the components of the building energy consumption were estimated using the simulation program. Values of these on a per square foot basis are listed in Table 5.1. Before the building was retrofitted, the total electrical energy consumption was

Table 5.1. Estimated components of the United Unions building electricity consumption before and after installation of energy conservation measures (170,000 sqft floor area)				
	Before Retrofit		After Retrofit	
<u>Electricity consumption</u>	<u>kWh/sqft·yr (Btu/sqft·yr)</u>		<u>kWh/sqft·yr (Btu/sqft·yr)</u>	
Total	41.4	(141,300)	26.2	(89,300)
Lighting	19.7	(67,300)	12.3	(42,000)
Office equipment	4.4	(15,000)	4.4	(15,000)
Elevators	0.5	(1,730)	0.5	(1,730)
Heating	3.1	(10,500)	2.7	(9,350)
DHW heating	0.1	(400)	0.1	(400)
Cooling	4.3	(14,640)	2.1	(8,200)
Fans	8.7	(29,650)	3.7	(12,700)
HVAC auxiliaries	0.6	(2,160)	0.3	(920)
<u>Peak demand</u>	<u>W/sqft (Btu/hr·sqft)</u>		<u>W/sqft (Btu/hr·sqft)</u>	
Winter	10.2	(34.8)	7.9	(27.0)
Summer	9.5	(32.3)	5.8	(19.8)

considerably higher than that for a normal office building in the area. After the building was retrofitted, the energy consumption was about the same as that for a normal office building (EIA 1992).

Energy required for lighting was the largest consumer of energy before and after the conservation measures were installed. The second largest energy consumer was the circulating air system fans. In both cases, there were large energy savings after these components were retrofitted. It was estimated that the retrofit reduced the energy required to operate the cooling equipment. The heating energy savings are not as dramatic. For this particular situation, however, the winter season utility rates are lower than the summer season rates. Thus, the economic importance of the heating season energy is somewhat less than that of the cooling season.

For the building, the peak power demand was greater in the winter than in the summer. After the building was renovated, there was a significant reduction in the demand during the winter, but it was not as large as that achieved during the summer.

5.1.3 Energy Cost Savings

Fig. 5.2a shows the simulated monthly billing charges before and after the building was retrofitted using the PEPCO 1989 rate schedule. Savings of \$163,000, about 35% of the original energy cost, was realized for the normalized year. The monthly savings were greater during the summer when the energy rates and the demand charges were higher. The monthly savings for July and August were each about \$20,000, about 40% of the original monthly values. Demand charges were a significant portion of the energy costs, as illustrated in Fig. 5.2b. They accounted for slightly less than half of the costs. During the summer, when the rates were high, they were reduced by about 40% by the conservation measures. During the winter, they were reduced about 33%.

Fig. 5.2a. Monthly billing charges before and after the installation of the energy conservation measures.

Fig. 5.2b. Monthly demand charges before and after the installation of the energy conservation measures.

The effect of using the PEPCO 1992 rate schedule (Appendix A) is shown in Fig. 5.3. The annual cost savings is \$183,000, compared with \$163,000 using the 1989 rate schedule. This reflects the higher 1992 rates, particularly for the summer season. In the 1992 rate schedule, the winter season demand charges play a smaller role, but the summer season demand charges still account for about half of the total costs.

Fig. 5.3. Monthly billing charges before and after the installation of the energy conservation measures using PEPCO 1992 rate schedule.

The total construction cost for retrofitting the United Unions building was about \$700,000 (Powell 1988). Using the 1989 electricity rate schedule, this is equivalent to a simple payback time of about 4.3 years.

5.2 BENEFITS OF THE INDIVIDUAL CONSERVATION MEASURES

5.2.1 Annual Benefit Fractions

Fig. 5.4a presents the estimated percentage savings for each measure relative to the overall annual energy consumption in the pre-retrofitted United Unions building. Of the total 37% savings, the lighting retrofits account for 17%, about half of the total. The remaining 20% savings are due to HVAC systems improvements. Replacement of the terminal mixing

Fig. 5.4a. Contributions of the individual measures to the United Unions building annual energy savings.

boxes with damper control boxes (simulated using the box dampers to control the air flow rate) saves 3%, disconnecting the excess interior zone heating coils saves 2%, adding frequency control to the fan motors (speed control) saves 7%, and activating the economizer with the new EMCS saves 8%.

The fractions of the associated cost savings are shown in Fig. 5.4b. Again, lighting accounts for about half, 17% of the total 35% cost savings. The cost savings for the HVAC systems measures are slightly lower than the energy use savings, about 18% of the pre-retrofit energy costs. Installing the damper boxes results in a 1% cost

Fig. 5.4b. Contributions of the individual measures to the United Unions building energy cost savings.

savings, disconnecting the excess heating capacity adds 3% cost savings, the fan speed control adds a 7% cost savings, and the activated economizer provides a 7% cost savings. The slightly lower percentage cost savings are due to the fact that the HVAC systems measures do not reduce the peak demand and time-of-use energy loads as much as they reduce total energy consumption.

5.2.2 Monthly Benefit Contributions

A breakdown of the contributions of the individual conservation measures to the monthly savings is given in Figs. 5.5a, 5.5b, and 5.5c. These figures show the cumulative reductions in the billing period energy consumption, peak power use, and energy costs as the different measures are installed. The curves in the figures are identified by letters, each letter representing a set of installed measures listed in Table 5.2. The upper and lower curves are the same as those in Figs. 5.1a, 5.1b, and 5.2a, and they are repeated here for the reader's convenience.

Lighting Savings. Our results show large energy, demand, and cost benefits for the lighting measures, which shows their importance for office buildings in similar or

Fig. 5.5a. Billing period energy consumption as the retrofit measures are individually installed in the United Unions building. (See Table 5.2 for definition of curve legends.)

Fig. 5.5b. Billing period peak power as the retrofit measures are individually installed in the United Unions building. (See Table 5.2 for definitions of curve legends.)

warmer climates. The greatest benefits are during the cooling season, as illustrated by the differences in Curves A and C in the figures. During the heating season, the heat generated by lights offsets some of the heating energy that would otherwise be supplied

Fig. 5.5c. Billing period charges as the retrofit measures are individually installed in the United Unions building. (See Table 5.2 for definition of curve legends.)

Table 5.2. Measures installed corresponding to the legends for the curves in Figs. 5.5a, 5.5b, and 5.5c	
Legend	Measures installed
A	None — Pre-retrofit configuration
B	Lighting — Fixture power reduction only
C	Lighting — Total energy reduction
D	Lighting and damper terminal boxes (VAV)
E	Lighting, damper terminal boxes (VAV) and reduced heating capacity
F	Lighting, damper terminal boxes (VAV), reduced heating capacity, and fan speed control
G	Lighting, damper terminal boxes (VAV), reduced heating capacity, fan speed control, and enthalpy controlled economizer — Post-retrofit configuration

by the HVAC systems. During the cooling season, however, heat from the lighting fixture must be removed by the cooling system, which increases the cooling energy and power requirements. This interaction is quantified by Curve B in the figures, which was generated by subtracting the reduction in the energy supplied to the fixtures from the total energy supplied to the building. Comparison of Curves B and C shows significant

cooling energy savings during the summer, but also shows that additional heating is required during the winter.

The total annual lighting retrofit energy saving is 1.21 GWh per year. The savings realized by reducing the fixture power is 1.26 GWh, but the additional winter heating requirements slightly lower the overall savings. The additional heating energy needed to compensate for the reduction in the lighting energy in the winter is 0.18 GWh. In the summer, however, the annual cooling energy is reduced by 0.13 GWh because of the lower lighting loads.

The billing period energy savings vary from a low of 54,000 MWh in February to 138,000 MWh in July, which represents 9 to 22% savings. The lower winter savings, of course, reflect the heating energy to compensate for the lighting energy reduction. The total monthly peak load savings are in the range of 80 to 320 kW, as compared with a 230-kW monthly peak reduction for the lighting fixtures alone.

The total annual cost savings for the lighting measure is \$78,600. Of this, \$74,000 of the savings is due to the reduction of the fixture power requirements and \$4,600 is due to the reduction of the HVAC systems requirements. The annual cooling system cost savings due to the lighting measures is \$13,100, but the annual heating system cost increase for the same measures is \$8,500. In the summer, the total monthly savings is about \$10,000, but in the winter, the total cost increase is about \$1,400 to \$1,900 per month.

VAV Savings. Replacing the dual-duct system mixing boxes with damper controlled terminal boxes, where the air flow rate is controlled by the dampers, effectively converts the system to a VAV system. Without incorporating fan motor variable-frequency controls, the savings are limited, as seen by comparing Curves B and C in the figures. The annual energy and cost savings for damper boxes are 0.21 GWh and \$4,500, respectively. Inlet vanes located at the fan entrances also could result in additional energy savings, but the use of motor speed controls results in still greater savings (LBL 1989; Lorenzetti 1992).

The monthly billing energy savings for the damper boxes vary from about 6,000 kWh in January to about 27,000 kWh in the spring and fall months, which represents 1 to 5% of the total pre-retrofit building values. There is a small (1 to 3%) decrease in the peak power demand in the summer, but an increase of 1 to 4% in the winter. (A 7% increase in March and an 11% increase in November were calculated.)

For most of the year, the monthly energy costs are 1 to 3% lower with the installation of the damper boxes. During the winter, however, the change in these costs can range from an 1% decrease to a 7% increase because of the changes in the peak demand power.

Reduced Heating Capacity Savings. Eliminating excess heating capacity in the building interior zones saves 0.12 GWh of energy and \$12,000 in energy costs annually. The savings are about 2% of the original energy use and 3% of the original energy cost. The greatest monthly savings are in January and February. For January, they are 38,000 kWh for energy, 160 kW for demand, and \$2,600 for cost. For February, these savings are 32,000 kWh, 240 kW, and \$3,000, respectively. There are no savings in the summer, as can be seen by comparing Curves C and D in the figures.

Fan Speed Control Savings. Addition of variable-frequency motor drives to the fans provides substantial energy and cost savings during the cooling season, as shown by comparing Curves D and E in the figures. This occurs because reducing the lighting power and converting the circulating air system to a VAV system causes the existing circulating air fans to be oversized. This means that the required air flow rate is below the maximum for most of the year. Powell (1988) reported that after the United Nations building was refurbished, the main circulating fans operated at about 85% of their design speed most of the time, and only four of the eight return air fans were needed.

The annual energy and cost savings from adding the fan speed control are about 0.49 GWh and \$34,200, respectively, or about 7% of the original total building values. The monthly billing energy savings varies from about 9,100 kWh in January to 69,100 kWh in July, or about 1 to 11% of the pre-retrofit values. In January, the fan motors consumed less energy, but additional resistance heating is then needed to compensate

for this in the building spaces requiring heat. There is very little difference in the peak power demand in the winter, but savings up of to 190 kW, about 12% of the total pre-retrofit peak power, are achieved during the summer. These savings are reflected in the energy cost savings, which are only about \$600 per month, about 2% of the original, during December and January, but are in the range of \$5,600 to \$5,900 per month, about 10% to 12% of the original values, during June through August.

Economizer Savings. Activation of the economizer results in additional annual energy savings of 0.56 GWh and cost savings of \$32,000, about 8% and 7% of the original totals, respectively. Most of the savings are in the winter, as illustrated by the difference in Curves E and F in the figures. The monthly billing period energy savings varies from 6,800 kWh in June to 119,000 kWh in January, or about 1% to 16% of the total monthly pre-retrofit values. The greatest reduction in the monthly peak power demand is in the spring, where it can be high as 270 KW, or about 19% of the original. During the peak heating winter months, there is little change in the peak power. In the summer, however, the monthly peak power reduction can be as high as 110 kW, or about 7% of the original value.

The savings in the monthly billing charges are more uniform, as shown in Fig. 5.5c because of the higher energy rates during the summer months (Appendix A). The cost savings vary from about \$1,100 in October to \$4,500 in March, about 2% to 14% of the original totals.

Alternative Implementation of Measures. We considered the effect of an alternative order of implementing the measures, activating the economizer and removing the excess interior zone heating capacity prior to installing the damper-controlled terminal boxes and the fan motor variable-frequency control. The impact of this order is shown in Figs. 5.6a and 5.6b, where the economizer was activated after the lighting measures were installed. (Note that the legend for these figures is described in Table 5.3.) Here the annual energy and cost savings for the economizer reactivation are about 0.63 GWh and \$37,300, respectively, which are 9% and 8% of the original totals. The savings for converting the circulating air system to a dual-duct VAV system as the last measure are correspondingly reduced.

Fig. 5.6a. Billing period energy consumption as the retrofit measures are installed in an alternative order in the United Unions building. (See Table 5.3 for definition of the curve legends.)

Fig. 5.6b. Billing period charges as the retrofit measures are installed in an alternative order in the United Unions building. (See Table 5.3 for definition of the curve legends.)

The patterns for the monthly energy use and costs for this alternative sequence are the same as those for activating the economizer last. However the magnitudes of the energy savings, shown as the difference between Curves B and C in Fig. 5.6a, are greater

Table 5.3. Measures installed corresponding to the legends for the curves in Figs. 5.6a and 5.6b	
Legend	Measures installed
A	None — Pre-retrofit configuration
B	Lighting
C	Lighting and enthalpy controlled economizer
D	Lighting, enthalpy controlled economizer, and reduced heating capacity
E	Lighting, enthalpy controlled economizer, reduced heating capacity, damper terminal boxes (VAV), and fan speed control — Post-retrofit configuration

than those for the previous case, shown as the difference between Curves F and G in Fig. 5.5a. The greatest monthly energy savings of about 145,100 kWh is in January, which is about 20% of the energy used in the pre-retrofitted building. Again, during the summer the savings are small, dropping to about 6,700 kWh, or about 1% of the original value.

The third measure implemented in this alternative sequence was the removal of the interior zone excess heating capacity. The effect of this action here is small, as seen by comparing Curves C and D in Figs. 5.6a and 5.6b. The annual energy and cost savings are 0.04 GWh and \$6,200, respectively. They are about 1% of the original total energy consumption and cost. The greatest monthly savings are in January, 7,000 kWh for energy and \$1,800 for cost. There are no savings in the summer.

Based on comparing the analogous cost curves in Figs. 5.5c (F to G) and 5.6b (B to C), activating the economizer before installing the VAV retrofit measures results in greater cost savings for the economizer measure. In January it is \$6,200, about 17% of the building total. It drops to about \$760, about 2% of the building total, in June. Although this is an increase over activating the economizer last, the summer season savings are still small compared with the terminal box replacement and fan speed control measures.

5.3 TIME-SCHEDULE HVAC SYSTEM OPERATION

The United Unions building HVAC systems were operated in a time-schedule mode before and after the energy conservation measures were installed. Basically, the time-schedule mode of operation involves shutting down the systems when the building is not being used for business during nights, weekends and holidays. Prior to retrofitting the building, the systems were manually started and stopped at specified times. They were started 2 to 4 hours before occupancy to allow the building air temperatures to reach the desired level at the start of the daily operation. After the building was retrofitted, the EMCS was programmed to optimize (minimize) the times that the HVAC systems needed to run before building occupancy.

5.3.1 Energy Savings

Based on our short-term test of the building's HVAC systems operating in a continuous mode and our matched DOE-2.1D model, we estimated that 2.34 GWh less energy was used each year in the pre-retrofitted building because of the manual time-schedule control. For the post-retrofitted building having EMCS time-schedule control, we estimate that 1.03 GWh less energy is used each year. These values are about 25% and 19% of total energy that would be used in the building if the HVAC systems were operated continuously.

Comparative curves for the monthly energy use for continuous and time-schedule modes of HVAC systems operation are presented in Fig. 5.7. These curves are for the retrofitted building. Here, the energy savings vary from 53,000 kWh in May to 158,000 kWh in January, which

Fig. 5.7. Monthly billing energy consumption for the retrofitted United Unions building HVAC systems operating in continuously and time-schedule modes.

represent 14% and 24% of the monthly energy use if the building systems had operated continuously. For the building in its pre-retrofitted configuration, the curves are similar to those in Fig. 5.7, except there are greater billing period energy savings because of the greater energy consumption for that configuration.

5.3.2 Cost Savings

The energy cost saving resulting from the time-schedule operation of the HVAC systems was calculated using the matched DOE-2.1D model. For the building in its post-retrofit configuration, the annual savings were calculated to be \$2,600, or about 1% of those for the continuous operation of the systems. For the building in its pre-retrofit configuration, these values were calculated to be \$49,000 and 10%.

We have reasons to question the low calculated cost savings for the post-retrofitted building. However, the utility rate schedule and the continuously operating systems' lower peak power demand and peak time-of-use energy use all do contribute to the lower cost savings. The 1989 PEPCO rate schedule (Appendix A) used for these calculations has large peak power demand and peak time-of-use energy charges. The peak power demand and the peak time-of-use energy use charges for the HVAC systems operating in the time-schedule mode were much higher. This resulted in a much lower cost savings for this operating mode than would have been if a straight uniform energy rate was used.

The matched DOE-2.1D model used in these calculations may have generated questionable estimates of the magnitudes of the reduction of the power demand and the peak-hour energy consumption for the building for the continuous operating mode. As shown in Sect. 4.3 (Fig 4.5), the matched model predicted about 10% lower peak demand than was measured for the week that the HVAC systems were operated in a continuous mode in September 1992. This modeling result is consistent with previous experience predicting lower peak demands and peak time-of-use energy loads for buildings with continuously operating HVAC systems (Braun 1990). However, in this study, the measured data showed about the same peak loads for the systems operating in either mode. Unfortunately, we could not ascertain the reasons for this difference. If the peak

loads for the continuous HVAC system operation were increased 10%, the time-schedule mode would easily increase the cost savings to \$12,000, or about 4% of the total energy costs, for the retrofitted building. Thus we are uncertain about the level of the cost savings associated with the time-schedule versus continuous modes of HVAC system operation.

An additional point should be made here about the cost savings for the time-schedule mode of operation. Many buildings, including the United Nations building, require the presence of an equipment operator whenever the HVAC systems are operating. Thus, a very significant additional cost savings can be realized by shutting the systems down and not having operators at the site during the times when the building is not in use.

5.3.3 EMCS Optimized Control

Control of the HVAC systems startup and shutdown times was optimized (minimized) by the new EMCS (Sect. 2.3.2). In our analysis, this operation was approximated using the DOE-2.1D optimum fan start routine for the building in its post-retrofit configuration. (See the program input data listing in Appendix C.) This simulation routine delays the system start time on an hourly basis until the heat added or extracted matches that required to bring the zone to the desired temperature at the start of the working day (LBL 1989). This is an approximation, as the actual systems use much smaller time increments. For comparison, the same building was simulated using the same startup and shutdown times as was used for the building in its pre-retrofit configuration. The difference in energy savings predicted by the simulations using the optimized control compared with manual control was about 1%, which is small. But the model is not so precise as to say that the savings could not be higher, say 3%. Also, manual control is very largely dependent on the operators' capability and dedication. The savings for manually controlled systems can approach those for EMCS controlled systems if the operators are capable and dedicated (Gettings 1988). Conversely, they can be lower if the operators are less capable or dedicated.

6. DISCUSSION OF RESULTS

6.1 OVERALL SAVINGS

The savings for the energy conservation measures, presented in the previous section are summarized in Table 6.1. The breakdown of the total savings for the

Table 6.1. Summary of the annual energy conservation measure savings for the United Nations building				
	Energy (GWh)	Energy savings (%)	Energy cost (\$)	Cost, savings (%)
Before measures	7.04		464,000	
After measures	4.45		301,000	
Total savings	2.59	37	163,000	35
Lighting savings				
Total	1.21	17	79,000	17
Reduced power	1.26	18	74,000	16
Other loads	- 0.05	- 1	5,000	1
HVAC system savings				
Total	1.38	20	84,000	18
VAV	0.21	3	4,000	1
Reduced htg cap	0.12	2	14,000	3
Fan speed control	0.47	7	34,000	7
Economizer	0.56	8	32,000	7
HVAC system savings				
Alternate order				
Total	1.38	20	84,000	18
Economizer	0.63	9	37,000	8
Reduced htg cap	0.04	1	6,000	1
VAV and fan speed control	0.71	10	41,000	9

individual measures is slightly arbitrary, since there are interactions between the measures. The specific savings are dependent on the order that the measures are installed (or evaluated analytically). HVAC component savings for an alternate order of installing the system measures are listed in the Table 6.1. In all cases, the lighting measures are assumed to be installed first, since they result in the greatest energy savings.

The overall savings for the retrofits are about 37% for energy and about 35% for costs. The slightly lower percentage for the cost savings reflects the peak demand and time-of-use energy charges in the electricity rate schedule (Appendix A). The simple payback time for this project is 4.3 years (Sect. 5.1.3). The United Unions building renovation was financed through a 10-year lease, which led to a significant positive cash flow for the building operations (Powell 1988).

The payback times for the individual measures were not estimated directly since initial cost data for the measures were not available. But data for other buildings suggest that the lighting measures and the HVAC systems measures as a group each can have simple payback times in the neighborhood of 4 years (Abel 1992; SERI 1984).

6.2 BUILDING ENVELOPE

Before the United Unions building was refurbished, there were apparently very significant air leaks around the windows. The original windows had a two pane, gray tinted glazing. They were replaced with windows having two-pane, bronze-tinted glazing. It was assumed for the analysis that there were no differences in the characteristics of these two glazings. This appears to be a reasonable assumption since calculations using the WINDOW 3.1 program (ASHRAE 1989a; LBL 1988) indicated that the heat gain through the two glazing types agrees within 4%.

However, the effect of the air leakage through windows was considered together with the total air leakage in the building. The amount of air leakage in the United Unions building was estimated by using air infiltration as one of the parameters that were adjusted to make the simulations agree with the measured energy consumption data. The approach in this study was very simplistic, and it needs to be investigated thoroughly in the future. However, this adjustment procedure did indicate that there was greater air infiltration in the building before it was refurbished (Tables 4.1 and 4.2). We estimated that the building energy consumption is about 0.5% lower because of the reduced air infiltration through the new windows.

6.3 LIGHTING AND EQUIPMENT SAVINGS

In the simulations, reducing the peak lighting power from 3.0 W/sqft to 1.6 W/sqft reduced the building energy consumption and costs about 17%. It was assumed that the peak office equipment power level is 0.8 W/sqft and that it did not change after the building was renovated. While this investigation showed large savings from reducing the lighting power, similar savings could be realized from reducing of the office equipment power. The recent trend is toward the use of more equipment in offices, such as personal computers with color monitors, printers, and copying machines. This trend has resulted in higher plug-in equipment loads, and office equipment loads of 1.5 W/sqft are not uncommon (Abel 1992, Kaplan 1992). Thus, measures for reducing the equipment power should be considered.

For the United Unions building, the benefits of reducing the lighting and plug-in equipment power are realized the entire year, but they are more important in the cooling season. Most of the lighting savings in this analysis were due to the reduction of the lighting fixture power. Thermal interactions led to additional cooling energy and cost savings during the summer, but they led to increased heating energy use and costs during the winter. Because of the higher summer utility rates, the net effect of the thermal interactions was to lower the annual energy savings but raise the annual cost savings for this measure. The magnitudes of these impacts are shown in Table 6.1.

6.4 HVAC SYSTEM SAVINGS

Generally, balancing the water and air flow rates in the HVAC systems to just meet the heating and cooling requirements, improving economizer control, and shutting down the systems when they are not needed are cost-effective measures for HVAC systems (Abel 1992).

For the United Unions building, there were about 3% energy and 1% cost savings from replacing the terminal mixing boxes with the damper-controlled air flow terminals. However, adding variable-frequency motor drives to the large supply air fans resulted in an additional 7% energy and cost savings. This analytical exercise shows the magnitudes

of the savings for the VAV systems components. It shows why energy-efficient VAV systems with variable-speed drives are becoming more popular in commercial buildings (Lorenzetti 1992). Both these measures were most beneficial during the summer, when they reduced both the energy and peak power demands. For this building, the benefits were partly due to the fact that the original air circulation fans continued to be used after the energy conservation measures were installed, while the demands on systems were lower. Since the fan motors are large consumers of energy (Table 5.1), they generated a significant amount of heat within the building that had to be removed during the summer. Thus, dual benefits can be gained by adding fan speed controls.

The activation of the economizer was also beneficial, resulting in a 7% energy cost reduction. This measure resulted in significant reductions in the energy load during the winter and in the peak loads during the summer. The reductions in the summer peak loads are due to the decrease in the rate at which the outside air is entering the air handling systems during the peak cooling hours. Prior to activating the economizer, we estimated that 20% of the HVAC systems' circulating air was being replaced with outside air for the entire year. After activation, air replacement was specified to be in the range of 3 to 50% of the maximum circulating air flow rate. The 3% makeup air flow was used when there was no thermal energy benefit to using additional outside air.

All of the electric resistance heating coils located in the HVAC systems' hot decks serving the interior zones of the building were not needed. Most of these interior zone coils were disconnected from the power supply. The savings from this action occur only during the winter heating season and resulted in 1 to 2% reduction in energy use and 1 to 3% reduction in energy cost. A large part of the cost saving was due to the reduction in the peak demand.

6.5 EMCS SAVINGS

The energy and cost savings associated with the installation of the EMCS are somewhat more difficult to quantify. The savings associated with the activation of the economizer, discussed above, can be credited to the EMCS. The disabled economizer

was activated by connecting it to the EMCS, which was used to control the unit and monitor its performance (Powell 1988).

The EMCS at the United Unions building allows monitoring and control of other HVAC equipment, such as chiller sequencing and demand shedding, if required. It provides the operating staff a central point from which to track the building interior temperatures and energy consumption and to monitor equipment operation. This helps the staff to do its job more effectively by producing records of unusual occurrences and warnings of impending or actual equipment failure (Powell 1988).

The cost and complexity of an EMCS must be weighed against the benefits of the system. The cost of a microcomputer EMCS can vary from \$1,000 to over \$1,000,000 (Piette 1991). The advent of low-cost electronics and microprocessors has allowed more sophisticated control strategies, equipment monitoring, and more reliable operation of the HVAC systems at reduced cost (Burns 1987). However, there have been both successes and disappointments in the use of EMCSs. The military has found EMCSs to be a cost effective method to control the energy use and peak demand at many installations. Also, it can monitor unusual occurrences or problems associated with the energy distribution systems. But in some cases, EMCSs used expensive non-standard components, were not maintained, or were not designed correctly to be of much use to the operator. In these cases, the benefits of the EMCSs were limited, and they were not cost effective (Gettings 1988).

The installation of the EMCS at the United Unions building allowed optimization of the HVAC systems startup and shutdown times. Before the building was refurbished, the systems were started and shut down at specified times. The impact of optimizing these times appears to be minimal. It is recognized, however, that the DOE-2.1D simulation program used for this estimate is not sufficiently precise to say whether the savings are 1% or higher, say 3%. This calculation does suggest that in this particular case the building operators had a good understanding of how to operate the HVAC systems for minimal energy use before the EMCS was installed.

The time-schedule and optimized startup and shutdown of the HVAC systems resulted in significant energy savings, but the very limited cost savings calculated by the simulation model were surprising. The limited cost savings were because of the lower calculated peak power demands and energy consumption that occurred during the hours having the highest utility rates when the systems were operated continuously. This phenomenon was due to the thermal mass of the building, and has been observed in many situations. For the time-schedule mode of operation, the building thermal mass is allowed be heated above or cooled below the thermostat set-point temperatures when the HVAC systems are shut down nights and weekends. This leads to greater peak thermal loads on the HVAC systems, particularly on Mondays following weekend shutdowns, since these systems must remove the stored heat or replace the depleted heat in the thermal mass in addition to meeting the steady-state load demands.

We did have some questions about the short-term test and simulation of the building for the week of continuous HVAC systems operation in this study (Sect. 4.3), which could imply higher cost savings than those that were calculated. However, the model was sufficient to show that the influence of the electricity rate structure with high demand and peak time-of-use charges is very important.

Braun (1990) did a conceptual study of using HVAC system controls and the building thermal mass to optimize energy costs. This concept is called "dynamic building control," and it takes advantage of the building's thermal mass to shift the loads to the off-peak night periods. This reduces the peak time-of-use and demand charges, resulting in lower energy costs. In addition to the rate schedules and building mass, the savings are dependent on the part-load characteristics of the cooling plant and the air handling systems, climate, and internal load schedules. However, allowing the building to cool to lower temperatures at night may result in lower internal surface temperatures, which can cause discomfort. The United Nations building occupants complained of being cold during the week that the HVAC systems were operated continuously.

Piette (1991) reported that an all-electric office building in England used many concepts of dynamic control. It was found that using this control resulted in about 7% more energy consumption than would have been used for optimized time system control.

6.6 OTHER EMCS FUNCTIONS

The greatest use of EMCSs has been controlling the startup and shutdown times of building HVAC systems. (Building temperature setup and setback is an alternate form of this control.) Other uses of an EMCS include duty cycling of the building equipment and load shedding to reduce the building peak demands (Piette 1991). These functions can be accomplished using relatively simple EMCS equipment. It was shown in this study and at one military base (Gettings 1988) that the increase in energy savings from using the EMCS instead of manual control can be small.

Other major benefits of EMCSs are diagnostics and controlling the operation of HVAC systems under additional constraints, such as may be needed for controlling the indoor air quality. Monitoring of equipment performance and the comfort conditions throughout a building tends to result in quicker response by the operating staff to malfunctions and better recognition of incipient equipment failures. Selkowitz (1992) stated that an EMCS can be linked with building simulation tools, which can help with building commissioning and changes in building functions. This linkage might also allow one to check the adequacy of the simulation routines.

In some cases, a building EMCS can be used to collect data for analyzing building performance. This approach was used for collecting the hourly data in the United Nations building in 1992 for our study. The primary function of the EMCS is for control, and not all existing systems can be used for collecting building energy data. Access to the collected data is sometimes difficult, and there is no standard format for recording the data (Claridge 1993). Heinemeier (1992) has proposed guidelines for using the EMCS for building performance monitoring.

Although EMCSs can be used in many ways, the benefits must be weighed against the cost of installing and maintaining the systems. In many cases, simple controls can suffice, and there is little gain in saving energy by installing an expensive, elaborate system. Indirect EMCS benefits can be realized from improved equipment maintenance and building diagnostics. It is important that the sensing elements be maintained to ensure correct data are being recorded. The use of an EMCS also has the potential to

reduce the manpower requirements for the building. The bottom line is that the cost and reliability of the EMCS must be weighed against the direct and indirect benefits to determine its cost effectiveness and value.

7. CONCLUSIONS

The results of this study highlight the importance of installing major energy conservation measures in existing large commercial buildings for saving large amounts of energy and reducing peak power demands. The simulations with the DOE-2.1D model, adjusted to match both monthly and hourly measured whole-building data, allowed a better understanding of the energy, demand, and cost impacts of specific measures. The values of the adjusted parameters in the model appear to be consistent with those observed elsewhere in large office buildings. The simulated results reasonably matched the measured energy consumption, peak load, and energy cost data. The selection of the most appropriate independent parameter values for a matched model having many variables, such as DOE-2.1D, is strongly dependent on the user's knowledge and experience. One parameter worthy of further study is air infiltration into the building, since during the process of adjusting the parameters, it surfaced as a significant variable for taller buildings.

The analysis confirmed that the selected energy conservation measures installed in the United Unions building were good choices. About 2.6 GWh of electricity is saved each year, and costs are reduced by \$163,000. This represents a 37% energy savings and a 35% cost savings. The monthly energy savings are more or less uniform during the year, but the monthly cost savings are much greater during the summer because of the high demand and peak time-of-use energy charges during that season.

About half of the savings resulted from the lighting system measures. These measures are particularly important during the summer, when the heat generated at the lighting fixtures adds to the building cooling load. Although the office equipment loads were not changed in the simulations, their contributions can be very significant because of recent trends toward the increasing use of electrical equipment.

The remaining half of the savings resulted from the measures applied to the HVAC systems. The importance of reducing the HVAC air flow rates to the minimum required to add heat to or extract it from the conditioned spaces is reiterated. Simply replacing

the dual-duct system mixing boxes with the VAV control boxes was helpful, but also adding the fan motor variable frequency controls led to about a 9 to 10% savings. Including this feature in the HVAC systems being converted to VAV systems is now becoming common.

Most of the energy savings obtained by reactivating the air economizer were realized during the heating season. There was also a large reduction in the peak energy use during the summer since the economizer was partially open before its controls were reactivated. This emphasizes the importance of keeping the economizer dampers in good working condition.

Eliminating excess electric heating capacity in the building interior zones led to about a 1% savings. The savings are realized during the winter, and a large part of the cost savings is due to the reduction in the demand charges.

The analysis showed that shutting down the HVAC systems nights and weekends saves about 20% of the energy that would be consumed if the HVAC systems operated continuously. The calculated cost saving, using the 1989 rate schedule, is only about 1%, however. The reason for this is that the peak demand and peak time-of-use energy loads were calculated to be lower for the systems running continuously. These trends appear to be reasonable, although the magnitude of the cost savings can be questioned. There was difficulty in matching the model with the daily peak load data when the system was operating continuously. Although the predicted peak loads were lower than those when the systems were shut down nights and weekends, the short-term tests at the United Nations building showed that the daily peak loads were about the same for the continuous mode operation as for the time-schedule operation. The differences between the predicted and measured results were not resolved satisfactorily.

The effectiveness of using an EMCS to optimize the HVAC system startup and shutdown times appears to be small. To the extent that the DOE-2.1D program can simulate optimum startup and shutdown times, there was little energy use or cost reduction from using this method of control rather than manually starting and stopping the systems. It appears that the building operators had a good understanding of and

commitment to the HVAC systems operation. Thus, they were able to control the systems about as effectively as was the EMCS.

The preceding paragraph is not meant to imply that one should abandon the EMCS concept. It does imply that one must consider the benefits, initial cost, and maintenance cost of the EMCS, as well as the availability of suitable operators, before investing in the system. The EMCS shows promise as a monitoring and diagnostic tool. It can be used to signal and locate actual or incipient problems associated with the operation of building heating and cooling systems. There have been significant barriers to making many EMCSs user-friendly for this purpose, however (Claridge 1993). New low-cost electronics and microprocessors will help to produce more sophisticated and reliable systems at lower costs in the future. But the results obtained in this study reinforce earlier findings (Gettings 1988) that simple EMCSs can often provide most of the energy savings benefits, and that many EMCSs should have simpler designs.

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APPENDIX A

UTILITY ELECTRICITY RATE SCHEDULES

Electricity required for the operation of the United Unions building is purchased from the Potomac Electric Power Company (PEPCO). The rate schedule, used for billing, includes both demand and time-of-day charges. Moreover, the rates are different for the summer and winter months.

Both the 1989 and the 1992 PEPCO rate schedules are presented below. The data for the 1989 schedule were obtained from the building's billing statements and data published by White, Cumbow, and Sumner (1990). The 1992 data were obtained directly from PEPCO (1992).

Table A1. 1989 and 1992 PEPCO electricity rate schedules for the United Unions building				
	1989		1992	
	Nov-May	Jun-Oct	Nov-May	Jun-Oct
<u>Energy, \$/kWh^a</u>				
On-peak	0.03558	0.05126	0.04169	0.05582
Int-peak	0.03095	0.04310	0.03990	0.04067
Off-peak	0.02244	0.02243	0.03032	0.02822
<u>Fuel adjustment, \$/kWh</u>	- 0.0004102	0.0013413	b	b
<u>Demand, \$/kW^c</u>				
Base	8.20	8.20	6.50	6.50
On-peak	-	6.00	-	10.40
<u>Sales tax, %</u>	6.0	6.0	6.0	6.0
^a On-peak hours: 12 noon - 8:00 pm, Mon-Fri. Int-peak hours: 8:00 am - 12:00 noon, 8:00 pm - 12:00 midnight. Off-peak hours: All remaining hours, including holidays. ^b Data unavailable. Assumed equal to the 1989 values for analysis. ^c Based on 30-min time interval.				

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APPENDIX B

**AMBIENT AIR TEMPERATURES AT UNITED UNIONS BUILDING FOR
SEPTEMBER 13, 1992 THROUGH SEPTEMBER 26, 1992**

Fig. B.1 presents the ambient air temperatures measured at the United Unions building during the 2 week period of September 13, 1992 through September 26, 1992. These are the 2 weeks for which the recorded hourly energy consumption data were used in adjusting the DOE-2.1D input data parameters (Sect. 4.3). The HVAC systems were run continuously during the week of September 13 through September 19. They were operating with the EMCS optimized startup/shutdown control during the following week.

Fig. B.1. Ambient air temperatures measured at the United Unions building for the period of September 13 through September 26, 1992.

APPENDIX C

DOE-2.1D INPUT FILE LISTINGS

C.1. INPUT FILE FOR PRE-RETROFIT CONFIGURATION

INPUT LOADS ..

TITLE LINE-1 *UNITED UNIONS BUILDING*
 LINE-2 *WASHINGTON D.C.* ..

DIAGNOSTIC=CAUTIONS ..
 ABORT=ERRORS ..

LOADS-REPORT S=(LS-D,LS-F) ..

RUN-PERIOD JAN 1 1987 THRU DEC 31 1987 ..
 BUILDING-LOCATION LATITUDE=38.85 LONGITUDE=77.03
 TIME-ZONE=5 ALTITUDE=14 AZ=0 ..

\$ BUILDING DESCRIPTION \$

\$ STRUCTURE STEEL FRAME WITH CARPETED. CONCRETE FLOORS AND ROOF.
 \$ 8 OCCUPIED STORIES. 10'-6" FLOOR TO FLOOR HEIGHT.
 \$ 9 FT CEILING. RETURN AIR CEILING PLENUMS ARE NOT DEFINED.
 \$ INPUT USES THE SIMPLE APPROACH OF <RETURN-AIR-PATH=DUCT>.

\$ CURTAIN WALL 4 IN THICK PRECAST CONCRETE OF 7' BY 10'-6" IN DIMENSION.
 \$ CONSTRUCTION=CC33. U-VALUE OF 0.282 BTU/HR.SQFT.F

\$ ROOF CONSTRUCTION=(RG01,BR01,IN74,AS01,AL33,GP02)
 \$ U-VALUE OF 0.125 BTU/HR.SQFT.F

\$ WINDOWS 1/4" DOUBLE PANES WITH REFLECTIVE COATING ON INSIDE.
 \$ GLASS-TYPE=9. U-VALUE OF 0.370 BTU/SQFT.F.
 \$ 25% REFLECTANCE. SHADING COEFFICIENT OF 0.4.

\$ INTERIORS CEILINGS ARE SUSPENDED ACOUSTIC TILE.
 \$ PARTITIONS ARE FRAME WALLS WITH GYPSUM BOARD ON EACH SIDE.

\$ SPACE LOADS LIGHTING 3.0 W/SQFT.
 \$ OFFICE EQUIPMENT 0.8 W/SQFT.

\$ HVAC DESCRIPTIONS ARE TO BE FOUND WITH EACH INDIVIDUAL SYSTEM AND PLANT INPUT.

NEIGHBOR=BUILDING-SHADE

HEIGHT=73.5 WIDTH=105.0 TRANSMITTANCE=0.0
 X=195.0 Y=0.0 Z=0.0 AZIMUTH=90.0 TILT=90.0 ..

\$ SCHEDULES \$

OC1=D-SCH (1,5) (.025) (6,7) (.05,.1) (8) (.5) (9,11) (.95) (12) (.9)
 (13) (.8) (14,17) (.95) (18) (.75) (19,20) (.5) (21,22) (.1)
 (23,24) (.025) ..

OC2=D-SCH (1,6) (.025) (7,8) (.1,.3) (9,15) (.3) (16)(1) (17) (.05)
 (18,24) (.025) ..

OC3=D-SCH (1,24) (.025) ..

PEOPLE=W-SCH (WD) OC1 (SAT) OC2 (SUN,HOL) OC3 ..

OCCUP=SCHEDULE THRU DEC 31 PEOPLE ..

LG1=D-SCH (1,7) (.49) (8,20) (.65,.75,.95,1,1,.
 .95,1,.,95,.95,.9,.8,.8,.7) (21,24) (.49) ..

LG2=D-SCH (1,6) (.49) (7) (.5) (8,14) (.55) (15,24) (.49) ..

LG3=D-SCH (1,24) (.49) ..

WLTG=W-SCH (WD) LG1 (SAT) LG2 (SUN,HOL) LG3 ..

LIGHTS=SCHEDULE THRU DEC 31 WLTG ..

C-2

WEQPT=W-SCH (WD) LG1 (SAT) LG2 (SUN,HOL) LG3 ..
EQUIP=SCHEDULE THRU DEC 31 WEQPT ..

INF11=D-SCH (1,5) (.25) (6,20) (.05) (21,24) (.25) ..
INF12=D-SCH (1,8) (.25) (7,20) (.05) (21,24) (.25) ..
INF13=D-SCH (1,8) (.25) (9,20) (.05) (21,24) (.25) ..
INF14=D-SCH (1,8) (.25) (9,14) (.05) (15,24) (.25) ..
INF15=D-SCH (1,24) (.25) ..
INF21=D-SCH (1,4) (.5) (5,21) (.35) (22,24) (.5) ..
INF22=D-SCH (1,5) (.5) (6,21) (.35) (22,24) (.5) ..
INF23=D-SCH (1,6) (.5) (7,21) (.35) (22,24) (.5) ..
INF24=D-SCH (1,6) (.5) (7,14) (.35) (15,24) (.5) ..
INF25=D-SCH (1,24) (.5) ..
INF31=D-SCH (1,4) (.9) (5,21) (.65) (22,24) (.9) ..
INF32=D-SCH (1,5) (.9) (6,21) (.65) (22,24) (.9) ..
INF33=D-SCH (1,6) (.9) (7,21) (.65) (22,24) (.9) ..
INF34=D-SCH (1,6) (.9) (7,14) (.65) (15,24) (.9) ..
INF35=D-SCH (1,24) (.9) ..
INF41=D-SCH (1,4) (1) (5,21) (.75) (22,24) (1) ..
INF42=D-SCH (1,5) (1) (6,21) (.75) (22,24) (1) ..
INF43=D-SCH (1,6) (1) (7,21) (.75) (22,24) (1) ..
INF44=D-SCH (1,6) (1) (7,14) (.75) (15,24) (1) ..
INF45=D-SCH (1,24) (1) ..

WIFL1=W-SCH (MON) INF11 (TUE) INF12 (WED,FRI) INF13
(SAT) INF14 (SUN,HOL) INF15 ..
WIFL2=W-SCH (MON) INF21 (TUE) INF22 (WED,FRI) INF23
(SAT) INF24 (SUN,HOL) INF25 ..
WIFL3=W-SCH (MON) INF31 (TUE) INF32 (WED,FRI) INF33
(SAT) INF34 (SUN,HOL) INF35 ..
WIFL4=W-SCH (MON) INF41 (TUE) INF42 (WED,FRI) INF43
(SAT) INF44 (SUN,HOL) INF45 ..
INFIL=SCHEDULE THRU FEB 28 WIFL4
THRU APR 30 WIFL3
THRU SEP 30 WIFL1
THRU NOV 30 WIFL2
THRU DEC 31 WIFL4 ..

DH1=D-SCH (1,7) (.025) (8,24) (.15,.3,.35,.35,.55,.55,.5,.3,.3,.4,
.2,.2,.1,.15,.05,.025,.025) ..
DH2=D-SCH (1,7) (.025) (8,15) (.1,.1,.2,.15,.15,.1)
(16,24) (.025) ..
DHWTR=W-SCH (WD) DH1 (SAT) DH2 (SUN,HOL) OC3 ..
DHW=SCHEDULE THRU DEC 31 DHWTR ..

EL1=D-SCH (1,5) (.025) (6,20) (.05,.35,.7,.55,.45,.35,.45,.5,.5,
.35,.45,.6,.35,.2,.1) (21,24) (.025) ..
EL2=D-SCH (1,5) (.025) (6,15) (.05,.25,.45,.15,.2,.2,.25,.2,.15,.35)
(16,24) (.025) ..
ELE=W-SCH (WD) EL1 (SAT) EL2 (SUN,HOL) OC3 ..
ELEV=SCHEDULE THRU DEC 31 ELE ..

\$ MATERIALS NOT IN DOE-2 LIBRARY \$

EARTH=MAT TH=2.50 COND=0.50 DENS=120 S-H=0.20 ..

\$ CONSTRUCTION \$

PA1=LAYERS MAT (GP01,AL21,GP01) ..
PA2=LAYERS MAT (CB26,GP04) ..
PA3=LAYERS MAT (GP01,IN03,GP01) ..
GW1=LAYERS MAT (EARTH,CC04,BP03) ..
AW1=LAYERS MAT (CC04) ..
EW1=LAYERS MAT (CC33,AL11,GP01) ..
TOF=LAYERS MAT (CP01,CC03) ..
GOF=LAYERS MAT (EARTH,CC03,CC01) ..
BOF=LAYERS MAT (CC03,CC01) ..
AOF=LAYERS MAT (CT11,AR01,CC04) ..
ROF=LAYERS MAT (RG01,BR01,IN74,AS01,AL33,GP02) ..

EWL=CONS LA=EW1 .. \$ EXTERIOR WALL
GWL=CONS LA=GW1 .. \$ GROUND WALL
AWL=CONS LA=AW1 .. \$ EXTERIOR WALL FOR UNCONDITIONED SPACE

C-3

PART = CONS LA = PA1 .. \$ INTERIOR PARTITION
 PART2 = CONS LA = PA2 .. \$ INTERIOR WALL TO MECHANICAL ROOM
 PART3 = CONS LA = PA3 .. \$ INTERIOR PARTITION TO UNCONDITIONED
 RF = CONS LA = ROF .. \$ ROOF
 FL = CONS LA = TOF .. \$ TYPICAL FLOOR
 BFL = CONS LA = BOF .. \$ BASEMENT FLOOR
 GFL = CONS LA = GOF .. \$ GROUND FLOOR
 AFL = CONS LA = AOF .. \$ EXTERIOR PAVEMENT ABOVE BASEMENT
 GLS = G-T P=2 G-T-C=7 G-C=0.42 .. \$ WINDOW GLAZING
 GLSD = G-T P=1 G-T-C=4 G-C=1.24 .. \$ ENTRANCE DOOR

SHADCO1 = SCH THRU DEC 31 (ALL) (1,24) (7) ..

\$ SPACE DESCRIPTION \$

OFFICE = SPACE-CONDITIONS

TEMPERATURE = (75) FLOOR-WEIGHT = 70
 LIGHTING-TYPE = REC-FLUOR-RV LIGHTING-SCHEDULE = LIGHTS
 LIGHTING-W/SQFT = 3.0 LIGHT-TO-SPACE = 1.0
 EQUIP-SCHEDULE = EQUIP EQUIPMENT-W/SQFT = 0.8
 PEOPLE-SCHEDULE = OCCUP PEOPLE-HEAT-GAIN = 450
 INF-SCHEDULE = INFIL INF-METHOD = AIR-CHANGE
 AIR-CHANGES/HR = 0.3 INF-CFM/SQFT = 0.2
 ZONE-TYPE = CONDITIONED ..

GARAGE = SPACE-CONDITIONS

TEMPERATURE = (75) FLOOR-WEIGHT = 140
 LIGHTING-TYPE = SUS-FLUOR LIGHTING-SCHEDULE = LIGHTS
 LIGHTING-W/SQFT = 1.0 LIGHT-TO-SPACE = 1.0
 ZONE-TYPE = UNCONDITIONED ..

PH1 = SPACE S-C = GARAGE V = 103194 A = 11466 N-O-P = 0 ..
 PW1 = E-W CONS = EWL H = 10.5 W = 126 AZ = 180 ..
 PW2 = E-W CONS = EWL H = 10.5 W = 91 AZ = 90 ..
 PW3 = E-W LIKE PW1 AZ = 0 ..
 PW4 = E-W LIKE PW2 AZ = 270 ..
 RF1 = ROOF W = 91 H = 126 CONS = RF TILT = 0 GND-REFLECTANCE = 0 ..
 PF1 = I-W A = 11466 CONS = FL TILT = 180 I-W-TYPE = ADIABATIC ..

RZ1 = SPACE S-C = OFFICE V = 103194 A = 11466 N-O-P = 27 ..
 IN1 = I-W A = 1134 CONS = PART N-T = RZ2 ..
 IN2 = I-W A = 819 CONS = PART N-T = RZ3 ..
 I-W LIKE IN1 N-T = RZ4 ..
 I-W LIKE IN2 N-T = RZ5 ..
 FL1 = I-W A = 11466 CONS = FL TILT = 180 I-W-TYPE = ADIABATIC ..

RZ2 = SPACE S-C = OFFICE V = 15876 A = 1764 N-O-P = 8 ..
 W11 = E-W CONS = EWL H = 10.5 W = 14 X = 28 Y = 14 Z = 84 AZ = 270 ..
 W12 = E-W CONS = EWL H = 10.5 W = 126 X = 28 Y = 0 Z = 84 AZ = 180 ..
 WN12 = WI G-T = GLS H = 6 W = 72 X = 27 Y = 3.5 S-SCH = SHADCO1 ..
 W13 = E-W CONS = EWL H = 10.5 W = 14 X = 154 Y = 0 Z = 84 AZ = 90 ..
 RF2 = ROOF LIKE RF1 W = 14 H = 126 ..
 FL2 = I-W LIKE FL1 A = 1764 ..

RZ3 = SPACE S-C = OFFICE V = 22932 A = 2548 N-O-P = 12 ..
 W14 = E-W CONS = EWL H = 10.5 W = 28 X = 154 Y = 14 Z = 84 AZ = 180 ..
 W15 = E-W CONS = EWL H = 10.5 W = 91 X = 182 Y = 14 Z = 84 AZ = 90 ..
 WN15 = WI G-T = GLS H = 6 W = 52 X = 19.5 Y = 3.5 S-SCH = SHADCO1 ..
 W16 = E-W CONS = EWL H = 10.5 W = 28 X = 182 Y = 105 Z = 84 AZ = 0 ..
 RF3 = ROOF LIKE RF1 W = 91 H = 28 ..
 FL3 = I-W LIKE FL1 A = 2548 ..

RZ4 = SPACE LIKE RZ2 ..
 W17 = E-W LIKE W13 X = 154 Y = 105 Z = 84 AZ = 90 ..
 W18 = E-W LIKE W12 X = 154 Y = 119 Z = 84 AZ = 0 ..
 WN18 = WI LIKE WN12 ..
 W19 = E-W LIKE W11 X = 28 Y = 119 Z = 84 AZ = 270 ..
 ROOF LIKE RF2 ..
 I-W LIKE FL2 ..

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RZ5=SPACE      LIKE RZ3 ..
W110=E-W      LIKE W16  X=28 Y=105 Z=84 AZ=0 ..
W111=E-W      LIKE W15  X=0  Y=105 Z=84 AZ=270 ..
WN111=WI      LIKE WN15 ..
W112=E-W      LIKE W14  X=0  Y=14  Z=84 AZ=180 ..
  ROOF LIKE RF3 ..
  I-W  LIKE FL3 ..

TZ1=SPACE      LIKE RZ1 F-M=5 ..
  I-W  LIKE IN1 N-T=TZ2 ..
  I-W  LIKE IN2 N-T=TZ3 ..
  I-W  LIKE IN1 N-T=TZ4 ..
  I-W  LIKE IN2 N-T=TZ5 ..

TZ2=SPACE      LIKE RZ2 F-M=5 ..
W21=E-W      LIKE W11  X=28 Y=14  Z=52.5 ..
W22=E-W      LIKE W12  X=28 Y=0   Z=52.5 ..
WN22=WI      LIKE WN12 ..
W23=E-W      LIKE W13  X=154 Y=0   Z=52.5 ..

TZ3=SPACE      LIKE RZ3 F-M=5 ..
W24=E-W      LIKE W14  X=154 Y=14  Z=52.5 ..
W25=E-W      LIKE W15  X=182 Y=14  Z=52.5 ..
WN25=WI      LIKE WN15 ..
W26=E-W      LIKE W16  X=182 Y=105 Z=52.5 ..

TZ4=SPACE      LIKE RZ4 F-M=5 ..
W27=E-W      LIKE W17  X=154 Y=105 Z=52.5 ..
W28=E-W      LIKE W18  X=154 Y=119 Z=52.5 ..
WN28=WI      LIKE WN18 ..
W29=E-W      LIKE W19  X=28  Y=119 Z=52.5 ..

TZ5=SPACE      LIKE RZ5 F-M=5 ..
W210=E-W     LIKE W110 X=28  Y=105 Z=52.5 ..
W211=E-W     LIKE W111 X=0   Y=105 Z=52.5 ..
WN211=WI     LIKE WN111 ..
W212=E-W     LIKE W112 X=0   Y=14  Z=52.5 ..

ST1=SPACE      LIKE TZ1 F-M=1 ..
  I-W  LIKE IN1 N-T=ST2 ..
  I-W  LIKE IN2 N-T=ST3 ..
  I-W  LIKE IN1 N-T=ST4 ..
  I-W  LIKE IN2 N-T=ST5 ..

ST2=SPACE      LIKE TZ2 F-M=1 ..
W31=E-W      LIKE W21  X=28  Y=14  Z=21 ..
W32=E-W      LIKE W22  X=28  Y=0   Z=21 ..
WN32=WI      LIKE WN22 ..
W33=E-W      LIKE W23  X=154 Y=0   Z=21 ..
AFL2=E-W     CONS=AFL H=126 W=14 TILT=180 ..

ST3=SPACE      LIKE TZ3 F-M=1 ..
W34=E-W      LIKE W24  X=154 Y=14  Z=21 ..
W35=E-W      LIKE W25  X=182 Y=14  Z=21 ..
WN35=WI      LIKE WN25 ..
W36=E-W      LIKE W26  X=182 Y=105 Z=21 ..
AFL3=E-W     CONS=AFL H=28  W=91 TILT=180 ..

ST4=SPACE      LIKE TZ4 F-M=1 ..
W37=E-W      LIKE W27  X=154 Y=105 Z=21 ..
W38=E-W      LIKE W28  X=154 Y=119 Z=21 ..
WN38=WI      LIKE WN28 ..
W39=E-W      LIKE W29  X=28  Y=119 Z=21 ..
AFL4=E-W     CONS=AFL H=126 W=14 TILT=180 ..

ST5=SPACE      LIKE TZ5 F-M=1 ..
W310=E-W     LIKE W210 X=28  Y=105 Z=21 ..
W311=E-W     LIKE W211 X=0   Y=105 Z=21 ..
WN311=WI     LIKE WN211 ..
W312=E-W     LIKE W212 X=0   Y=14  Z=21 ..
AFL5=E-W     CONS=AFL H=28  W=91 TILT=180 ..

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FT1=SPACE S-C=OFFICE V=26460 A=2940 N-O-P=7 ..
 IN3=I-W A=756 CONS=PART N-T=FT2 ..
 IN4=I-W A=315 CONS=PART N-T=FT3 ..
 I-W LIKE IN3 N-T=FT4 ..
 I-W LIKE IN4 N-T=FT5 ..

FT2=SPACE S-C=OFFICE V=26460 A=2940 N-O-P=14 L-W=1.0 ..
 I-W LIKE IN4 N-T=FT5 ..
 I-W LIKE IN4 N-T=FT3 ..
 W42=E-W LIKE W32 X=28 Y=14 Z=10.5 ..
 WN42=WI G-T=GLS H=7 W=90 X=18 Y=2.5 ..

FT3=SPACE S-C=OFFICE V=11907 A=1323 N-O-P=7 ..
 I-W LIKE IN4 N-T=FT4 ..
 W45=E-W LIKE W35 X=154 Y=14 Z=10.5 ..
 WN45=WI G-T=GLS H=7 W=65 X=13 Y=2.5 ..

FT4=SPACE LIKE FT2 ..
 I-W LIKE IN4 N-T=FT5 ..
 W48=E-W LIKE W38 X=154 Y=105 Z=10.5 ..
 WN48=WI LIKE WN42 ..
 WD48=WI G-T=GLSD H=8 W=30 X=48 Y=0 ..

FT5=SPACE LIKE FT3 ..
 W411=E-W LIKE W311 X=28 Y=105 Z=10.5 ..
 WN411=WI LIKE WN45 ..

GF1=SPACE S-C=OFFICE V=71442 A=7938 N-O-P=18 ..
 I-W LIKE IN2 A=567 N-T=GF3 ..
 ING3=I-W A=1134 CONS=PART2 N-T=GF4 ..
 ING4=I-W A=567 CONS=PART3 N-T=GF5 ..
 I-W LIKE FL1 A=7938 I-W-TYPE=ADIABATIC ..
 BFL1=I-W A=7938 CONS=BFL TILT=180 N-T=BT1 ..

GF2=SPACE S-C=OFFICE V=47628 A=5292 N-O-P=10 ..
 I-W LIKE ING4 A=378 N-T=GF5 ..
 W52=E-W LIKE W42 X=28 Y=0 Z=0 ..
 WN52=WI LIKE WN42 H=7 W=60 X=33 Y=2.5 ..
 WD52=WI G-T=GLSD H=8 W=30 X=48 Y=0 ..
 W53=E-W CONS=EWL H=10.5 W=42 X=154 Y=0 Z=0 AZ=90 ..
 I-W LIKE FL1 A=5292 I-W-TYPE=ADIABATIC ..
 I-W LIKE BFL1 A=5292 N-T=BT1 ..

GF3=SPACE S-C=OFFICE V=15876 A=1764 N-O-P=4 ..
 W54=E-W CONS=EWL H=10.5 W=28 X=154 Y=42 Z=0 AZ=180 ..
 W55=E-W LIKE W45 H=10.5 W=63 X=182 Y=42 Z=0 ..
 WN55=WI LIKE WN45 H=7 W=45 X=9 Y=2.5 ..
 I-W LIKE ING3 A=252 N-T=GF4 ..
 I-W LIKE FL1 A=1764 I-W-TYPE=ADIABATIC ..
 I-W LIKE BFL1 A=1764 N-T=BT1 ..

GF4=SPACE S-C=GARAGE V=48510 A=5390 N-O-P=0 ..
 GWL1=U-W CONS=GWL W=75.4 H=10.5 ..
 U-W LIKE GWL1 W=144 H=9 ..
 AFL1=E-W CONS=AWL W=73.5 H=73.5 TILT=0
 GND-REFLECTANCE=.22 X=28 Y=105 Z=10.5 ..
 I-W LIKE BFL1 A=5390 N-T=BT4 ..

GF5=SPACE S-C=GARAGE V=67365 A=7485 N-O-P=0 ..
 U-W LIKE GWL1 W=100 H=10.5 ..
 U-W LIKE GWL1 W=60 H=10.5 ..
 AWL1=E-W CONS=AWL W=90 H=10.5 AZ=180 ..
 E-W LIKE AFL1 W=86.5 H=86.5 X=-62 Y=0 Z=10.5 ..
 I-W LIKE BFL1 A=7485 N-T=BT1 ..

BT1=SPACE S-C=GARAGE V=212895 A=23655 N-O-P=0 F-M=2 ..
 U-W LIKE GWL1 W=509 H=10.5 ..
 I-W LIKE ING3 A=1386 N-T=BT4 ..
 I-W LIKE BFL1 A=23655 N-T=BG1 ..

BT4=SPACE S-C=GARAGE V=48510 A=5390 N-O-P=0 F-M=2 ..
 U-W LIKE GWL1 W=219.4 H=10.5 ..

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I-W LIKE BFL1 A=5390 N-T=BG4 ..

BG1=SPACE      S-C=GARAGE V=212895 A=23655 N-O-P=0 ..
  U-W LIKE GWL1 W=509 H=10.5 ..
  I-W LIKE ING3 A=1386 N-T=BG4 ..
  GFL1=U-F CONS=GFL W=154 H=154 TILT=180 ..

BG4=SPACE      S-C=GARAGE V=48510 A=5390 N-O-P=0 ..
  U-W LIKE GWL1 W=219.4 H=10.5 ..
  U-F LIKE GFL1 W=73.5 H=73.5 ..

BUILDING-RESOURCE VERT-TRANS-KW=50 VERT-TRANS-SCH=ELEV
HOT-WATER=40000 HW-SCHEDULE=DHW ..

END ..
COMPUTE LOADS ..

INPUT SYSTEMS ..

TITLE          LINE-3 *CONSTANT VOLUME DUAL DUCT SYSTEM* ..

SYSTEMS-REPORT V=(SV-A) S=(SS-A) ..

      $ HVAC SYSTEM DESCRIPTION $

$ DESIGN TEMP   HEATING: 72 F. COOLING: 76 F.
$ SYSTEM TYPE   CONSTANT VOLUME DUAL-DUCT SYSTEM.
$               FOUR-50 HP MAIN AIR SUPPLY FANS.
$               EIGHT-30 HP RETURN FANS.

$ FAN SCHEDULE  VENTILATION BETWEEN 06:45 - 19:30.

      $ SCHEDULE $

HRS1=D-SCH      (1,3) (0) (4,20) (1) (21,24) (0) ..
HRS2=D-SCH      (1,5) (0) (6,20) (1) (21,24) (0) ..
HRS3=D-SCH      (1,5) (0) (6,14) (1) (15,24) (0) ..
HRS4=D-SCH      (1,24) (0) ..
WFAN=W-SCH      (MON) HRS1 (TUE,FRI) HRS2 (SAT) HRS3 (SUN,HOL) HRS4 ..
FSCH=SCHEDULE   THRU DEC 31 WFAN ..      $ FAN $

HRHS1=D-SCH     (1,3) (55) (4,20) (72) (21,24) (55) ..
HRHS2=D-SCH     (1,5) (55) (6,20) (72) (21,24) (55) ..
HRHS3=D-SCH     (1,5) (55) (6,14) (72) (15,24) (55) ..
HRHS4=D-SCH     (1,24) (55) ..
DAYHT=W-SCH     (MON) HRHS1 (TUE,FRI) HRHS2 (SAT) HRHS3 (SUN,HOL) HRHS4 ..
THHT=SCHEDULE   THRU DEC 31 DAYHT ..      $ HEAT-TEMPERATURE $

HRCS1=D-SCH     (1,3) (99) (4,20) (76) (21,24) (99) ..
HRCS2=D-SCH     (1,5) (99) (6,20) (76) (21,24) (99) ..
HRCS3=D-SCH     (1,5) (99) (6,14) (76) (15,24) (99) ..
HRCS4=D-SCH     (1,24) (99) ..
DAYCL=W-SCH     (MON) HRCS1 (TUE,FRI) HRCS2 (SAT) HRCS3 (SUN,HOL) HRCS4 ..
THCL=SCHEDULE   THRU DEC 31 DAYCL ..      $ COOL-TEMPERATURE $

      $ ZONE SUB-COMMANDS $

CONTRL=Z-C      D-H-T=72 H-T-SCH=THHT D-C-T=76 C-T-SCH=THCL
THROTTLING-RANGE=4 ..

      $ ZONE DESCRIPTION $

PH1=ZONE Z-TYPE=UNCONDITIONED ..
RZ1=ZONE Z-TYPE=CONDITIONED A-CFM=12039 Z-C=CONTRL S-O=ADJUST-LOADS ..
RZ2=ZONE Z-TYPE=CONDITIONED A-CFM=2646 Z-C=CONTRL S-O=ADJUST-LOADS ..
RZ3=ZONE Z-TYPE=CONDITIONED A-CFM=3822 Z-C=CONTRL S-O=ADJUST-LOADS ..
RZ4=ZONE Z-TYPE=CONDITIONED A-CFM=2646 Z-C=CONTRL S-O=ADJUST-LOADS ..
RZ5=ZONE Z-TYPE=CONDITIONED A-CFM=3822 Z-C=CONTRL S-O=ADJUST-LOADS ..
TZ1=ZONE Z-TYPE=CONDITIONED A-CFM=12039 Z-C=CONTRL S-O=ADJUST-LOADS ..
TZ2=ZONE Z-TYPE=CONDITIONED A-CFM=2646 Z-C=CONTRL S-O=ADJUST-LOADS ..
TZ3=ZONE Z-TYPE=CONDITIONED A-CFM=3822 Z-C=CONTRL S-O=ADJUST-LOADS ..
TZ4=ZONE Z-TYPE=CONDITIONED A-CFM=2646 Z-C=CONTRL S-O=ADJUST-LOADS ..

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TZ5=ZONE Z-TYPE=CONDITIONED A-CFM=3822 Z-C=CONTRL S-O=ADJUST-LOADS ..
 ST1=ZONE Z-TYPE=CONDITIONED A-CFM=12039 Z-C=CONTRL S-O=ADJUST-LOADS ..
 ST2=ZONE Z-TYPE=CONDITIONED A-CFM=2646 Z-C=CONTRL S-O=ADJUST-LOADS ..
 ST3=ZONE Z-TYPE=CONDITIONED A-CFM=3822 Z-C=CONTRL S-O=ADJUST-LOADS ..
 ST4=ZONE Z-TYPE=CONDITIONED A-CFM=2646 Z-C=CONTRL S-O=ADJUST-LOADS ..
 ST5=ZONE Z-TYPE=CONDITIONED A-CFM=3822 Z-C=CONTRL S-O=ADJUST-LOADS ..
 FT1=ZONE Z-TYPE=CONDITIONED A-CFM=3087 Z-C=CONTRL S-O=ADJUST-LOADS ..
 FT2=ZONE Z-TYPE=CONDITIONED A-CFM=4410 Z-C=CONTRL S-O=ADJUST-LOADS ..
 FT3=ZONE Z-TYPE=CONDITIONED A-CFM=1985 Z-C=CONTRL S-O=ADJUST-LOADS ..
 FT4=ZONE Z-TYPE=CONDITIONED A-CFM=4410 Z-C=CONTRL S-O=ADJUST-LOADS ..
 FT5=ZONE Z-TYPE=CONDITIONED A-CFM=1985 Z-C=CONTRL S-O=ADJUST-LOADS ..
 GF1=ZONE Z-TYPE=CONDITIONED A-CFM=8335 Z-C=CONTRL S-O=ADJUST-LOADS ..
 GF2=ZONE Z-TYPE=CONDITIONED A-CFM=7938 Z-C=CONTRL S-O=ADJUST-LOADS ..
 GF3=ZONE Z-TYPE=CONDITIONED A-CFM=2646 Z-C=CONTRL S-O=ADJUST-LOADS ..
 GF4=ZONE Z-TYPE=UNCONDITIONED ..
 GF5=ZONE Z-TYPE=UNCONDITIONED ..
 BT1=ZONE Z-TYPE=UNCONDITIONED ..
 BT4=ZONE Z-TYPE=UNCONDITIONED ..
 BG1=ZONE Z-TYPE=UNCONDITIONED ..
 BG4=ZONE Z-TYPE=UNCONDITIONED ..

\$ SYSTEM SUB-COMMANDS \$

S-CTRL=S-C MAX-S-T=115 MIN-S-T=55 C-C=WARMEST H-C=COLDEST ..

S-AIR=S-A MIN-OUTSIDE-AIR=0.2 OA-CONTROL=FIXED ..

S-FAN=S-FANS F-SCH=FSCH F-C=CONSTANT-VOLUME N-C-C=CYCLE-ON-FIRST
 SUPPLY-STATIC=3.4 SUPPLY-EFF=0.55
 RETURN-STATIC=4.1 RETURN-EFF=0.55 ..

\$ SYSTEMS DESCRIPTION \$

SYS1=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-887372
 R-A-P=DUCT ZONE-NAMES=(PH1,RZ1,TZ1,ST1,FT1,GF1,BT1,BG1) ..

SYS2=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-323720
 R-A-P=DUCT ZONE-NAMES=(RZ2,TZ2,ST2,FT2,GF2) ..

SYS3=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-329096
 R-A-P=DUCT ZONE-NAMES=(RZ3,TZ3,ST3,FT3,GF3) ..

SYS4=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-240401
 R-A-P=DUCT ZONE-NAMES=(RZ4,TZ4,ST4,FT4,GF4,BT4,BG4) ..

SYS5=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-301323
 R-A-P=DUCT ZONE-NAMES=(RZ5,TZ5,ST5,FT5,GF5) ..

END ..
 COMPUTE SYSTEMS ..

INPUT PLANT ..

PLANT-REPORT S=(PS-A,PS-B,PS-C) R-F=DAILY ..

CHL=P-E TYPE=HERM-CENT-CHLR SIZE=4.44 I-N=2 ..
 CTW=P-E TYPE=COOLING-TWR SIZE=2.80 I-N=4 ..
 WHR=P-E TYPE=ELEC-DHW-HEATER SIZE=-999 ..

RPTSCH=SCH THRU DEC 31 (ALL) (1,24) (1) ..
 OUT-1=R-B V-T=PLANT V-L=(10) ..
 HR-RPT=H-R R-SCH=RPTSCH R-B=(OUT-1) ..

END ..
 COMPUTE PLANT ..

STOP ..

C.2. INPUT FILE FOR POST-RETROFIT CONFIGURATION

INPUT LOADS ..

TITLE LINE-1 *UNITED UNIONS BUILDING*
 LINE-2 *WASHINGTON D.C.* ..

DIAGNOSTIC=CAUTIONS ..

ABORT=ERRORS ..

LOADS-REPORT S=(LS-D,LS-F) ..

RUN-PERIOD JAN 1 1989 THRU DEC 31 1989 ..
 BUILDING-LOCATION LATITUDE=38.85 LONGITUDE=77.03
 TIME-ZONE=5 ALTITUDE=14 AZ=0 ..

\$ BUILDING DESCRIPTION \$

\$ STRUCTURE STEEL FRAME WITH CARPETED. CONCRETE FLOORS AND ROOF.
 \$ 8 OCCUPIED STORIES. 10'-6" FLOOR TO FLOOR HEIGHT.
 \$ 9 FT CEILING. RETURN AIR CEILING PLENUMS ARE NOT DEFINED.
 \$ INPUT USES THE SIMPLE APPROACH OF <RETURN-AIR-PATH=DUCT>.

\$ CURTAIN WALL 4 IN THICK PRECAST CONCRETE OF 7' BY 10'-6" IN DIMENSION.
 \$ CONSTRUCTION=CC33. U-VALUE OF 0.282 BTU/HR.SQFT.F

\$ ROOF CONSTRUCTION=(RG01,BR01,IN74,AS01,AL33,GP02)
 \$ U-VALUE OF 0.125 BTU/HR.SQFT.F

\$ WINDOWS 1/4" DOUBLE PANES WITH REFLECTIVE COATING ON INSIDE.
 \$ GLASS-TYPE=9. U-VALUE OF 0.370 BTU/SQFT.F.
 \$ 25% REFLECTANCE. SHADING COEFFICIENT OF 0.4.

\$ INTERIORS CEILINGS ARE SUSPENDED ACOUSTIC TILE.
 \$ PARTITIONS ARE FRAME WALLS WITH GYPSUM BOARD ON EACH SIDE.

\$ SPACE LOADS LIGHTING 744 PL-SERIES FLUORESCENT AT 1.6 W/SQFT.
 \$ OFFICE EQUIPMENT 0.8 W/SQFT.

\$ HVAC DESCRIPTIONS ARE TO BE FOUND WITH EACH INDIVIDUAL SYSTEM AND PLANT INPUT.

NEIGHBOR=BUILDING-SHADE
 HEIGHT=73.5 WIDTH=105.0 TRANSMITTANCE=0.0
 X=195.0 Y=0.0 Z=0.0 AZIMUTH=90.0 TILT=90.0 ..

\$ SCHEDULES \$

OC1=D-SCH (1,5) (.025) (6,7) (.05,.1) (8) (.5) (9,11) (.95) (12) (.9)
 (13) (.8) (14,17) (.95) (18) (.75) (19,20) (.5) (21,22) (.1)
 (23,24) (.025) ..

OC2=D-SCH (1,6) (.025) (7,8) (.1,.3) (9,15) (.3) (16)(.1) (17) (.05)
 (18,24) (.025) ..

OC3=D-SCH (1,24) (.025) ..

PEOPLE=W-SCH (WD) OC1 (SAT) OC2 (SUN,HOL) OC3 ..

OCCUP=SCHEDULE THRU DEC 31 PEOPLE ..

LG1=D-SCH (1,7) (.49) (8,20) (.65,.75,.95,1,1..
 .95,1,..95,.95,.9,.8,.8,.7) (21,24) (.49) ..

LG2=D-SCH (1,6) (.49) (7) (.5) (8,14) (.55) (15,24) (.49) ..

LG3=D-SCH (1,24) (.49) ..

WLTG=W-SCH (WD) LG1 (SAT) LG2 (SUN,HOL) LG3 ..

LIGHTS=SCHEDULE THRU DEC 31 WLTG ..

WEQPT=W-SCH (WD) LG1 (SAT) LG2 (SUN,HOL) LG3 ..

EQUIP=SCHEDULE THRU DEC 31 WEQPT ..

INF11=D-SCH (1,5) (.25) (6,20) (.05) (21,24) (.25) ..

INF12=D-SCH (1,6) (.25) (7,20) (.05) (21,24) (.25) ..

INF13=D-SCH (1,8) (.25) (9,20) (.05) (21,24) (.25) ..

INF14=D-SCH (1,8) (.25) (9,14) (.05) (15,24) (.25) ..

INF15=D-SCH (1,24) (.25) ..

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INF21 = D-SCH      (1,4) (.5) (5,21) (.35) (22,24) (.5) ..
INF22 = D-SCH      (1,5) (.5) (6,21) (.35) (22,24) (.5) ..
INF23 = D-SCH      (1,6) (.5) (7,21) (.35) (22,24) (.5) ..
INF24 = D-SCH      (1,6) (.5) (7,14) (.35) (15,24) (.5) ..
INF25 = D-SCH      (1,24) (.5) ..
INF31 = D-SCH      (1,4) (.9) (5,21) (.65) (22,24) (.9) ..
INF32 = D-SCH      (1,5) (.9) (6,21) (.65) (22,24) (.9) ..
INF33 = D-SCH      (1,6) (.9) (7,21) (.65) (22,24) (.9) ..
INF34 = D-SCH      (1,6) (.9) (7,14) (.65) (15,24) (.9) ..
INF35 = D-SCH      (1,24) (.9) ..
INF41 = D-SCH      (1,4) (1) (5,21) (.75) (22,24) (1) ..
INF42 = D-SCH      (1,5) (1) (6,21) (.75) (22,24) (1) ..
INF43 = D-SCH      (1,6) (1) (7,21) (.75) (22,24) (1) ..
INF44 = D-SCH      (1,6) (1) (7,14) (.75) (15,24) (1) ..
INF45 = D-SCH      (1,24) (1) ..
WIFL1 = W-SCH      (MON) INF11 (TUE) INF12 (WED,FRI) INF13
                   (SAT) INF14 (SUN,HOL) INF15 ..
WIFL2 = W-SCH      (MON) INF21 (TUE) INF22 (WED,FRI) INF23
                   (SAT) INF24 (SUN,HOL) INF25 ..
WIFL3 = W-SCH      (MON) INF31 (TUE) INF32 (WED,FRI) INF33
                   (SAT) INF34 (SUN,HOL) INF35 ..
WIFL4 = W-SCH      (MON) INF41 (TUE) INF42 (WED,FRI) INF43
                   (SAT) INF44 (SUN,HOL) INF45 ..
INFIL = SCHEDULE   THRU APR 30 WIFL3
                   THRU SEP 30 WIFL1
                   THRU NOV 30 WIFL2
                   THRU DEC 31 WIFL4 ..

DH1 = D-SCH        (1,7) (.025) (8,24) (.15,.3,.35,.35,.55,.55,.5,.3,.3,.4,
                   .2,.2,.1,.15,.05,.025,.025) ..
DH2 = D-SCH        (1,7) (.025) (8,15) (.1,.1,.2,.15,.2,.15,.15,.1)
                   (16,24) (.025) ..
DHWTR = W-SCH      (WD) DH1 (SAT) DH2 (SUN,HOL) OC3 ..
DHW = SCHEDULE     THRU DEC 31 DHWTR ..

EL1 = D-SCH        (1,5) (.025) (6,20) (.05,.35,.7,.55,.45,.35,.45,.5,.5,
                   .35,.45,.6,.35,.2,.1) (21,24) (.025) ..
EL2 = D-SCH        (1,5) (.025) (6,15) (.05,.25,.45,.15,.2,.2,.25,.2,.15,.35)
                   (16,24) (.025) ..
ELE = W-SCH        (WD) EL1 (SAT) EL2 (SUN,HOL) OC3 ..
ELEV = SCHEDULE     THRU DEC 31 ELE ..

$ MATERIALS NOT IN DOE-2 LIBRARY $

EARTH = MAT        TH = 2.50 COND = 0.50 DENS = 120 S-H = 0.20 ..

$ CONSTRUCTION $

PA1 = LAYERS       MAT (GP01,AL21,GP01) ..
PA2 = LAYERS       MAT (CB26,GP04) ..
PA3 = LAYERS       MAT (GP01,IN03,GP01) ..
GW1 = LAYERS       MAT (EARTH,CC04,BP03) ..
AW1 = LAYERS       MAT (CC04) ..
EW1 = LAYERS       MAT (CC33,AL11,GP01) ..
TOF = LAYERS       MAT (CP01,CC03) ..
GOF = LAYERS       MAT (EARTH,CC03,CC01) ..
BOF = LAYERS       MAT (CC03,CC01) ..
AOF = LAYERS       MAT (CT11,AR01,CC04) ..
ROF = LAYERS       MAT (RG01,BR01,IN74,AS01,AL33,GP02) ..

EWL = CONS         LA = EW1 .. $ EXTERIOR WALL
GWL = CONS         LA = GW1 .. $ GROUND WALL
AWL = CONS         LA = AW1 .. $ EXTERIOR WALL FOR UNCONDITIONED SPACE
PART = CONS        LA = PA1 .. $ INTERIOR PARTITION
PART2 = CONS       LA = PA2 .. $ INTERIOR WALL TO MECHANICAL ROOM
PART3 = CONS       LA = PA3 .. $ INTERIOR PARTITION TO UNCONDITIONED
RF = CONS          LA = ROF .. $ ROOF
FL = CONS          LA = TOF .. $ TYPICAL FLOOR
BFL = CONS         LA = BOF .. $ BASEMENT FLOOR
GFL = CONS         LA = GOF .. $ GROUND FLOOR
AFL = CONS         LA = AOF .. $ EXTERIOR PAVEMENT ABOVE BASEMENT
GLS = G-T          P = 2 G-T-C = 7 G-C = 0.42 .. $ WINDOW GLAZING

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GLSD=G-T P=1 G-T-C=4 G-C=1.24 .. \$ ENTRANCE DOOR

SHADCO1=SCH THRU DEC 31 (ALL) (1,24) (.7) ..

\$ SPACE DESCRIPTION \$

OFFICE = SPACE-CONDITIONS

TEMPERATURE = (75) FLOOR-WEIGHT = 70
 LIGHTING-TYPE = REC-FLUOR-RV LIGHTING-SCHEDULE = LIGHTS
 LIGHTING-W/SQFT = 1.6 LIGHT-TO-SPACE = 1.0
 EQUIP-SCHEDULE = EQUIP EQUIPMENT-W/SQFT = 0.8
 PEOPLE-SCHEDULE = OCCUP PEOPLE-HEAT-GAIN = 450
 INF-SCHEDULE = INFIL INF-METHOD = AIR-CHANGE
 AIR-CHANGES/HR = 0.3 INF-CFM/SQFT = 0.2
 ZONE-TYPE = CONDITIONED ..

GARAGE = SPACE-CONDITIONS

TEMPERATURE = (75) FLOOR-WEIGHT = 140
 LIGHTING-TYPE = SUS-FLUOR LIGHTING-SCHEDULE = LIGHTS
 LIGHTING-W/SQFT = 1.0 LIGHT-TO-SPACE = 1.0
 ZONE-TYPE = UNCONDITIONED ..

PH1=SPACE S-C=GARAGE V=103194 A=11466 N-O-P=0 ..
 PW1=E-W CONS=EWL H=10.5 W=126 AZ=180 ..
 PW2=E-W CONS=EWL H=10.5 W=91 AZ=90 ..
 PW3=E-W LIKE PW1 AZ=0 ..
 PW4=E-W LIKE PW2 AZ=270 ..
 RF1=ROOF W=91 H=126 CONS=RF TILT=0 GND-REFLECTANCE=0 ..
 PF1=I-W A=11466 CONS=FL TILT=180 I-W-TYPE=ADIABATIC ..

RZ1=SPACE S-C=OFFICE V=103194 A=11466 N-O-P=27 ..
 IN1=I-W A=1134 CONS=PART N-T=RZ2 ..
 IN2=I-W A=819 CONS=PART N-T=RZ3 ..
 I-W LIKE IN1 N-T=RZ4 ..
 I-W LIKE IN2 N-T=RZ5 ..
 FL1=I-W A=11466 CONS=FL TILT=180 I-W-TYPE=ADIABATIC ..

RZ2=SPACE S-C=OFFICE V=15876 A=1764 N-O-P=8 ..
 W11=E-W CONS=EWL H=10.5 W=14 X=28 Y=14 Z=84 AZ=270 ..
 W12=E-W CONS=EWL H=10.5 W=126 X=28 Y=0 Z=84 AZ=180 ..
 WN12=WI G-T=GLS H=6 W=72 X=27 Y=3.5 S-SCH=SHADCO1 ..
 W13=E-W CONS=EWL H=10.5 W=14 X=154 Y=0 Z=84 AZ=90 ..
 RF2=ROOF LIKE RF1 W=14 H=126 ..
 FL2=I-W LIKE FL1 A=1764 ..

RZ3=SPACE S-C=OFFICE V=22932 A=2548 N-O-P=12 ..
 W14=E-W CONS=EWL H=10.5 W=28 X=154 Y=14 Z=84 AZ=180 ..
 W15=E-W CONS=EWL H=10.5 W=91 X=182 Y=14 Z=84 AZ=90 ..
 WN15=WI G-T=GLS H=6 W=52 X=19.5 Y=3.5 S-SCH=SHADCO1 ..
 W16=E-W CONS=EWL H=10.5 W=28 X=182 Y=105 Z=84 AZ=0 ..
 RF3=ROOF LIKE RF1 W=91 H=28 ..
 FL3=I-W LIKE FL1 A=2548 ..

RZ4=SPACE LIKE RZ2 ..
 W17=E-W LIKE W13 X=154 Y=105 Z=84 AZ=90 ..
 W18=E-W LIKE W12 X=154 Y=119 Z=84 AZ=0 ..
 WN18=WI LIKE WN12 ..
 W19=E-W LIKE W11 X=28 Y=119 Z=84 AZ=270 ..
 ROOF LIKE RF2 ..
 I-W LIKE FL2 ..

RZ5=SPACE LIKE RZ3 ..
 W110=E-W LIKE W16 X=28 Y=105 Z=84 AZ=0 ..
 W111=E-W LIKE W15 X=0 Y=105 Z=84 AZ=270 ..
 WN111=WI LIKE WN15 ..
 W112=E-W LIKE W14 X=0 Y=14 Z=84 AZ=180 ..
 ROOF LIKE RF3 ..
 I-W LIKE FL3 ..

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TZ1=SPACE LIKE RZ1 F-M=5 ..
 I-W LIKE IN1 N-T=TZ2 ..
 I-W LIKE IN2 N-T=TZ3 ..
 I-W LIKE IN1 N-T=TZ4 ..
 I-W LIKE IN2 N-T=TZ5 ..

TZ2=SPACE LIKE RZ2 F-M=5 ..
 W21=E-W LIKE W11 X=28 Y=14 Z=52.5 ..
 W22=E-W LIKE W12 X=28 Y=0 Z=52.5 ..
 WN22=WI LIKE WN12 ..
 W23=E-W LIKE W13 X=154 Y=0 Z=52.5 ..

TZ3=SPACE LIKE RZ3 F-M=5 ..
 W24=E-W LIKE W14 X=154 Y=14 Z=52.5 ..
 W25=E-W LIKE W15 X=182 Y=14 Z=52.5 ..
 WN25=WI LIKE WN15 ..
 W26=E-W LIKE W16 X=182 Y=105 Z=52.5 ..

TZ4=SPACE LIKE RZ4 F-M=5 ..
 W27=E-W LIKE W17 X=154 Y=105 Z=52.5 ..
 W28=E-W LIKE W18 X=154 Y=119 Z=52.5 ..
 WN28=WI LIKE WN18 ..
 W29=E-W LIKE W19 X=28 Y=119 Z=52.5 ..

TZ5=SPACE LIKE RZ5 F-M=5 ..
 W210=E-W LIKE W110 X=28 Y=105 Z=52.5 ..
 W211=E-W LIKE W111 X=0 Y=105 Z=52.5 ..
 WN211=WI LIKE WN111 ..
 W212=E-W LIKE W112 X=0 Y=14 Z=52.5 ..

ST1=SPACE LIKE TZ1 F-M=1 ..
 I-W LIKE IN1 N-T=ST2 ..
 I-W LIKE IN2 N-T=ST3 ..
 I-W LIKE IN1 N-T=ST4 ..
 I-W LIKE IN2 N-T=ST5 ..

ST2=SPACE LIKE TZ2 F-M=1 ..
 W31=E-W LIKE W21 X=28 Y=14 Z=21 ..
 W32=E-W LIKE W22 X=28 Y=0 Z=21 ..
 WN32=WI LIKE WN22 ..
 W33=E-W LIKE W23 X=154 Y=0 Z=21 ..
 AFL2=E-W CONS=AFL H=126 W=14 TILT=180 ..

ST3=SPACE LIKE TZ3 F-M=1 ..
 W34=E-W LIKE W24 X=154 Y=14 Z=21 ..
 W35=E-W LIKE W25 X=182 Y=14 Z=21 ..
 WN35=WI LIKE WN25 ..
 W36=E-W LIKE W26 X=182 Y=105 Z=21 ..
 AFL3=E-W CONS=AFL H=28 W=91 TILT=180 ..

ST4=SPACE LIKE TZ4 F-M=1 ..
 W37=E-W LIKE W27 X=154 Y=105 Z=21 ..
 W38=E-W LIKE W28 X=154 Y=119 Z=21 ..
 WN38=WI LIKE WN28 ..
 W39=E-W LIKE W29 X=28 Y=119 Z=21 ..
 AFL4=E-W CONS=AFL H=126 W=14 TILT=180 ..

ST5=SPACE LIKE TZ5 F-M=1 ..
 W310=E-W LIKE W210 X=28 Y=105 Z=21 ..
 W311=E-W LIKE W211 X=0 Y=105 Z=21 ..
 WN311=WI LIKE WN211 ..
 W312=E-W LIKE W212 X=0 Y=14 Z=21 ..
 AFL5=E-W CONS=AFL H=28 W=91 TILT=180 ..

FT1=SPACE S-C=OFFICE V=26460 A=2940 N-O-P=7 ..
 IN3=I-W A=756 CONS=PART N-T=FT2 ..
 IN4=I-W A=315 CONS=PART N-T=FT3 ..
 I-W LIKE IN3 N-T=FT4 ..
 I-W LIKE IN4 N-T=FT5 ..

FT2=SPACE S-C=OFFICE V=26460 A=2940 N-O-P=14 L-W=1.0 ..
 I-W LIKE IN4 N-T=FT5 ..

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I-W LIKE IN4 N-T=FT3 ..
 W42=E-W LIKE W32 X=28 Y=14 Z=10.5 ..
 WN42=WI G-T=GLS H=7 W=90 X=18 Y=2.5 ..
 FT3=SPACE S-C=OFFICE V=11907 A=1323 N-O-P=7 ..
 I-W LIKE IN4 N-T=FT4 ..
 W45=E-W LIKE W35 X=154 Y=14 Z=10.5 ..
 WN45=WI G-T=GLS H=7 W=65 X=13 Y=2.5 ..
 FT4=SPACE LIKE FT2 ..
 I-W LIKE IN4 N-T=FT5 ..
 W48=E-W LIKE W38 X=154 Y=105 Z=10.5 ..
 WN48=WI LIKE WN42 ..
 WD48=WI G-T=GLSD H=8 W=30 X=48 Y=0 ..
 FT5=SPACE LIKE FT3 ..
 W411=E-W LIKE W311 X=28 Y=105 Z=10.5 ..
 WN411=WI LIKE WN45 ..
 GF1=SPACE S-C=OFFICE V=71442 A=7938 N-O-P=18 ..
 I-W LIKE IN2 A=567 N-T=GF3 ..
 ING3=I-W A=1134 CONS=PART2 N-T=GF4 ..
 ING4=I-W A=567 CONS=PART3 N-T=GF5 ..
 I-W LIKE FL1 A=7938 I-W-TYPE=ADIABATIC ..
 BFL1=I-W A=7938 CONS=BFL TILT=180 N-T=BT1 ..
 GF2=SPACE S-C=OFFICE V=47628 A=5292 N-O-P=10 ..
 I-W LIKE ING4 A=378 N-T=GF5 ..
 W52=E-W LIKE W42 X=28 Y=0 Z=0 ..
 WN52=WI LIKE WN42 H=7 W=60 X=33 Y=2.5 ..
 WD52=WI G-T=GLSD H=8 W=30 X=48 Y=0 ..
 W53=E-W CONS=EWL H=10.5 W=42 X=154 Y=0 Z=0 AZ=90 ..
 I-W LIKE FL1 A=5292 I-W-TYPE=ADIABATIC ..
 I-W LIKE BFL1 A=5292 N-T=BT1 ..
 GF3=SPACE S-C=OFFICE V=15876 A=1764 N-O-P=4 ..
 W54=E-W CONS=EWL H=10.5 W=28 X=154 Y=42 Z=0 AZ=180 ..
 W55=E-W LIKE W45 H=10.5 W=63 X=182 Y=42 Z=0 ..
 WN55=WI LIKE WN45 H=7 W=45 X=9 Y=2.5 ..
 I-W LIKE ING3 A=252 N-T=GF4 ..
 I-W LIKE FL1 A=1764 I-W-TYPE=ADIABATIC ..
 I-W LIKE BFL1 A=1764 N-T=BT1 ..
 GF4=SPACE S-C=GARAGE V=48510 A=5390 N-O-P=0 ..
 GWL1=U-W CONS=GWL W=75.4 H=10.5 ..
 U-W LIKE GWL1 W=144 H=9 ..
 AFL1=E-W CONS=AWL W=73.5 H=73.5 TILT=0
 GND-REFLECTANCE=.22 X=28 Y=105 Z=10.5 ..
 I-W LIKE BFL1 A=5390 N-T=BT4 ..
 GF5=SPACE S-C=GARAGE V=67365 A=7485 N-O-P=0 ..
 U-W LIKE GWL1 W=100 H=10.5 ..
 U-W LIKE GWL1 W=60 H=10.5 ..
 AWL1=E-W CONS=AWL W=90 H=10.5 AZ=180 ..
 E-W LIKE AFL1 W=86.5 H=86.5 X=-62 Y=0 Z=10.5 ..
 I-W LIKE BFL1 A=7485 N-T=BT1 ..
 BT1=SPACE S-C=GARAGE V=212895 A=23655 N-O-P=0 F-M=2 ..
 U-W LIKE GWL1 W=509 H=10.5 ..
 I-W LIKE ING3 A=1386 N-T=BT4 ..
 I-W LIKE BFL1 A=23655 N-T=BG1 ..
 BT4=SPACE S-C=GARAGE V=48510 A=5390 N-O-P=0 F-M=2 ..
 U-W LIKE GWL1 W=219.4 H=10.5 ..
 I-W LIKE BFL1 A=5390 N-T=BG4 ..
 BG1=SPACE S-C=GARAGE V=212895 A=23655 N-O-P=0 ..
 U-W LIKE GWL1 W=509 H=10.5 ..
 I-W LIKE ING3 A=1386 N-T=BG4 ..
 GFL1=U-F CONS=GFL W=154 H=154 TILT=180 ..
 BG4=SPACE S-C=GARAGE V=48510 A=5390 N-O-P=0 ..

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U-W LIKE GWL1 W=219.4 H=10.5 ..
U-F LIKE GFL1 W=73.5 H=73.5 ..

BUILDING-RESOURCE VERT-TRANS-KW=50 VERT-TRANS-SCH=ELEV
HOT-WATER=40000 HW-SCHEDULE=DHW ..

END ..
COMPUTE LOADS ..

INPUT SYSTEMS ..

TITLE LINE-3 *VARIABLE AIR VOLUME FLOW* ..

SYSTEMS-REPORT V=(SV-A) S=(SS-A,SS-H) ..

$ HVAC SYSTEM DESCRIPTION $

$ DESIGN TEMP HEATING: 72 F. COOLING: 76 F.
$ SYSTEM TYPE REDUCED THE AIR DELIVERY VOLUME BY 30%.
$ REPLACED 251 DUAL-DUCT MIXING BOXES W/ VAV DAMPERS.
$ THERMOSTATIC CONTROLS OF VAV DAMPERS.
$ VARIABLE FREQUENCY MOTOR SPEED CONTROLS OF FOUR-50 HP
$ MAIN AIR SUPPLY FANS BY STATIC PRESSURE.
$ CONTROLS OF EIGHT-30 HP RETURN FANS BY STATIC PRESSURE.
$ BACK-DRAFT DAMPERS AT EACH RETURN FANS.

$ CONTROLS ROBERTSHAW DM-S-35 ENERGY MANAGEMENT SYSTEMS W/ IBM-PS2.
$ 56 PNEUMATIC CONTROL POINTS.
$ 32 SENSOR POINTS.

$ FAN SCHEDULE VENTILATION BETWEEN 06:45 - 19:30.

$ SCHEDULE $

HRS1=D-SCH (1,4) (-999) (5,20) (1) (21,24) (0) ..
HRS2=D-SCH (1) (0) (2,5) (-999) (6,20) (1) (21,24) (0) ..
HRS3=D-SCH (1,2) (0) (3,6) (-999) (7,20) (1) (21,24) (0) ..
HRS4=D-SCH (1,2) (0) (3,6) (-999) (7,14) (1) (15,24) (0) ..
HRS5=D-SCH (1,24) (0) ..
WFAN1=W-SCH (MON) HRS1 (TUE,FRI) HRS3 (SAT) HRS4 (SUN,HOL) HRS5 ..
WFAN2=W-SCH (MON) HRS2 (TUE,FRI) HRS3 (SAT) HRS4 (SUN,HOL) HRS5 ..
FSCH=SCHEDULE THRU FEB 28 WFAN1
THRU JUN 30 WFAN2
THRU AUG 31 WFAN1
THRU NOV 30 WFAN2
THRU DEC 31 WFAN1 .. $ FAN $

HRHS1=D-SCH (1,8) (55) (9,20) (72) (21,24) (55) ..
HRHS2=D-SCH (1,8) (55) (9,14) (72) (15,24) (55) ..
HRHS3=D-SCH (1,4) (55) (5,20) (72) (21,24) (55) ..
HRHS4=D-SCH (1,5) (55) (6,20) (72) (21,24) (55) ..
HRHS5=D-SCH (1,6) (55) (7,20) (72) (21,24) (55) ..
HRHS6=D-SCH (1,6) (55) (7,14) (72) (15,24) (55) ..
HRHS7=D-SCH (1,24) (55) ..
DAYHT1=W-SCH (WD) HRHS1 (SAT) HRHS2 (SUN,HOL) HRHS7 ..
DAYHT2=W-SCH (WD) HRHS5 (SAT) HRHS6 (SUN,HOL) HRHS7 ..
DAYHT3=W-SCH (MON) HRHS3 (TUE,FRI) HRHS5 (SAT) HRHS6 (SUN,HOL) HRHS7 ..
DAYHT4=W-SCH (MON) HRHS4 (TUE,FRI) HRHS5 (SAT) HRHS6 (SUN,HOL) HRHS7 ..
THHT=SCHEDULE THRU FEB 28 DAYHT4
THRU APR 30 DAYHT3
THRU MAY 31 DAYHT2
THRU SEP 30 DAYHT1
THRU OCT 31 DAYHT2
THRU NOV 30 DAYHT3
THRU DEC 31 DAYHT4 .. $ HEAT-TEMPERATURE $

DYHT1=W-SCH (ALL) (1,24) (1) ..
DYHT2=W-SCH (ALL) (1,24) (0) ..
HTS=SCHEDULE THRU DEC 31 DYHT1 .. $ HEATING $

HTS1=SCH THRU MAY 31 DYHT1
THRU SEP 30 DYHT2

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THRU DEC 31 DYHT1 .. \$ NO SUMMER HEATING \$

HRC51 = D-SCH (1,4) (99) (5,20) (76) (21,24) (99) ..
HRC52 = D-SCH (1,5) (99) (6,20) (76) (21,24) (99) ..
HRC53 = D-SCH (1,6) (99) (7,20) (76) (21,24) (99) ..
HRC54 = D-SCH (1,6) (99) (7,14) (76) (15,24) (99) ..
HRC55 = D-SCH (1,24) (99) ..
DAYCL1 = W-SCH (MON) HRC51 (TUE,FRI) HRC53 (SAT) HRC54 (SUN,HOL) HRC55 ..
DAYCL2 = W-SCH (MON) HRC52 (TUE,FRI) HRC53 (SAT) HRC54 (SUN,HOL) HRC55 ..
THCL = SCHEDULE THRU JUN 30 DAYCL2
THRU AUG 31 DAYCL1
THRU DEC 31 DAYCL2 .. \$ COOL-TEMPERATURE \$

CS1 = D-SCH (1,4) (0) (5,20) (1) (21,24) (0) ..
CS2 = D-SCH (1,5) (0) (6,20) (1) (21,24) (0) ..
CS3 = D-SCH (1,6) (0) (7,20) (1) (21,24) (0) ..
CS4 = D-SCH (1,6) (0) (7,14) (1) (15,24) (0) ..
CS5 = D-SCH (1,24) (0) ..
DYCL1 = W-SCH (MON) CS1 (TUE,FRI) CS3 (SAT) CS4 (SUN,HOL) CS5 ..
DYCL2 = W-SCH (MON) CS2 (TUE,FRI) CS3 (SAT) CS4 (SUN,HOL) CS5 ..
CLS = SCHEDULE THRU JUN 30 DYCL2
THRU AUG 31 DYCL1
THRU DEC 31 DYCL2 .. \$ COOLING \$

\$ ZONE SUB-COMMANDS \$

CONTRL = Z-C D-H-T = 72 H-T-SCH = THHT D-C-T = 76 C-T-SCH = THCL
T-TYPE = REVERSE-ACTION THROTTLING-RANGE = 4 ..

\$ ZONE DESCRIPTION \$

PH1 = ZONE Z-TYPE = UNCONDITIONED ..
RZ1 = ZONE Z-TYPE = CONDITIONED A-CFM = 12039 Z-C = CONTRL S-O = ADJUST-LOADS ..
RZ2 = ZONE Z-TYPE = CONDITIONED A-CFM = 2646 Z-C = CONTRL S-O = ADJUST-LOADS ..
RZ3 = ZONE Z-TYPE = CONDITIONED A-CFM = 3822 Z-C = CONTRL S-O = ADJUST-LOADS ..
RZ4 = ZONE Z-TYPE = CONDITIONED A-CFM = 2646 Z-C = CONTRL S-O = ADJUST-LOADS ..
RZ5 = ZONE Z-TYPE = CONDITIONED A-CFM = 3822 Z-C = CONTRL S-O = ADJUST-LOADS ..
TZ1 = ZONE Z-TYPE = CONDITIONED A-CFM = 12039 Z-C = CONTRL S-O = ADJUST-LOADS ..
TZ2 = ZONE Z-TYPE = CONDITIONED A-CFM = 2646 Z-C = CONTRL S-O = ADJUST-LOADS ..
TZ3 = ZONE Z-TYPE = CONDITIONED A-CFM = 3822 Z-C = CONTRL S-O = ADJUST-LOADS ..
TZ4 = ZONE Z-TYPE = CONDITIONED A-CFM = 2646 Z-C = CONTRL S-O = ADJUST-LOADS ..
TZ5 = ZONE Z-TYPE = CONDITIONED A-CFM = 3822 Z-C = CONTRL S-O = ADJUST-LOADS ..
ST1 = ZONE Z-TYPE = CONDITIONED A-CFM = 12039 Z-C = CONTRL S-O = ADJUST-LOADS ..
ST2 = ZONE Z-TYPE = CONDITIONED A-CFM = 2646 Z-C = CONTRL S-O = ADJUST-LOADS ..
ST3 = ZONE Z-TYPE = CONDITIONED A-CFM = 3822 Z-C = CONTRL S-O = ADJUST-LOADS ..
ST4 = ZONE Z-TYPE = CONDITIONED A-CFM = 2646 Z-C = CONTRL S-O = ADJUST-LOADS ..
ST5 = ZONE Z-TYPE = CONDITIONED A-CFM = 3822 Z-C = CONTRL S-O = ADJUST-LOADS ..
FT1 = ZONE Z-TYPE = CONDITIONED A-CFM = 3087 Z-C = CONTRL S-O = ADJUST-LOADS ..
FT2 = ZONE Z-TYPE = CONDITIONED A-CFM = 4410 Z-C = CONTRL S-O = ADJUST-LOADS ..
FT3 = ZONE Z-TYPE = CONDITIONED A-CFM = 1985 Z-C = CONTRL S-O = ADJUST-LOADS ..
FT4 = ZONE Z-TYPE = CONDITIONED A-CFM = 4410 Z-C = CONTRL S-O = ADJUST-LOADS ..
FT5 = ZONE Z-TYPE = CONDITIONED A-CFM = 1985 Z-C = CONTRL S-O = ADJUST-LOADS ..
GF1 = ZONE Z-TYPE = CONDITIONED A-CFM = 8335 Z-C = CONTRL S-O = ADJUST-LOADS ..
GF2 = ZONE Z-TYPE = CONDITIONED A-CFM = 7938 Z-C = CONTRL S-O = ADJUST-LOADS ..
GF3 = ZONE Z-TYPE = CONDITIONED A-CFM = 2646 Z-C = CONTRL S-O = ADJUST-LOADS ..
GF4 = ZONE Z-TYPE = UNCONDITIONED ..
GF5 = ZONE Z-TYPE = UNCONDITIONED ..
BT1 = ZONE Z-TYPE = UNCONDITIONED ..
BT4 = ZONE Z-TYPE = UNCONDITIONED ..
BG1 = ZONE Z-TYPE = UNCONDITIONED ..
BG4 = ZONE Z-TYPE = UNCONDITIONED ..

\$ SYSTEM SUB-COMMANDS \$

S-CTRL = S-C MAX-S-T = 115 MIN-S-T = 55 C-C = WARMEST H-C = COLDEST
H-SCH = HTS ECONO-LIMIT-T = 68 ..

S-CTRL1 = S-C MAX-S-T = 115 MIN-S-T = 55 C-C = WARMEST H-C = COLDEST
H-SCH = HTS1 ECONO-LIMIT-T = 68 ..

S-AIR = S-A MIN-OUTSIDE-AIR = 0.03 OA-CONTROL = ENTHALPY
MAX-OA-FRACTION = 0.5 ..

C-15

S-FAN=S-FANS F-SCH=FSCH F-C=SPEED N-C-C=CYCLE-ON-FIRST
 SUPPLY-STATIC=3.4 SUPPLY-EFF=0.55
 RETURN-STATIC=4.1 RETURN-EFF=0.55
 MIN-F-R=0.5 ..

S-TERM=S-T MIN-CFM-RATIO=0.5 ..

\$ SYSTEMS DESCRIPTION \$

SYS1=SYSTEM S-TYPE=DDS S-C=S-CTRL1 S-A=S-AIR S-FANS=S-FAN S-T=S-TERM
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-341297
 R-A-P=DUCT ZONE-NAMES=(PH1,RZ1,TZ1,ST1,FT1,GF1,BT1,BG1) ..

SYS2=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN S-T=S-TERM
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-323720
 R-A-P=DUCT ZONE-NAMES=(RZ2,TZ2,ST2,FT2,GF2) ..

SYS3=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN S-T=S-TERM
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-329096
 R-A-P=DUCT ZONE-NAMES=(RZ3,TZ3,ST3,FT3,GF3) ..

SYS4=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN S-T=S-TERM
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-240401
 R-A-P=DUCT ZONE-NAMES=(RZ4,TZ4,ST4,FT4,GF4,BT4,BG4) ..

SYS5=SYSTEM S-TYPE=DDS S-C=S-CTRL S-A=S-AIR S-FANS=S-FAN S-T=S-TERM
 PREHEAT=ELECTRIC HEAT-S=ELECTRIC H-CAP=-301323
 R-A-P=DUCT ZONE-NAMES=(RZ5,TZ5,ST5,FT5,GF5) ..

END ..
 COMPUTE SYSTEMS ..

INPUT PLANT ..

PLANT-REPORT S=(PS-A,PS-B,PS-C) ..

CHL=P-E TYPE=HEAT-CENT-CHLR SIZE=4.44 I-N=2 ..
 CTW=P-E TYPE=COOLING-TWR SIZE=2.80 I-N=4 ..
 WHR=P-E TYPE=ELEC-DHW-HEATER SIZE=-999 ..

RPTSCH=SCH THRU DEC 31 (ALL) (1,24) (1) ..
 OUT-1=R-B V-T=PLANT V-L=(10) ..
 HR-RPT=H-R R-SCH=RPTSCH R-B=(OUT-1) ..

END ..
 COMPUTE PLANT ..

INPUT ECONOMICS ..

E-R S=(ES-A,ES-D,ES-E) ..

E-C R=ELECTRICITY U=3412.97 E=0.0 A-SCH=TIME-OF-DAY ..

WINDEM=C-A R=ELECTRICITY S=1 C-A-L=SUMDEM TYPE=DEMAND U-C=8.692 ..

WINON=C-A R=ELECTRICITY S=1 TYPE=ENERGY U-C=0.03728 ..

WININT=C-A R=ELECTRICITY S=1 TYPE=ENERGY U-C=0.03237 ..

WINOFF=C-A R=ELECTRICITY S=1 TYPE=ENERGY U-C=0.02325 ..

SUMDEM=C-A R=ELECTRICITY S=2 C-A-L=WINDEM TYPE=DEMAND U-C=15.052 ..

SUMON=C-A R=ELECTRICITY S=2 TYPE=ENERGY U-C=0.05576 ..

SUMINT=C-A R=ELECTRICITY S=2 TYPE=ENERGY U-C=0.04711 ..

SUMOFF=C-A R=ELECTRICITY S=2 TYPE=ENERGY U-C=0.02520 ..

WINTER1=D-C-SCH (1,8) (WINOFF,WINDEM)

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      (9,12) (WININT,WINDEM)
      (13,20) (WINON,WINDEM)
      (21,24) (WININT,WINDEM) ..
WINTER2=D-C-SCH (1,24) (WINOFF,WINDEM) ..

SUMMER1=D-C-SCH (1,8) (SUMOFF,SUMDEM)
      (9,12) (SUMINT,SUMDEM)
      (13,20) (SUMON,SUMDEM)
      (21,24) (SUMINT,SUMDEM) ..
SUMMER2=D-C-SCH (1,24) (SUMOFF,SUMDEM) ..

TIME-OF-DAY=SCHEDULE THRU MAY 31 (WD) WINTER1 (WEH) WINTER2
      THRU OCT 31 (WD) SUMMER1 (WEH) SUMMER2
      THRU DEC 31 (WD) WINTER1 (WEH) WINTER2 ..

END ..
COMPUTE ECONOMICS ..

STOP ..

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