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Empirical validation of building energy simulation software: DOE2.E, HAP and TRACE

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Empirical validation of building energy simulation software; DOE2.E, HAP and TRACE

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LIST OF SYMBOLS

AHU	Air Handling Unit
BHP	Boiler Horse Power
CAVRH	Constant Air Volume Reheat System
CCM	Cloud Cover Modifier
CFM	Cubic Feet Per Minute
CHWS	Chilled Water System
DMACC	Des Moines Area Community College
DOE2	Hourly Simulation Program developed by Department of Energy in the U.S.
EAT	Entering Air Temperature
ERS	Energy Resource Station
EWT	Entering Water Temperature
4PFCU	Four Pipe Fan Coil Unit System
GPM	Gallon Per Minute
HAP	Hourly Analysis Program developed by Carrier Corporation
HVAC	Heating, Ventilating and Air-conditioning
HWS	Hot Water System
I_{DF}	Diffuse Irradiation on a Horizontal Surface
I_{DN}	Direct Normal Irradiation
I_{TH}	Total Irradiation on a Horizontal Surface
LAT	Leaving Air Temperature
LWT	Leaving Water Temperature
MPH	Mile Per Hour
MWT	Mixing Water Temperature
RMSE	Root Mean Square Error
RMSE	Root Mean Square Error
RTD	Resistance Temperature Device
TAB	Terminal Air Box
TMY	Typical Meteorological Year
TRACE	Trane Air Conditioning Economics Program developed by Trane Company
VAV	Variable Air Volume
VAVRH	Variable Air Volume Reheat System

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ABSTRACT

The purpose of this research project was to evaluate the accuracy of building energy simulation software by comparing actual building energy use to the results obtained from commercially available building energy simulation software. The building used in this project was the Iowa Energy Center's Energy Resource Station located on the DMACC campus in Ankeny, Iowa. Three different types of heating, ventilating and air-conditioning (HVAC) systems were used in the study. These systems were variable-air-volume with terminal reheat (VAVRH), constant-air-volume with terminal reheat (CAVRH), and four-pipe fan coil unit (4PFCU).

Three building energy simulation programs were used. The programs were DOE2, HAP and TRACE. These programs represent a wide range in the level of detail available for energy simulation software. Site weather data were used to build weather files for each program. Input data files representing the Energy Resource Station and its mechanical systems and equipment were used for each computer model.

Results from this research project show that the energy simulation programs predict cooling and heating energies better in cases with non-dynamic building operation than in cases with dynamic operation. The results also show that the programs do a better job of predicting heating energy than in predicting cooling energy. This was true for both dynamic and non-dynamic building operation.

Of three HVAC system types used in the study, the CAVRH system best matched the experimental results for all three programs. All three programs showed significant differences in cooling and heating energy predictions when they used the 4PFCU system. In the VAVRH system the programs predicted the heating energy reasonably well, but did not predict the cooling energy well. In general comparisons, the DOE2 program predicted the cooling energy best among the programs, and all three programs predicted the heating energy similarly.

Only the DOE2 program was used for the daylighting validation study. Prediction of lighting energy in the test rooms was very well matched to the measured lighting energy. The prediction of illuminance in the rooms showed differences depending on the orientation of the rooms.

1 INTRODUCTION

A number of computer programs are commercially available to estimate energy consumption in buildings. Often these building energy computer programs are used to help answer questions which arise in selecting HVAC systems. Part of the decision making process for system and/or equipment selection depends on the ability of the system to meet the building environmental needs while at the same time meeting the constraints of low life cycle costs. In some cases, building energy simulation analyses are used to justify the increased first cost of higher efficiency equipment if the life cycle costs show an acceptable return on investment.

The calculations performed by building energy analysis software are based on well established methods which have been developed over the past thirty years. The level of computational detail ranges from programs which model residential and light commercial structures with a single HVAC system utilizing unitary equipment to programs which model complex buildings with multiple systems with multiple pieces of mechanical equipment.

The underlying question for all building energy analysis programs is how well do they predict actual energy usage in a building? Furthermore, to what level of sophistication does the program have to be, and to what detail does the model have to be in order to achieve a reasonable estimate of the projected energy use? To some extent, the later questions can be answered by comparing the output from the various programs to each other. However, the answer to the first question can only be addressed by comparing model predictions to actual building energy consumption data.

There are generally three ways to evaluate the accuracy of the simulation software: a) empirical method, b) comparative method, c) analytical method. The empirical method is to compare results calculated by the simulation program with data collected from the real building. The comparative method is to compare a simulation computer program with the other programs. The analytical method is to compare the output from a program, subroutine, or algorithm to the result from a known analytical solution for isolated heat transfer mechanisms under very simple boundary conditions.

Many researchers have done validation studies using one of the three methods described above. The studies by the empirical method had limitations to set up ideal test conditions in a building or a house which provide a computer model with accurate information for its input. Because of the control limitation of test facilities, most of the computer modellers made assumptions for their model. Sometimes they used a simple building with a simple system instead of a realistic building with realistic HVAC systems. This was done to eliminate uncertainty due to the difficulty of measurement or control of operating parameters in the building.

In this research, the empirical method will be mainly used to investigate the degree of accuracy of the simulation software, and the comparative method and the analytical method will be partially used to verify building performance data. DOE2.1E, HAP (Hourly Analysis Program), and TRACE (Trane Air Conditions Economics), which are widely used for a building energy analysis, were used for the research.

The building used for this study is the Iowa Energy Center's Energy Resource Station (ERS) located on the DMACC (Des Moines Area Community College) campus in Ankeny, Iowa. The ERS is a research and training facility unique in the United States. It is the only public facility with the ability to simultaneously test and demonstrate multiple, full-scale commercial building systems. The ERS provides a good opportunity to conduct an empirical validation study.

The ERS has several features suited for this investigation. The ERS has the instrumentation and computer data acquisition system necessary to collect energy data on a continuous basis. In addition to the computerized data acquisition system, it has the ability to collect local weather data which are key factors when calculating thermal loads on the building and when estimating energy consumption for a certain period of time. The ERS has the flexibility of using different types of HVAC systems. This provides an opportunity to compare different system models used by the computer programs to actual system performance data. The detailed architectural plans and construction documents available for the new building made it possible to provide the level of detail required to model the building with the analysis programs.

Finally, the building is equipped with a building automation system (BAS) which not only provides for data acquisition but it also provides for complete flexibility in system control and test protocol.

2 LITERATURE REVIEW

Since the use of computer programs in the design of HVAC industry was first accepted in 1965, a number of building energy simulation programs have been developed, and they are being updated continuously. With the increase of the number of software programs, the number of program users has been increased, and at the same time the program users are from various fields.

Most of the simulation programs have similar algorithms to calculate loads and energy consumption, but they have different modeling methods for user convenience. In addition, they have different characteristics, capabilities and applications with different levels of sophistication, complexity, and cost. Over the years, many researchers have conducted validation studies to evaluate the level of the simulation programs' accuracy. There are three ways to evaluate the accuracy of simulation programs: empirical, analytical and comparative methods.

In the first section of the chapter, methods and approaches researchers used to measure the accuracy of a building energy simulation program are discussed. In the second section of the chapter, investigation results they obtained are discussed. The final section of the chapter addresses necessity of further research to quantify the level of the simulation programs' accuracy.

Use of the Validation Methods

Judkoff and Neymark (1995) evaluated and diagnosed nine building energy simulation programs: TRANSYS-BRE, TRANSYS-BEL, S3PAS, TASE, ESP-LP, BLAST, DOE2.1D, SUNCODE, SRES-BRE. The authors used a series of imaginary buildings to take the comparative testing approach, and compared the program outputs to each other for the cases, such as annual loads, annual maximum and minimum temperatures, peak loads, and some hourly data. For more realistic cases, they tested the ability of the programs to model such combined effects as thermal mass, direct solar gain through windows, window shading devices, internally generated heat, infiltration, sun spaces, earth coupling, and deadband and setback thermostat control. They used a simple building geometry for each case, and kept the input files equivalent for each program. Annual hourly typical meteorological year (TMY) weather data were used for each case.

Li and Ugursal (1992) used three simulation programs to evaluate the simulation accuracy by the empirical method. The simulation programs were hourly-based building energy simulation program (ESAS, developed by Ross F. Meriwether and Associates, Inc., 1990) and two simplified analysis programs (HAP2.01, developed by Carrier Corp.,1990; HOT-2000, developed by Energy, Mines and Resources Canada, 1989). The test building was a three-level, single-family house, which was equipped with an air-sources heat pump and monitored for one year by a computerized data acquisition system.

The authors measured infiltration rates during the test, and made an occupancy schedule that varied from week days to weekends. They also measured the building energy data such as indoor and outdoor temperatures, relative humidities, and power consumption. Throughout the data collection period, they kept the windows closed to eliminate uncontrolled ventilation and associated cooling or heating, and kept the venetian blinders set horizontally. The authors compared the simulation results with the measured data to evaluated the building energy simulation program's accuracy. In the first stage of the comparison, the authors compared the monthly heating/cooling loads and power consumption. Secondly, they compared the daily and hourly parameters for a particular day such as one day from the summer season, and one day from the winter season. They made several modification and averaging in input data to minimize the significant differences in input requirements and modeling techniques due to input limitations. The authors calculated the hourly dry-bulb and dew-point temperatures from the dry-bulb temperature and relative humidity data recorded at three-minute intervals. They used the measured cloud cover data for the hourly simulation program, and used the averaged long-term solar data for the simplified programs. Equipment performance profiles from manufacturers' specifications were used in the simulations. Part-load electricity consumption profiles of the heat pump, which were estimated from the collected data, were used for the hourly simulation program, but in the simplified simulation programs, the predefined part-load performance curves were used instead of the actual performance curve since these programs did not allow modification of performance curves.

Sorrell and Phelps (1985) investigated the accuracy of three hourly building energy simulation programs, DOE-2.1B, EMPS 2.1, and TARP84 using residential buildings. For validation of these programs, the authors used the empirical method as a validation tool. The hourly energy consumption, indoor temperature, and attic temperature were measured to validate the simulation software for three to six days during winter and summer. Six unoccupied houses were used. The authors measured the site weather, infiltration rate, internal loads, inside temperature and HVAC systems' performances for the test period. During the test, the interior of the buildings was kept at constant temperature using the electric heating in winter and a split system air-conditioner system in the summer. The authors measured the weather for a 14-day period while they measured the interior temperature and energy consumption only for the last three days allowing the buildings to reach equilibrium with the weather cycle. All of the weather data were written into a file in the TMY weather data format. As a comparison tool, they plotted the average hourly attic temperatures (measured and computed) for three days during winter. For the energy consumption, they compared the hourly measured and computed electrical energy consumption. For the summer period, the authors compared the hourly total coil load for three days.

Alereza and Hovander (1985) modeled 36 commercial buildings to validate a newly developed building energy simulation program. The test building included offices, restaurants, grocery stores, retail stores, medical clinics, a motel, a church, and repair shops. The authors obtained the required data by investigation of the buildings and interviews with building staffs. They compared the actual utility bills with the simulation results for one year. The authors used the TRY weather data, which were the data of the cities nearest to the building locations. However, they did not use the same weather data as that of the utility bills. They did not include the evaluation of all the distribution systems available in the model.

Robertson and Christian (1985) investigated the influences of the wall thermal mass to the various weather conditions using site weather data. Two test buildings located on a high desert site were used. Both the buildings had only one room. The exterior walls of the buildings had the same U-value while one had high mass wall without windows, and the other had low mass wall without windows. The authors used four hourly simulation programs (DOE-2.1A, DOE-2.1C, BLAST, and DEROB) to compare cumulative heating loads, interior temperatures and wall heat fluxes between the measured and the simulated by the four different analysists. The test buildings were instrumented to record building component temperatures and heat fluxes, outside weather conditions, and heating energy use. Simulations and measurements were done for midwinter, late winter and spring.

Yuill (1985) performed the verification of the BLAST simulation program by comparing BLAST's predictions of temperatures and energy consumption in two unoccupied houses with the results obtained by continuous monitoring of their thermal performance for one year. The author compared the annual and monthly energy consumptions, and compared the hourly energy consumption and temperatures of the basement, the main floor and the attic. They measured actual data such as space temperatures, ambient temperature, wind speed, and direction, and solar radiation. However, they did not use their own actual weather The hourly weather data was recorded at an airport 14 km south of the site and supplied by Atmospheric Environmental Service of Canada (AES). AES weather data is a format that can be used by BLAST. They examined this weather data to compare the data recorded at the site for one day of December.

Corson (1992) tested five simulation programs to investigate the input-output sensitivity of the programs using two buildings: one is a small retail building, and the other is a large office building. The author compared monthly and annual energy consumption between the measured and the estimated. For this study he had five experienced modelers run the programs with corresponding weather data. The software consisted of two bin-type programs (SEA 6, TrackLoad 3.1), one typical day program (VCACS 9,10), and two hourly programs (DOE-2.1, ADM-2 4.1).

Spielvogel (1977) performed the study to present some of reasons why the energy estimations by the different users and the different programs for the same building agreed or disagreed. The building analyzed was a 20 story, 315,000 ft^2 hypothetical office building with four pipe fan coil system on the perimeter and a terminal reheat system on the interior. Actual weather data were used for the simulation. The author took monthly heating and cooling demands and consumption as well as monthly gas and electric demands and consumption as a comparison parameter. For this analysis, the author invited various organizations to do an energy analysis on this building.

Results of the Validation Studies

Waltz (1992) stated that the energy services company did not guarantee 100% of its estimated energy savings. However, the author stated that a high level of simulation accuracy can be achieved through optimization of three factors: a) an intimate understanding of the simulation tool, b) an intimate understanding of the buildings to be simulated, and c) careful analysis and critique of output data. The author insisted that optimization of these factors regularly produce computer simulations within 5% of the measured energy consumption.

On the contrary, Spielvogle (1977) mentioned in the conclusion section of the comparison result report that several users using several programs on the same building would probably not get good agreement on the results of an energy analysis because the degree of agreement is dependent upon the interpretations made by the user and the ability of the computer programs to handle the building in question. The author added that the same user using several programs on the same building might or might not get good agreement depending on the complexity of the building and its system and the ability of the computer programs to handle the specific conditions in that building.

Corson (1992) reported in the study about input-output sensitivity of the simulation program that modelers have to concentrate their work on the most important - the most sensitive elements that go into their input files and energy conservation analyses in order to obtain a higher estimation accuracy. The author insisted that it is important to devote more time and attention to HVAC systems and plant than to building envelope and loads because HVAC systems and plant are more likely to impact the simulated building energy than building envelope.

Li and Ugursal (1992) concluded that the predictions of the three programs (one hourly program and two simplified programs) were close to the actual data, with a margin of error of less than 15% for most months, and mostly the predictions were lower than actual measured values. They stated that the hourly simulation program showed the best agreement with the actual data, but in the peak cooling months and peak heating months, monthly predictions of the simplified day-type program were close to actual values.

In the validation study to determine the accuracy of three hourly simulation programs (DOE-2.1B, EMPS 2.1 and TARP84), Sorrel et al. (1985) reported that these three hourly simulation programs were almost always in closer agreement with each other than the measured data for a typical residential building. In terms of accuracy, the authors reported that the accuracy in predicting absolute energy consumption was 5% to 20% for a one to three day period, while showing better agreement for a longer time period. They also added that DOE-2.1B was more accurate in predicting the energy consumption, but DOE-2.1B was less accurate in predicting the cooling load in a small high-mass building.

In the study to validate a newly developed hourly program, ADM-2, by modeling 36 commercial buildings, Alereza, et al (1985) reported that the estimated energy use values were within 10% of the actual usage indicated by the utility bills in most buildings used in the evaluation.

In the analysis study of the BLAST predictions and site measurements of annual energy consumption of the two houses, Yuill (1985) concluded that there was the overall agreement between the measured data and the BLAST predictions of energy and temperature, and as a result the BLAST would do a satisfactory job of modeling a set of similar houses in several different climates. However, the author admitted that this study had some limitations to the conclusions because the site measurements of weather parameters were incomplete, and the time and locations were not exactly as desired.

Summary

Since the degree of the simulation software accuracy has a number of independent factors affecting the estimation results, the users needs to have an equivalent ability to handle these independent factors. The user's ability may include insight about the building and HVAC system, experience of modeling the building, and knowledge about the simulation software. The building energy estimation is not an exact science, not because the calculation tools are inadequate, but because the complete input information is, in some way or other, almost always lacking (Black, 1977). In addition, a building energy simulation program needs three elements to satisfy the simulation run: a) test building including HVAC systems, b) operating condition of the building and the plant, c) weather data. Generally no one simulation program can satisfy all the requirements mentioned above, so some assumptions and idealizations are inevitable to model the building. These assumptions and idealizations should be rational and understandable to obtain more reasonable outputs. That is, only a combination of the clearest input data format, the most realistic weather data format and the skilled user can provide satisfactory answers for the question asking the degree of the estimation accuracy.

Over the years a number of building energy simulation programs have been developed, and at the same time a number of researchers have investigated the simulation accuracy of the building energy programs using various buildings and weather. However, there was no specific research project to investigate the simulation accuracy of the building energy programs by analyzing a HVAC system, building operation and site hourly weather simultaneously. Most of researches concentrated on the daily energy consumption or monthly energy consumption for a long period such as a week or more than several weeks. Also, some projects used assumptions to obtain a reasonable simulation results. For examples, they assumed internal load schedule such as people occupancy or infiltration schedule since they could not control the occupancy schedule of the actual building due to the experimental limitations.

For more profound investigation of the energy program's accuracy, it is necessary to investigate hourly zone temperature and load profile of the test building. Because eventually the energy program uses the hourly zone temperature and weather data to calculate the hourly energy consumption, and the hourly energy consumption is used to calculate the daily and weekly or monthly energy consumption. In addition, it is necessary to eliminate assumptions in the computer model as possible.

In this research project, the research is concentrated on the investigation of hourly load profile comparison between simulated result and measured performance data of the ERS building and HVAC systems.

3 VALIDATION TOOLS

There are four components necessary to perform an empirical validation study. They are a test building with a data acquisition system, HVAC systems, a weather station and simulation software. The test building and HVAC systems with the data acquisition system provide building thermal performance data that is used to compare to the results from computer models. The weather station provides the computer models with actual site weather. This chapter describes these four components necessary for the study.

Test Building

The test building used in this research project is the Energy Resource Station, located on the campus of the Des Moines Area Community College in Ankeny, Iowa. The Energy Resource Station is owned and operated by the Iowa Energy Center. Ankeny is located 41.75 degrees North latitude and 93.7 degrees West longitude, and it has an elevation of 948 feet above sea level. A photograph of the single-story building is shown in Figure 3.1. This building was built in 1995 and has a total of 8,503 ft^2 of floor area and 15 feet of building height. The construction is slab on grade.

The building consists of 8 test rooms, a computer room, an office, a class room and other rooms necessary to support the operation of the building. The building floor plan is shown in Figure 3.2. Six test rooms are located along the building perimeter, and two test rooms are located in the building interior. Figure 3.3 is a three dimensional view of the building.

The building is oriented on the site such that one wall faces true north. For the perimeter test rooms, two face east, two face south and two face west. The test rooms are designated as "A" test rooms and "B" test rooms. The "A" and "B" test rooms are served by separate HVAC

Figure 3.1 Energy Resource Station

systems. The remainder of the building is served by a third HVAC system independent of the systems used for the test rooms. Further discussion about these system is given in section 3.2.

All windows are double glazed. The exterior walls of the test rooms are composed of several layers of construction materials with 0.181 Btu/(hr-ft^2-°F) average U-value. The thermal mass is outside the insulation. The construction layers (from inside to outside) are 3/8 inch gypsumboard, 4 3/8 inch air space, 1 inch insulation and 4 inch precast concrete panel . The surface color of the exterior walls is light gray with 0.675 value of absorptivity. The office and computer room have curtain walls instead of precast concrete walls, and their windows have a different shading coefficient from that of the test room windows. Also these rooms are setback three feet from the building exterior walls. The shading coefficients of the test rooms and office are 0.828 and 0.497, respectively. The exterior walls of the other rooms such as the mechanical room, rest rooms and storage rooms do not have any windows. They have walls thicker than those of test rooms.

The building has a flat, built-up roof. However, the roof of the classroom has a different height, four feet lower than that for the others. The classroom roof has the thermal mass layer outside the insulation, but the rest of the building has the thermal mass on the inside. Each

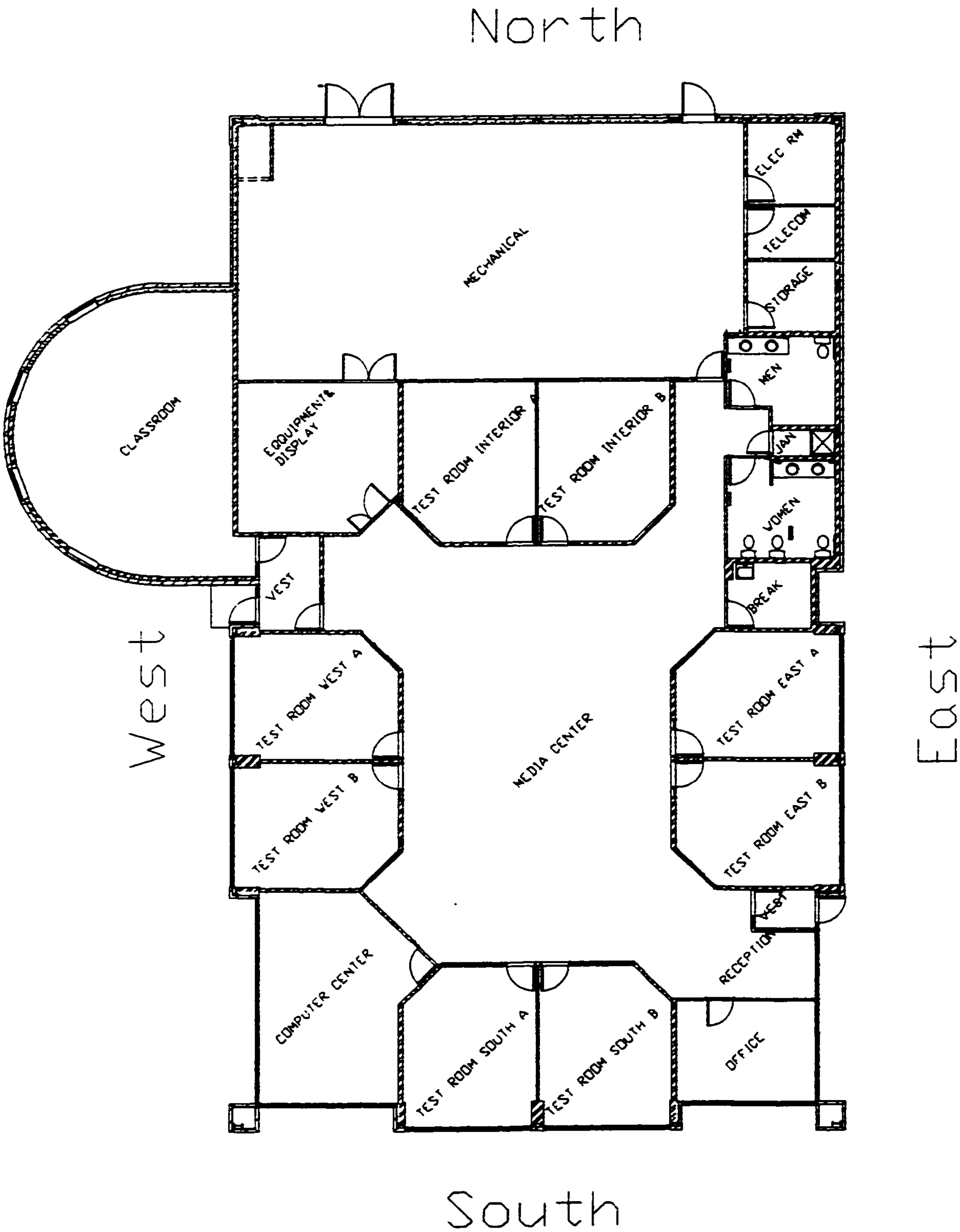


Figure 3.2 Floor plan of the Energy Resource Station

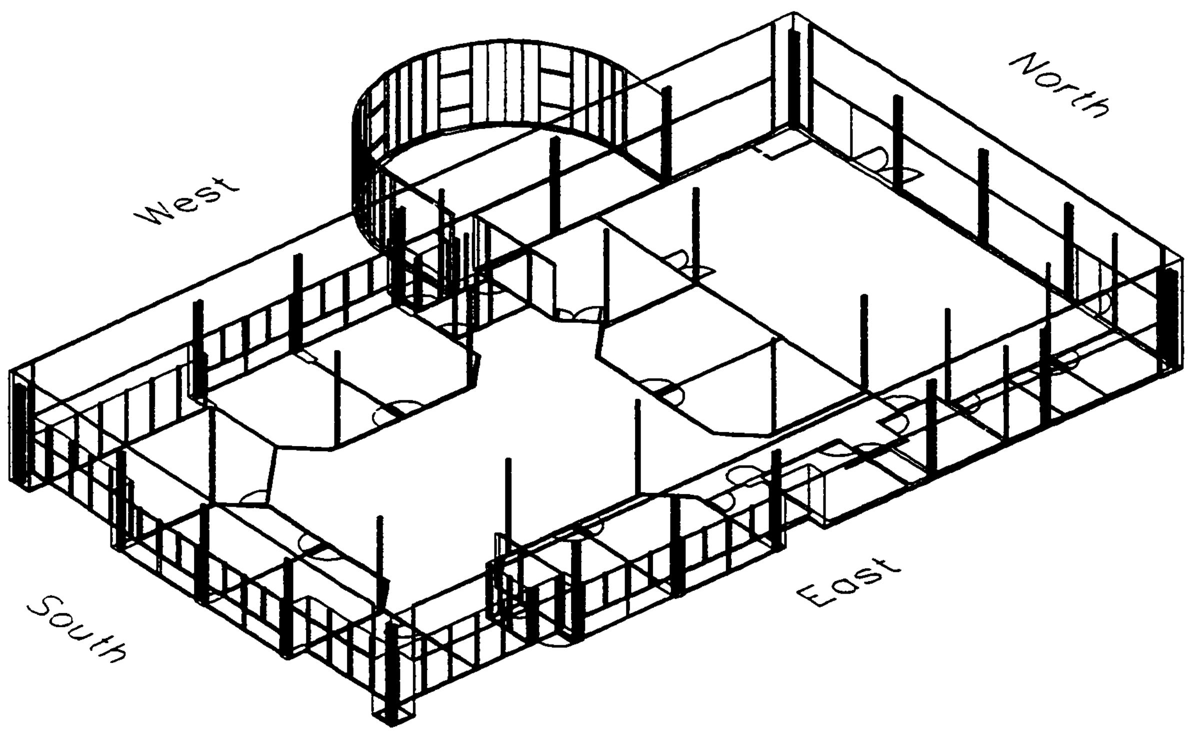


Figure 3.3 Three dimensional view of the Energy Resource Station

roof is supported by the steel-structured trusts. The layers for the rest of the building are composed of 8 inch cored concrete slab, 3/8 inch felt membrane, 4 inch insulation, 3/8 inch membrane, and gravel ballast. The roof layers of the class room consists of steel deck plate, 4 inch insulation, membrane and gravel.

The partition walls for the test rooms extend to the roof to prevent air exchange between adjacent spaces. The test rooms have ducted return air. The remaining rooms of the building use a ceiling plenum return. The ceiling height of the test rooms, office and computer room is 8.5 feet, and class room is 9 feet. The mechanical room and storage rooms do not have suspended ceilings, and the media center, located in the middle of the building, has 100 square feet of skylight on the roof and 10 feet of ceiling height. The floor of every room is 4 inch concrete on grade, and every room except the mechanical room and storage room is covered by carpet. Each room's size and volume is summarized in Table 3.1, and detail information about thermal properties of the building construction components such as walls, roofs and floors are described in Chapter 5, Computer Model.

There is no external shading device, but the windows of the computer room and office are set back 3 feet from the exterior walls. The percentages of window area to exterior wall area are 15% on the east side, 16% on the west side, 32% on the south, and 0% on the north, respectively. The building is surrounded by a grass area except for a concrete walk ways on the east and west sides.

Each test room is equipped with 2-stage baseboard electric heaters to provide internal loads if desired. The baseboard electric heaters can be one of 3 modes: stage 1 and 2 off; stage 1 on and stage 2 off; or stage 1 and 2 on. Each stage of heat is rated at 1.0 kW. In addition, each test room is equipped with recessed, non-vented fluorescent lighting fixtures with electronic ballast.

The building automation system is used for building control and data acquisition. The building performance data and weather data are recorded every minute by the data acquisition system during the test period. Sensors are installed at various locations in the rooms and HVAC systems to measure the building and HVAC systems' performance. RTDS are used to sense the dry-bulb temperature in each room, as well as supply air, return air, mixed air and outdoor

Table 3.1 Room size summary

Room	Net Floor area(ft^2)	Ceiling height(ft)	Plenum height(ft)	Exterior wall area(ft^2)	Window area(ft^2)
Test room "A"and "B"					
East	275	8.5	5.5	137	74
South	275	8.5	5.5	137	74
West	275	8.5	5.5	137	74
Interior	275	8.5	5.5	0	0
Rest of building					
Mech. room	1764	14.0	0.0	1080	0
Storage	90	14.0	0.0	294	0
Comm. room	66	14.0	0.0	88	0
Elec. room	110	14.0	0.0	119	0
Men's restroom	128	8.0	6.0	166	0
Women's	153	8.0	6.0	168	0
Janitor room	26	8.0	6.0	49	0
Break room	83	8.5	5.5	116	0
Display room	316	8.5	5.5	0	0
Classroom	769	9.0	1.0	762	70
Vestibule(west)	85	8.5	5.5	125	30
Vestibule(east)	36	8.5	5.5	33	30
Media center	1888	10.0	4.0	0	0
Reception room	178	8.5	5.5	75	40
Office	197	8.5	5.5	238	136
Computer room	415	8.5	5.5	383	197

Note: Each room area is calculated by the measurement of the center-to-center of the walls.

air temperatures. In addition, supply and return temperatures of the chilled water and heating water are recorded. The power consumption and the status of the fans, electric coils and pumps are monitored by the data acquisition system. A listing of available trend points for the data acquisition system is shown in Appendix A.

HVAC Systems

The ERS has the flexibility of using different types of HVAC systems. This provides an opportunity to compare different system models used by the computer programs to actual system performance data. There are three air handling systems and multiple hydronic loops in the building.

Air-Side Systems

The air handling units are AHU-A, AHU-B, and AHU-1. AHU-A serves the "A" test rooms and AHU-B servers the "B" test rooms. The remainder of the building is served by AHU-1. AHU's A and B are identical while AHU-1 is similar, but larger to accommodate the greater loads.

A schematic of the test rooms' AHU (A or B) is shown in Figure 3.4. This unit contains a hot water coil, a chilled water coil, supply and return fans, and dampers to allow mixing of outside air with return air. Both fans have variable frequency drives. The unit contains instrumentation to provide air and water flowrate data as well as temperatures and relative humidities at various points in the system. The specifications for the AHU are provided in Table 3.2. The same type of terminal air box (TAB) is used in both the "A" and "B" test rooms. A schematic of a TAB is shown in Figure 3.5.

Each terminal box is equipped to either use electric resistance heating coils (2 stages in interior test rooms, and 3 stages in perimeter test rooms) or a heating water coil as the method of terminal heating. Each box is instrumented to provide flowrate and temperature data as well as the status of the electric heating coils status and heating water control valve position. In addition, watt transducers provide power measurements of the electric heating coils.

The terminal air boxes in the AHU-1 serving the remainder of the building are classified as a parallel fan-powered variable-air-volume unit (PFPVAV). Each box is equipped to only use electric resistance heating coils as the method of terminal heating. The specifications for the terminal boxes are provided in Table 3.3.

Water-side systems

The ERS is equipped with multiple hydronic loops that provide chilled water and heating water throughout the building. Each loop has its own pump and is equipped with instrumentation to measure water flowrate, supply and return water temperatures and pump status.

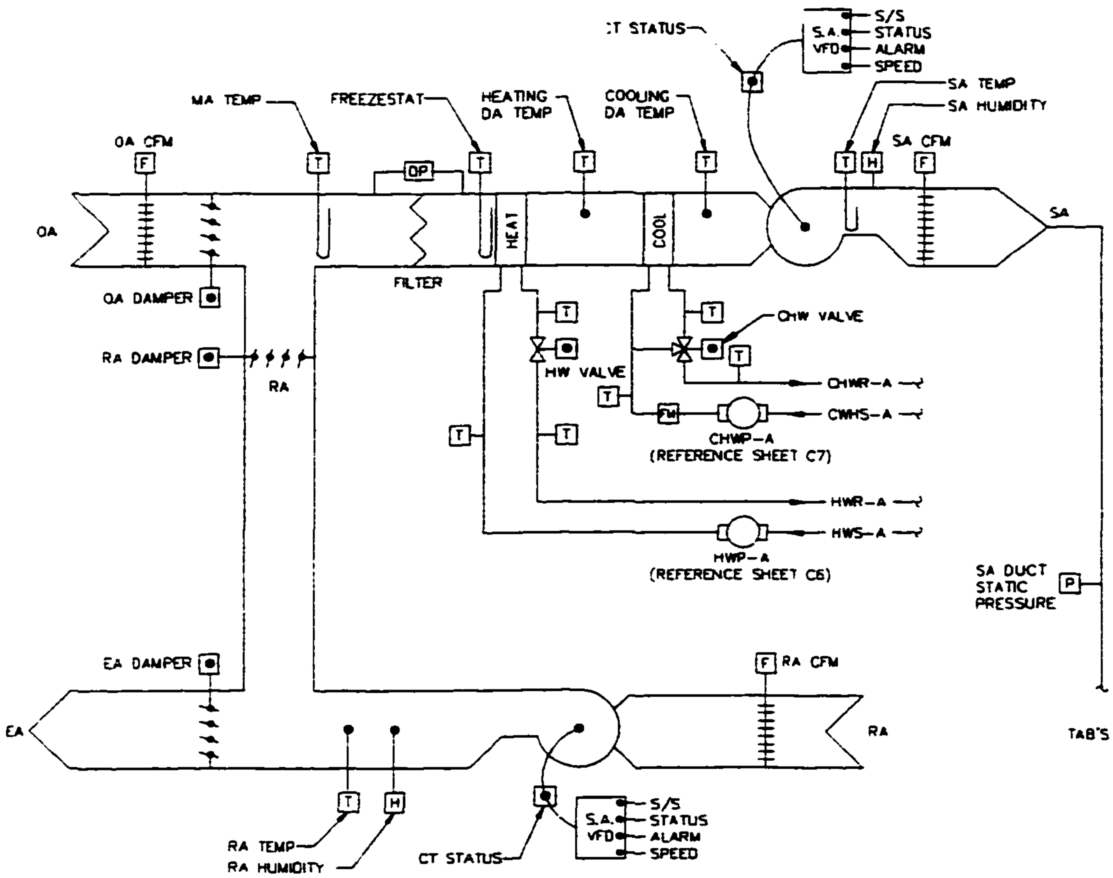


Figure 3.4 A schematic of the test rooms' AHU

A schematic of the heating water system is shown in Figure 3.6. Water is heated by a gas-fired hydronic boiler. As can be seen in the figure, heating water is supplied to all three air handling units. Heating water is also supplied to the "A" test rooms through HWS-LA and to the "B" test rooms through HWS-LB. All heating loops except loop "B" are equipped with constant speed pumps. Loop "B's" pump has a variable frequency drive to allow for variable speed pumping.

A schematic of the chilled water system is shown in Figure 3.7. This chilled water system is more complex than the heating water system because there are multiple methods for producing

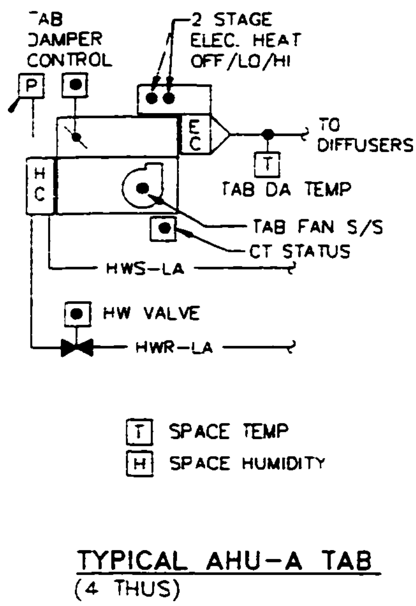
Table 3.2 Air handling unit specification

Specification	AHU-A	AHU-B	AHU-1
Service	Test room "A"	Test room "B"	General Bldg.
cfm	3,200	3,200	6,000
Supply fan static pressure (in H2O)	1.75	1.75	1.25
Return fan static pressure (in H2O)	0.25	0.25	0.25
Supply fan hp	5	5	5
Return fan hp	2	2	2
Heating coil			
Entering air temperature (°F)	40.0	40.0	40.0
Leaving air temperature (°F)	100.0	100.0	100.0
Entering water temperature(°F)	180.0	180.0	180.0
Leaving water temperature (°F)	160.0	160.0	160.0
MBtu/h	208	208	390
gpm	21	21	39
Cooling coil			
Entering air temperature (°F)	82.0	82.0	80.1
Leaving air temperature (°F)	54.4	54.4	54.0
Entering water temperature(°F)	44.0	44.0	44.0
Leaving water temperature (°F)	54.0	54.0	54.0
MBtu/h	135	135	224
gpm	28	28	45

chilled water. The ERS is connected to the DMACC campus chilled water system. The campus system can meet the design cooling loads for the whole building.

The ERS has an air-cooled chiller which can be used to meet part of the building cooling load. This chiller was sized to meet the design loads only for only one set of test rooms. Thus, for full-load cooling, this chiller can meet the requirements of either the "A" test rooms or the "B" test rooms, but not both simultaneously. At present, a second chiller is being considered which will allow side-by-side testing of the "A" and "B" systems.

A third source of chilled water is from the thermal storage tank. Ice is made using the air-cooled chiller which circulates a glycol-water mixture to the ice-building tubes in the storage tank. The tank is filled with water which freezes on the tube surfaces during the ice building mode. Once "charged" the glycol-water mixture can be circulated between the thermal storage



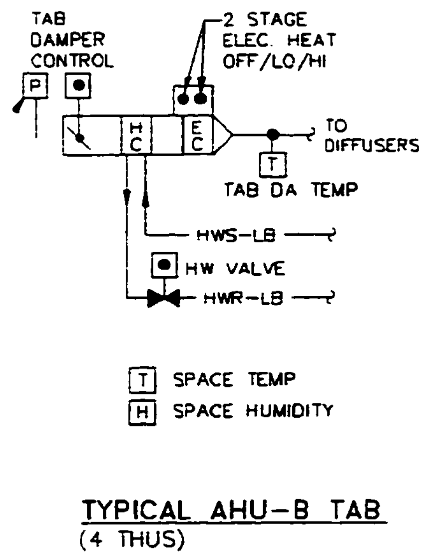


Figure 3.5 A schematic of a terminal box

tank and the cooling coils in the AHU's or through the chilled water loop to the test rooms.

Chilled water is made available to each test room to allow for cooling directly in the zone. The 4PFCU contains a fan which draws air in from the bottom of the unit. A portion of the air can be mixed with outside air before is passes across the coils in the unit The air can be heated with the heating water coil, or cooled and dehumidified with the chilled water coil. Presently only the "B" test rooms have fan coil units, and the outdoor air dampers are closed and sealed to prevent any outside air from entering the test rooms through the unit.

A schematic of a four-pipe fan coil unit is shown in Figure 3.8. The units are instrumented to provide mixed air temperature at the bottom of the unit and discharge air temperature from the top of the unit. Heating and cooling water valve positions are monitored as well as the fan status. There is no instrumentation to measure water flowrates or water temperatures at the unit. In addition there is no air flow instrumentation on the unit. For testing purposes, an air-flow hood was used to measure the air flowrate from the unit when operated at "medium" fan speed. The measured flowrates were used in calculating the unit coil loads. The specification

Table 3.3 Terminal air box specification

System	Room	Type	Hot water coil			Electric coil
			gpm	LAT (°F)[a]	Stages	Capacity (kW)
AHU-A&B	Perimeter rooms	VAV[b]	1.4	111	3	5 (1.67kW / stage)
	Interior room	VAV	0.9	95	2	2 (1kW / stage)
AHU-1	Other rooms	9 sets of PFPU[c] (different capacity), 1 set of VAV				

(a)LAT: leaving air temperature.
(b)VAV: variable air-volume unit.
(c)PFPU: parallel fan power unit.

for the fan coil units are provide in Table 3.4.

Plant Equipment

The primary plant heating and cooling equipment is the gas-fired boiler and the air-cooled chiller. The boiler is located in the mechanical room while the chiller is located on a concrete pad outside the building adjacent to the mechanical room. The specifications for these pieces of equipment are provided in Table 3.5.

Weather Station

A weather station and solar instrumentation were installed at the ERS to collect the site weather. The weather instruments shown in Figure 3.9 measure dry-bulb temperature, relative humidity, wind speed, wind direction, and atmospheric pressure. The solar instruments shown inFigure 3.10 measure direct normal solar flux and global horizontal solar flux. The weather data is trended on a one-minute interval basis by the building automation system.

Two types of solar instruments were set up on the roof of the ERS to measure solar radiation, a pyrheliometer and a pyranometer. The pyrheliometer is used to measure beam radiation at the normal incidence using a collimated detector. The pyranometer is used to measure total hemispherical solar radiation (beam plus diffuse) on a horizontal surface. These two instruments were calibrated by the instrument manufacturer, The Eppley Laboratory, Inc. This pyrheliometer is linear to within $\pm$ 0.5% up to the intensity of 1,400 W/m^2.

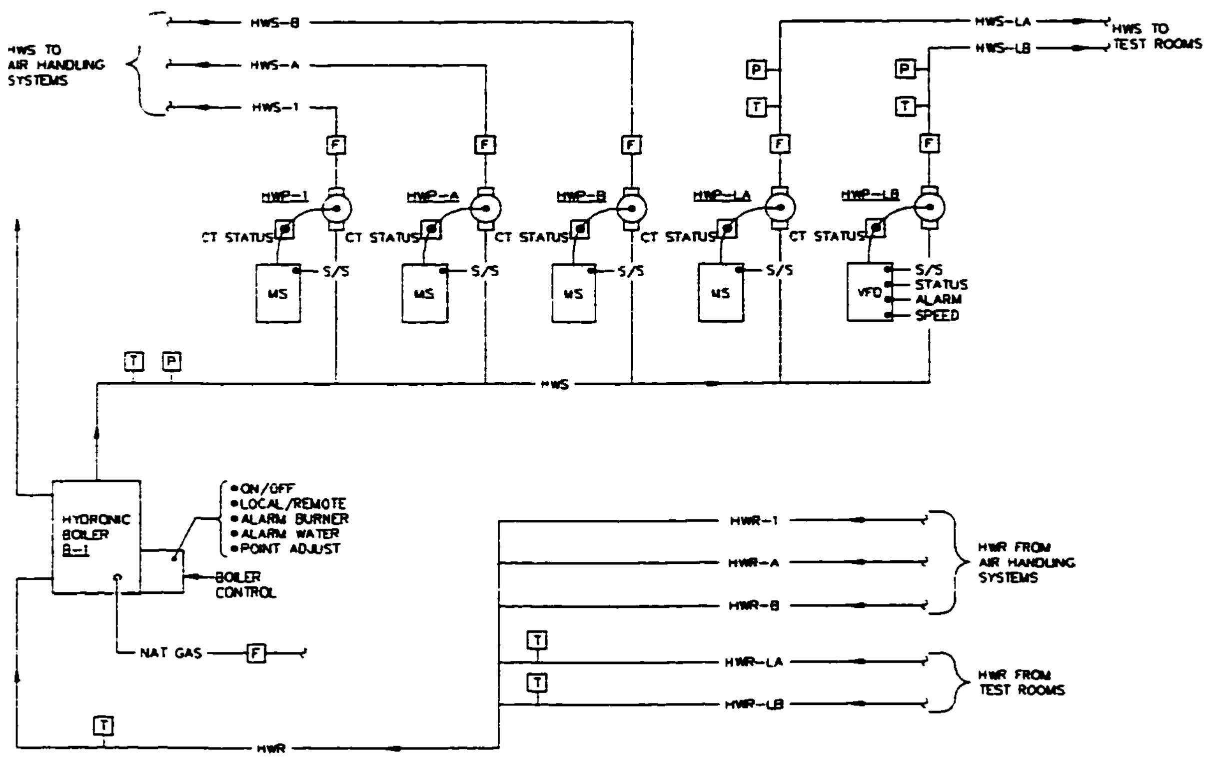


Figure 3.6 A schematic of the heating water system

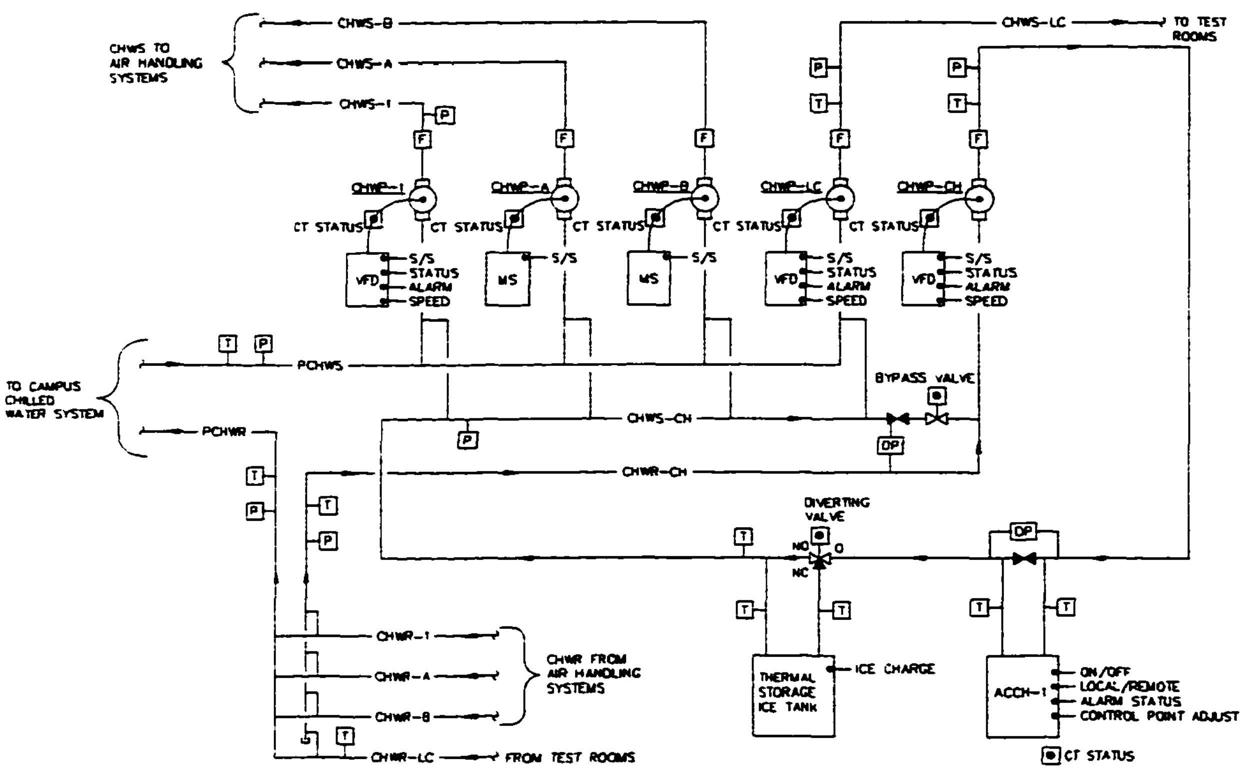


Figure 3.7 A schematic of the chilled water system

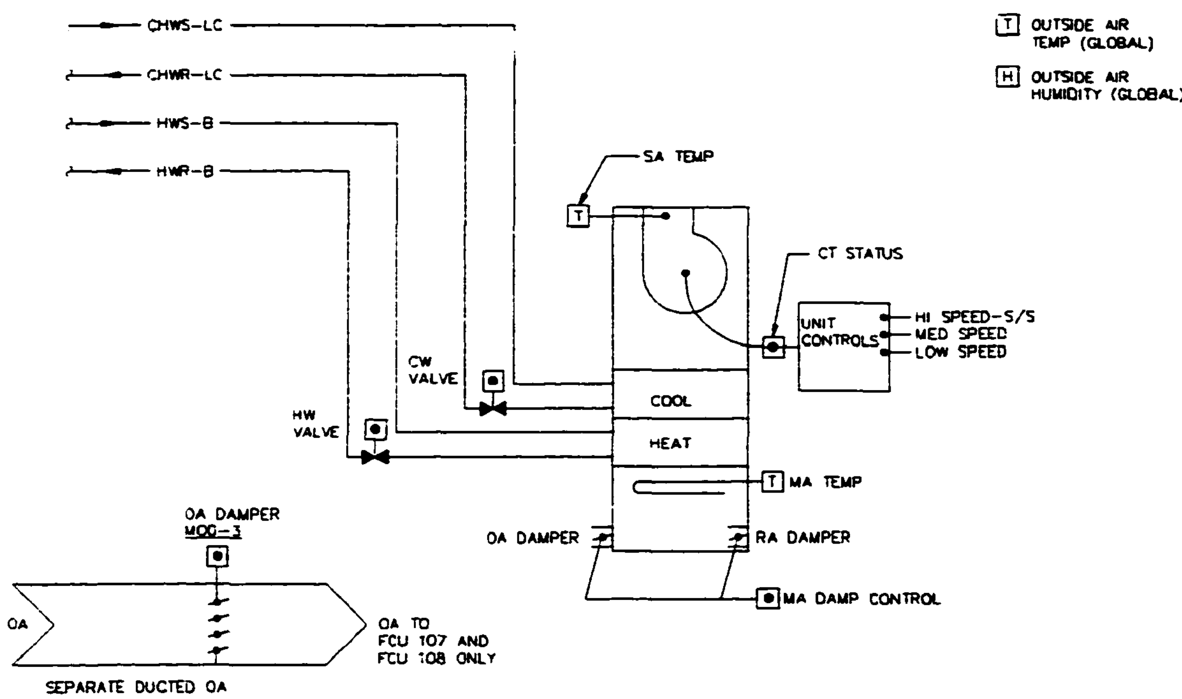


Figure 3.8 A schematic of a four-pipe fan coil unit

Table 3.4 Fan coil unit specification

Specification	East room	South room	West room	Interior room
cfm (high speed)	925	925	925	600
Watts	280	280	280	200
Cooling coil				
Capacity (MBtu/h)	28.2	28.2	28.2	16.3
EWT (°F)[a]	45.0	45.0	45.0	45.0
LWT (°F)[b]	55.0	55.0	55.0	55.0
gpm	5.7	5.7	5.7	3.3
Press. drop (ft H2O)	15.0	15.0	15.0	15.0
Heating coil				
Capacity (MBtu/h)	30.0	30.0	30.0	22.5
EWT (°F)	180.0	180.0	180.0	180.0
LWT (°F)	160.0	160.0	160.0	160.0
gpm	3.0	3.0	3.0	2.2
Press. drop (ft H2O)	5.0	5.0	5.0	5.0

(a)EWT: Entering water temperature.
(b)LWT: Leaving water temperature.

Table 3.5 Mechanical equipment specifications

CHILLER

Working Fluid	Chilled Water Mode with 100% Water	Ice Production Mode with 25% Ethylene Glycol
Capacity		
Nominal tons:	9.50	6.3
kW/Ton	1.15	1.5
EER	10.30	8.0
Steps of unloading	100 ~ 50	100 ~ 50
Evaporator Performance		
Inlet temperature:	54.0 (°F)	30.6 (°F)
Outlet temperature:	44.0 (°F)	24.0 (°F)
gpm:	24	24
Maximum pressure drop:	20 ft H2O	
Condenser Performance		
Refrigerant:	R-22	R-22
Number of fans:	2	2

BOILER

Nominal BHP	Fuel	Fuel Press. (in H2O)	Input Btu/h	Output Btu/h	Working Fluid	Max. Working Pressure
30	Gas	8.5	1,000,000	912,000	Water	30 psi

Capacity is at 180° F LWT, 160° F EWT, 120° F LWT, and 100° F EWT.

PUMP

Service	gpm	Head (ft H2O)	rpm	hp	Pump Efficiency(%)
For heating					
AHU-A coil	21	26	1,750	0.5	42
AHU-B coil	21	26	1,750	0.5	42
AHU-1 coil	40	26	1,750	0.75	40
TAB-A[a] coils	12	26	1,750	0.5	35
FCU-B[b] or TAB-B[c] coils	24	50	1,750	1.0	40
For cooling					
Chiller (Circulating)	24	50	1,750	1.0	40
AHU-A coil	28	26	1,750	0.5	48
AHU-B coil	28	26	1,750	0.5	48
AHU-1 coil	45	34	1,750	1.0	45
FCU-B coils	24	50	1,750	1.0	40

(a)TAB-A: Terminal air box for the test room "A".
(b)FCU-B: Fan coil unit for the test room "B".
(c)TAB-B: Terminal air box for the test room "B".

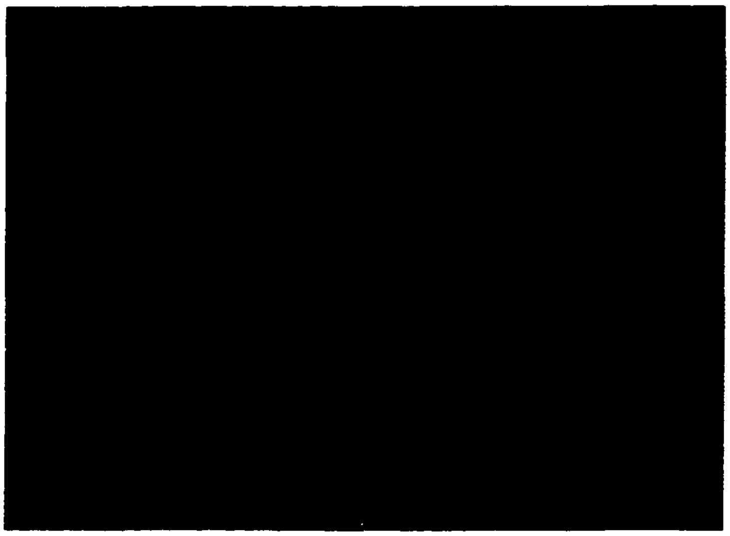


Figure 3.9 The Weather Station in the Energy Resource Station

For a continuous recording, the pyrheliometer was mounted on a power driven equatorial mount, The Eppley Solar Tracker. The Eppley Solar Tracker (model ST1) is electrically driven and geared to solar time so that it permits continuous measurements. The features of the tracker are a) pointing accuracy of ±0.25° daily; b) latitude setting of any value from 0 to 90°; c) declination setting of +23.5 to −23.5°. The solar tracker was set up on the roof of the ERS so that the tracker is free to rotate 360° with no object to cast a shadow over the location at any time during the entire year

There are four settings for the tracker that have to be aligned to insure proper tracking on the sun: North to South, latitude, declination, and time of the day. The axis of the tracker was set in a north to south direction putting it in the same plane as the axis of rotation of the earth. The drive end of the tracker was set so that it points south. The latitude of the solar tracker was set at 41.75 degrees which is the latitude of the site, and then the declination adjustment was accomplished. Finally the time of the day was set by hand. A pin hole on the front flange of the NIP is provided to align the instrument with the sun. The pyrheliometer was inspected three times per day to make sure it points at the sun, and to assure the output cable was not

Figure 3.10 The Solar Instruments (Pyrheliometer mounted on the solar tracker and pyranometer) in the Energy Resource Station

binding.

The Eppley Precision Spectral Pyranometer (Model PSP) is for the measurement of the total sky radiation. The PSP is covered with two hemispherical glasses to protect it from wind and other extraneous effects. This pyranometer is rectilinear to within ±0.5% up to the intensity of 1,400 W/m^2. The PSP was located so that a shadow would not be cast on it at any time; it is not close to light-colored walls or other objects likely to reflect sunlight onto it, and it is not exposed to artificial radiation sources. The roof of the ERS has enough environmental conditions to satisfy the installation requirements of the pyranometer. Precautions were also taken to avoid subjecting the instrument to shocks or vibration during installation. The cables used to connect the pyranometer and pyheliometer with the respective readout are shielded to eliminate electrical noise.

The NIP and PSP each produce a millivolt signal from the thermopile detectors. This voltage is below the 0 to 10 volt range required by the building automation system; therefore, a linear amplifier is used to increase the solar instruments output. The amplifier has a gain of 1000 which places the voltage in the correct range. Calibration of the amplifier assumed linear performance over the range of expected input voltages.

To gather wind data, wind speed and wind direction, sensors were mounted on a weather mast attached to an exterior wall of the ERS. The mast is 35 feet tall so that the wind sensors will not be influenced by the building. These sensor are EZ160 series manufactured by Earth and Atmospheric Sciences, Inc. The wind speed can be measured to 200 mph. The output signals from wind instruments are 4 to 20 mA which is an acceptable input to the building automation system.

The EZ315 was installed as a relative humidity and temperature sensor which is manufactured by E.A.S.I. The EZ315 sensor is a combination relative humidity and temperature sensor with each unit having its own signal conditioning and 4 to 20 mA transmitter. This sensor was assembled in a weatherproof housing and mounted on the weather mast. The EZ311 radiation shield was used for optimum protection from solar radiation and wind. Temperature measurement is performed using a PT100 platinum RTD (resistance temperature device) with a temperature coefficient of resistivity 0.00385 ohms per ohm per degree.

The EZ450 manufactured by E.A.S.I was installed on the mast to measure barometric pressure changes with respect to absolute pressure and uses a temperature compensated balanced bridge pressure sensor. The EZ450 utilizes an integrated circuit silicon sensor, housed in a stainless steel package. This unit is fully temperature compensated to give an operating range of 0 to 130°F, and it can measure the barometric pressure changes of 800 to 1100 mbar.

Simulation Software

For this study, three building energy simulation programs are used. The programs are TRACE, developed by the Trane Company; HAP, developed by Carrier Corporation; and DOE-2, developed by Lawrence Berkeley Laboratory. This section describes the characteristics and purpose of each program.

DOE-2

The DOE-2 program has been updated since the Simulation Research Group at Lawrence Berkeley Laboratory developed it in 1979 with major funding provided by the U.S. Department of Energy. This is used as a benchmark software because of its scope and flexibility of input parameters and especially because of its extensive engineering documentation. For those reasons, this program is used in many applications, especially those involving design of building envelope and systems, and selection of energy conserving or peak demand reduction alternatives. Applications can be divided by two categories; *Energy Analysis Studies and Building Design Studies.*

The Energy Analysis Studies include studies for a) effect of the thickness, order, type of materials, and orientation of exterior walls and roofs; b) effect of thermal storage in walls and floors, and in energy storage tanks coupled to HVAC systems; c) effect of occupancy, lighting, and equipment schedules; d) effect of intermittent operation, such as the shutdown of HVAC systems during the night, on weekend, holidays, or for any hour; e) effect of reduction in minimum outside air requirements and the scheduled use of outside air for cooling; f) effect of internal and external shading, tinted and reflected glass, use of daylighting.

The Building Design Studies include studies for a)initial design selection of basic elements of the building, primary and secondary HVAC systems, and energy source; b) during the design stage, evaluating specific design concepts such as system zoning, control strategies, and system selection; c) during the construction, evaluating contractor proposals for deviations from the construction plans and specifications; d) a base of comparison for monitoring the operation and maintenance of the finished building and systems; e) analysis of existing building for cost-effective retrofits.

DOE-2 predicts the hourly energy use and energy cost of a building given hourly weather information and a description of the building, its HVAC equipment and utility rate structure. During the simulation, the program uses the materials library, the construction library, the predefined HVAC equipment, and the given weather file along with the input data file. Calculations are performed for all 8,760 hours of a year.

DOE-2 uses FORTRAN as a program language that can be used on a large variety of computers, including desk-top computers, and it is also certified for use with energy standards and energy ratings from the government. It uses a Building Description Language called BDL as the input language. BDL input data are translated into a machine readable format. A person who wants to use DOE-2 as an energy analysis program, should understand HVAC systems and have a working knowledge of the BDL input commands and keywords.

DOE-2 utilizes various sources of weather data. The weather formats are TRY, TMY, CTZ, CDI44, TDI440, TDFI440 and WYEC tapes. These weather data files are ASCII text files which must be packed into a binary format for use in the program. This is done using a weather processing program. This feature is useful when the user needs to modify or replace a weather file with actual weather data. Because of the enormous number of variables from which the users can choose, using the program is difficult not only for the novice but also for the experienced user. However, for a simple building with a simple system, a lot of knowledge about the program is not required since the user only needs to know the basic commands. Developers indicate that DOE-2 Basics cover approximately 80% of normal simulation applications if the users are familiar with only 25% of the input variables available in the program.

HAP (Hourly Analysis Program)

This program is a microcomputer program developed by Carrier Corporation. HAP was developed to help engineers design HVAC systems for commercial buildings, and it uses predefined systems to simulate packaged systems and central heating-cooling equipment. This program uses performance equations based on Carrier's equipment test data to simulate the capacity and power use of their equipment. It is a comprehensive load estimating and system design tool, and it is an energy simulation and operating cost analysis tool. For load calculations, HAP uses the ASHRAE-endorsed transfer function method, and for the energy analysis, it uses detailed 8,760 hour-by-hour energy simulation techniques. Its applications are similar to the DOE-2. This program provides information needed for selecting and specifying equipment.

In the design stage, the program performs a) calculates design cooling and heating loads for spaces, zones and coils in the HVAC system; b) determines required airflow rates on a space, zone and system-wide basis; c) sizes cooling and heating coils; d) sizes air circulation fans; e) sizes chillers and boilers.

In the energy analysis Stage, the program performs a) simulates hour-by-hour operation of all heating and air-conditioning systems in the building for all 8,760 hours in a year; b) simulates hour-by-hour operation of all plant equipment in the building for all 8,760 hours in a year; c) uses results from (a) and (b) to calculate total annual energy use and total operating costs for all energy consuming systems in the building. Both HVAC equipment and non-HVAC systems, such as lighting and appliances, are considered in the annual totals.

Like the DOE-2 program, this program also uses a materials library, a construction library, a predefined HVAC equipment library, and the given weather file along with the input data file. HAP has several advantages for the novice user which are not in the DOE-2 program. For example, this program has an interactive ability to communicate with users when they model a building by providing on-line help screens. Also this program provides several options for displaying, printing and graphing data. Tabular data can be displayed, written to a disk file, or printed. At various points in the program, line, bar, and pie charts of program data can be generated.

TRACE (Trane Air Conditioning Economics)

This program is a microcomputer program developed by Trane company. Like HAP, it was developed to help engineers design HVAC systems for commercial buildings, and it uses predefined systems to simulate packaged systems and central heating-cooling equipment. This program uses performance equations based on Trane equipment test data to simulate the capacity and power use of their equipment. Unlike DOE-2 and HAP, it does not perform an hour-by-hour simulation for all 8760 hours of a year; instead, calculations are carried out for an average day of each month. Hourly weather data for a year is converted into "a typical day" of each month and the calculations performed for the 24 hours of each typical day. The program uses three day types: weekday, weekend day, holiday. The results for each day type are then multiplied by the number of times the day occurs in each month and summed to obtain monthly results. This program provides information needed for selecting and specifying equipment.

In the design stage, the program performs a) calculates design cooling and heating loads for spaces, zones and coils in the HVAC system; b) determines required airflow rates on a space, zone and system-wide basis; c) sizes cooling and heating coils; d) sizes air circulation fans; e) sizes chillers and boilers.

In the energy analysis Stage,the program performs a) simulates monthly operation of all heating and air-conditioning systems in the building for a year; b) simulates monthly operation of all plant equipment in the building for a year; c) provides a comparative study of operating efficiencies and costs of alternative air conditioning systems.

Like DOE-2 and HAP, TRACE also uses a materials library, a construction library, predefined HVAC equipment libraries, and the given weather file along with the input data file. Like HAP, TRACE has an interactive ability to communicate with users when they model a building by providing on-line help screens. The program provides a lot of options for displaying and printing data, but not graphing data. Tabular data can be displayed, written to a disk file or printed to a printer. TRACE provides hourly profile data for the system heating and cooling demand.

Comparison of Software

All three programs used in this study calculate loads and energy consumption on an hourly basis. They all use predefined HVAC systems to simulate packaged systems and central heating-cooling equipment. They primarily use packaged performance equations based on their equipment test data to simulate the capacity and power consumption of their equipment.

DOE-2 and HAP allow the users to input their own performance data, so these software can create custom equations in the program. However, TRACE does not allow the user to modify the performance data of the given equipment in the program. This means that DOE-2 and HAP have the capabilities to get a higher degree of accuracy for specific equipment.

DOE-2, HAP and TRACE use the weighting factor method. The weighting factor method is used to convert instantaneous heat gain/loss into heating and cooling loads. It also is used to convert from instantaneous cooling/heating capacity to heat extraction/addition rates, and calculate actual zone temperatures. Weighting factors use zone temperature, load, air exchange rate, and extraction/addition rate histories to drive heat extraction/addition rate and zone temperature to convergence employing a successive time-step method.

DOE-2 and HAP use TMY, TRY or actual weather data to simulate building loads and HVAC equipment performance for all 8,760 hours in the year to determine annual energy and operating cost. TRACE uses its own weather file consisting of an averaged 24-hour profile for each month of the year, for a total of 288 hours (24 hour 12 month) of simulation. For all three programs it is possible for the user to input his own weather data in the program, of course, some tasks are required to pack the actual data into the necessary format for the programs.

4 EXPERIMENTAL DESIGN

An empirical validation study needs to obtain actual thermal performance data from a building and HVAC systems. This study also needs to have the data for cases that have various building operating conditions and HVAC system types. Tests conducted at the ERS were designed to provide a range of HVAC system types and building operations. The systems that were analyzed are variable-air-volume with reheat (VAVRH), constant-air-volume with reheat (CAVRH) and four pipe fan coil (4PFCU).

The building operations were chosen to show dynamic and non-dynamic characteristics of the buildings. Dynamic tests are ones where there were operation schedules that change throughout the day. Examples include a night set-back room thermostat schedule and scheduled internal loads during typical occupancy periods for a building. Non-dynamic tests kept all internal loads and thermostat setpoints at a constant value.

One final test was planned to examine the affects of daylighting controls on system energy use, and to compare the test results with the DOE2 program.

Eight experimental runs were conducted at various times of the year for this study. Each experiment utilized either a different HVAC system configuration or a different building operation schedule. For all test runs, there was no shading device in the windows.

Both cooling and heating were available for the tests. However, the tests were designed so that the heating was available only at the zone level. Depending on the time of year, cooling was accomplished utilizing an air-side economizer cycle. Table 4.1 summarizes test configurations that were applied to the validation study. Each combination of the building operation schedule and the HVAC system represents one set of experiments. The following sections describe the building operating schedules, the configurations of HVAC systems and the test period for each

Table 4.1 Description of experiment runs applied to the study

Building operation schedule	System types		
	CAVRH	VAVRH	4PFCU
Non-dynamic: keep the control parameters constant	o	o	o
Dynamic: vary the control parameters	o	o	o
With daylight control	-	o	-
Without daylight control	-	o	-

test.

Tests Having Non-dynamic Characteristics of the Building

The tests having the non-dynamic characteristics of the buildings utilized 3 different HVAC systems: CAVRH, VAVRH and 4PFCU. The purpose of these tests was to provide thermal performance data that were used to evaluate how well the computer models predict building energy for the the cases where buildings have non-dynamic characteristics in the building operation. During each test, the building operation parameters such as room temperature and outside air flowrate were kept constant throughout the day. No any internal loads were used for these tests.

The Non-dynamic Test with CAVRH System

The CAVRH system test was conducted in the summer of 1998, from August 1 through August 2. Cooling and heating equipment were available for the test. The maximum, minimum and average dry bulb temperature at the site were 80°F, 61°F, and 70°F, respectively. Relative humidity values varied from a maximum of 99% to a minimum 43% with an average of 76%. Wind speed varied from 17.11 mph to 0.0 mph with an average of 6.0 mph. Sky conditions were sunny for August 1 and mostly cloudy for August 2. Outside temperatures and solar data for these two days are presented in Figure 4.1 and Figure 4.2, respectively. For this test, the chiller was available throughout the test period. The supply air temperature leaving the AHU was a constant 55 °F throughout the test.

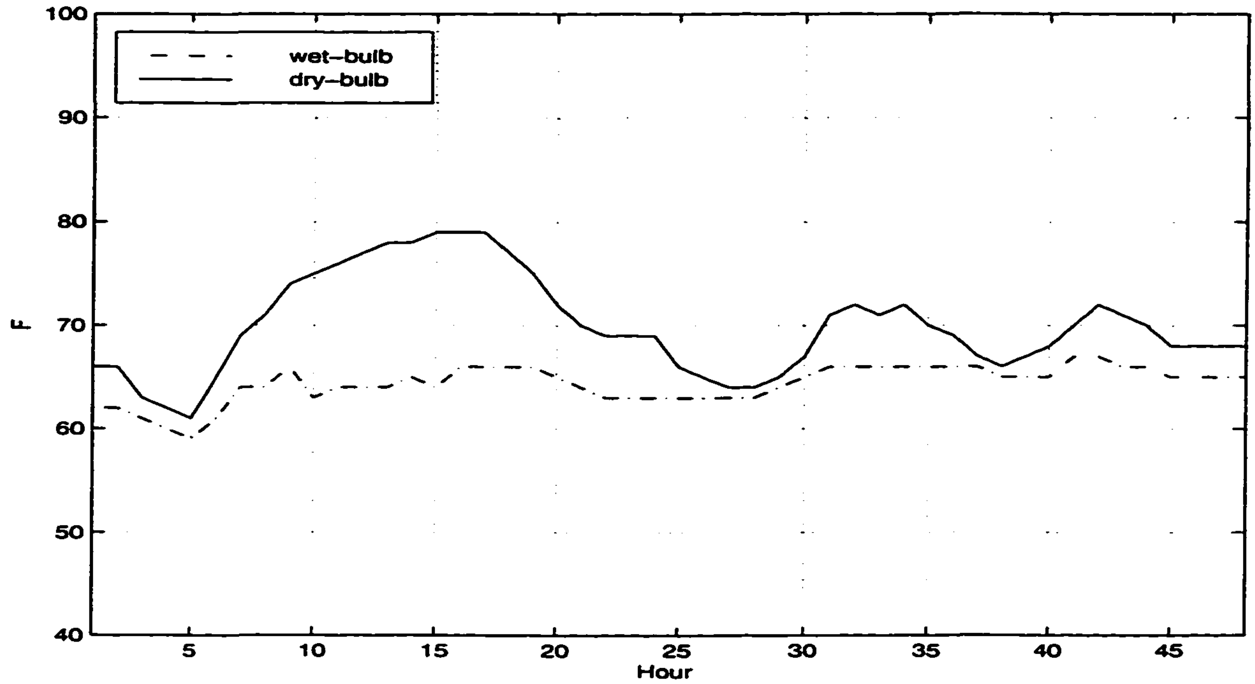


Figure 4.1 Outside air temperatures from 980801 through 980802

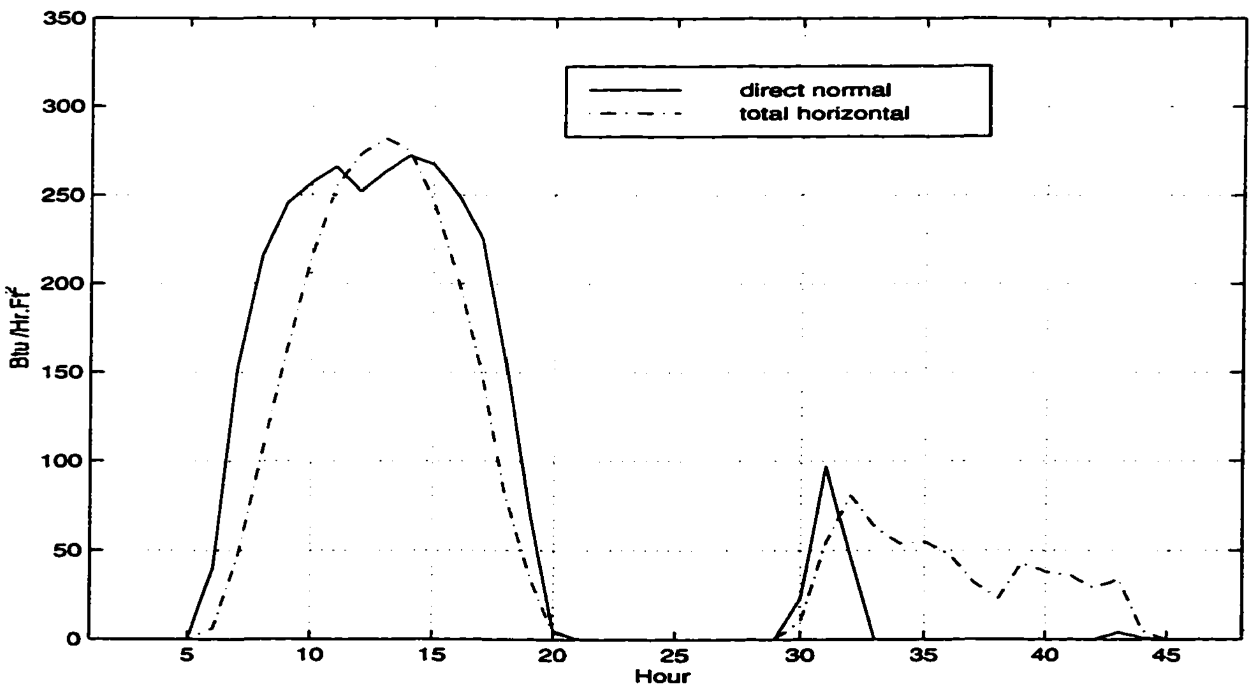


Figure 4.2 Solar fluxes from 980801 through 980802

A constant 400 CFM of outside air was supplied to the air handling unit, and electric reheat coils in the test room's terminal air box (TAB) were used for the zone heating.

The thermostat setpoints for all the test rooms were 73 °F and 72 °F for cooling and heating, respectively. Zone air flowrates for the exterior test rooms (east, south and west) were 600 CFM, and the zone air flowrate for the interior test room was 250 CFM.

The Non-dynamic Test with VAVRH System

The test was conducted from March 28, 1999 through March 31, 1999. The maximum, minimum and average dry bulb temperature at the site were 72°F, 55°F, and 38°F, respectively. Relative humidity values varied from a maximum of 89% to a minimum 20% with an average of 51%. Wind speed varied from 33.52 mph to 0.0 mph with an average of 9.30 mph. Sky conditions were sunny for 3 days and mostly cloudy for 1 day. Outside temperatures and solar data for these several days are presented in Figure 4.3 and Figure 4.4, respectively.

Outside air flow rate was setup to be constant at 50 CFM. AHU discharge air temperature was constant at 58 °F. The thermostat set points for the rooms were 73 °F and 72 °F for cooling and heating, respectively. Return air was pulled back to the AHU by the return fan through the plenum. Zone air flowrates for the exterior test rooms (east, south and west) were allowed to vary from maximum 900 CFM to minimum 450 CFM. The zone air flowrates for the interior test rooms were allowed to vary from a maximum 550 CFM to a minimum 270 CFM. Two stage of electric heating coils were used for zone reheat. Lights in the rooms were scheduled so that they were turned on at 6:00AM, and turned off at 8:00PM.

The Non-dynamic Test with 4PFCU System

The test was conducted from March 16, 1999 through March 18, 1999. One of the purposes of this test was to examine how the system responds to the building envelope load by itself. By closing the outdoor air dampers and using 100 percent recirculated air, no ventilation load was imposed on the system. The maximum, minimum and average dry bulb temperature at the site were 67°F, 30°F,and 47°F, respectively. Relative humidity values varied from a maximum of 78% to a minimum 33% with an average of 56%. Wind speed varied from 35.6 mph to 2.1

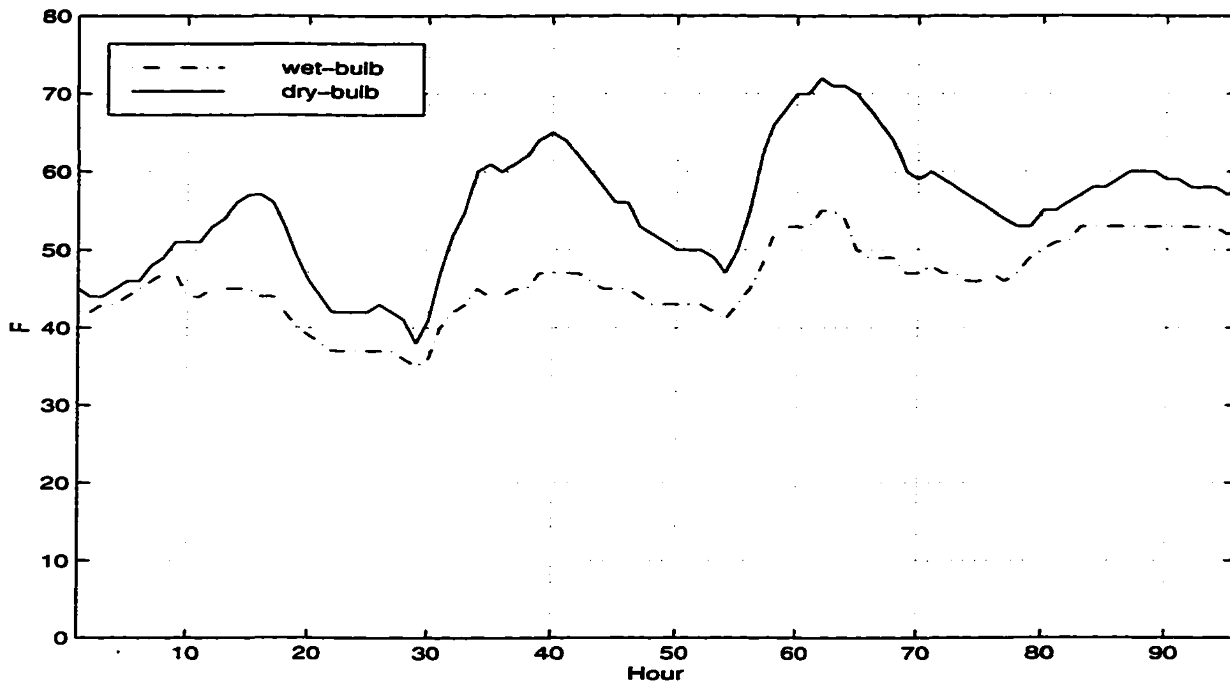


Figure 4.3 Outside air temperatures from 990328 through 990331

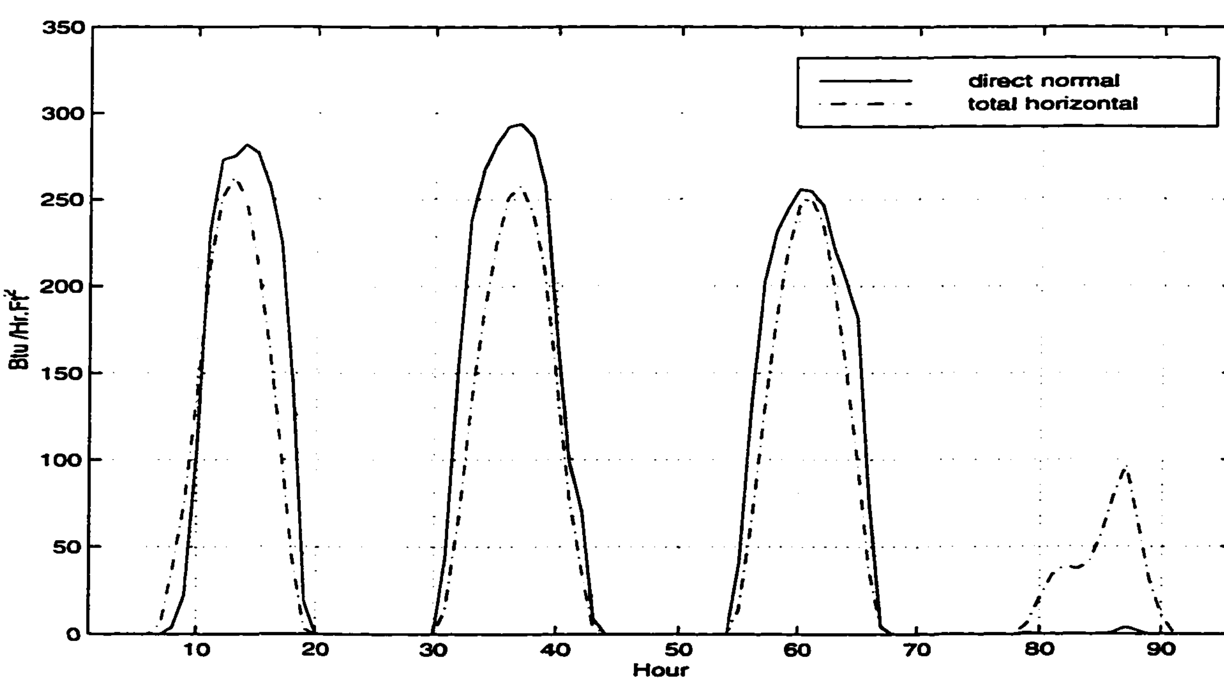


Figure 4.4 Solar fluxes from 990328 through 990331

mph with an average of 10.5 mph. Sky conditions were sunny for all three days of the test. Outside temperatures and solar data are presented in Figure 4.5 and Figure 4.6, respectively.

For the test, the cooling was provided by chilled water supplied to the FCU cooling coil and heating was provided by heating water supplied to the FCU heating coil. The thermostat setpoints for all the test rooms were 73 °F and 72 °F for cooling and heating, respectively. The fan speed of the FCUs was set at medium speed for the test period. The actual air flow rate out of the FCU was measured using a flow hood before the test. The measured flow rates are 580 CFM for the exterior test rooms and 370 CFM for the interior test room. The uncertainty value was ± 10 CFM.

Tests Having Dynamic Characteristics of the Building

The dynamic tests also used 3 different HVAC systems: CAVRH, VAVRH and 4PFCU. The purpose of these tests was to obtain thermal performance data to evaluate how well the computer models predict building heating and cooling loads for buildings having dynamic characteristics.

These tests utilized operation schedules that change for occupied and unoccupied periods. These included a night set-back room thermostat schedule and an internal loads schedule which simulated a typical occupancy period for a building. Electric baseboard heaters in the test rooms were used for the internal loads. The lights in the test rooms were turned off throughout the tests. The outside air flowrate scheduled was the same as the thermostat schedule. Particular schedules for each test are described in the following sections along with their test configurations.

The Dynamic Test with CAVRH System

The test was conducted from February 23, 1999 through February 25, 1999. The maximum, minimum and average dry bulb temperature at the site were 46°F, 19°F, and 30°F, respectively. Relative humidity values varied from a maximum of 98% to a minimum 55% with an average of 84%. Wind speed varied from 20.7 mph to 0.0 mph with an average of 6.3 mph. Sky conditions were mostly cloudy for the first 2 days and sunny for the last day. Outside temperatures and solar data for these three days are presented in Figure 4.7 and Figure 4.8, respectively.

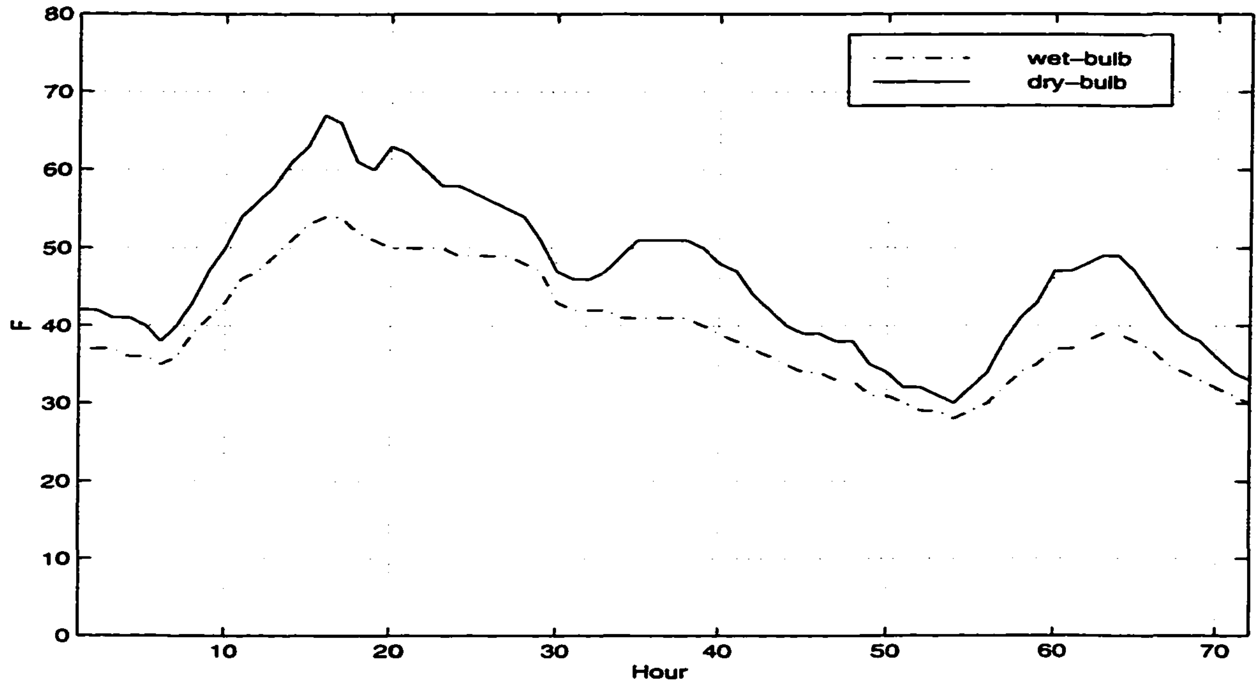


Figure 4.5 Outside air temperatures from 990316 through 990318

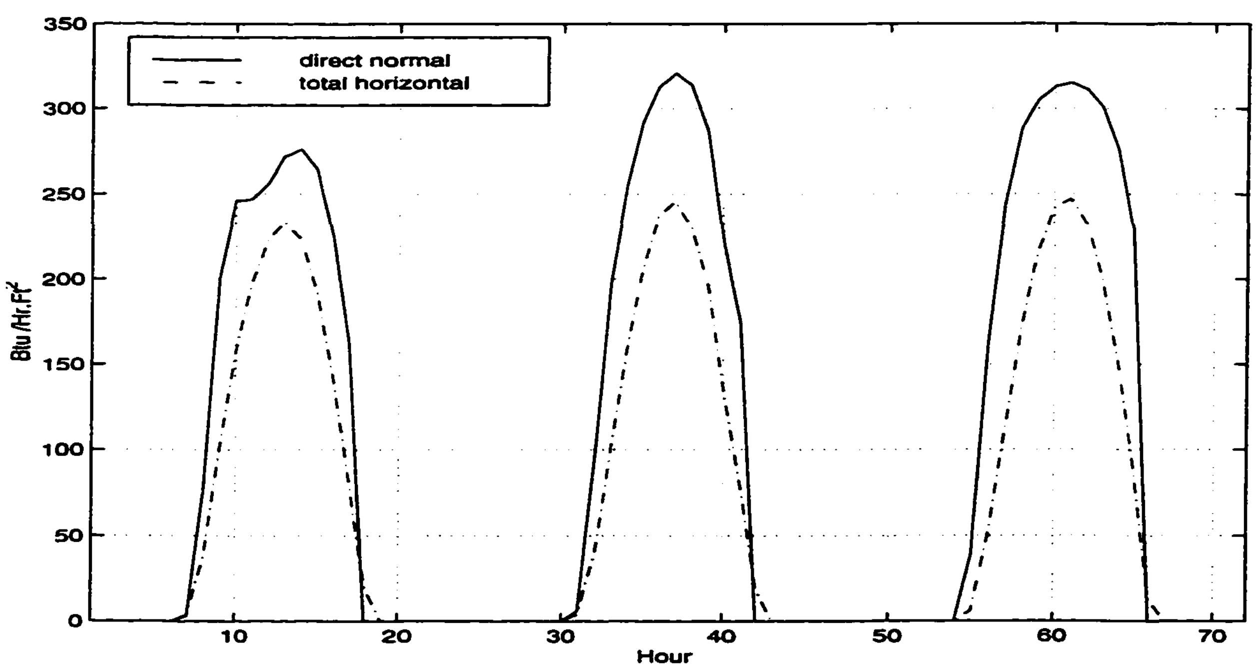


Figure 4.6 Solar fluxes from 990316 through 990318

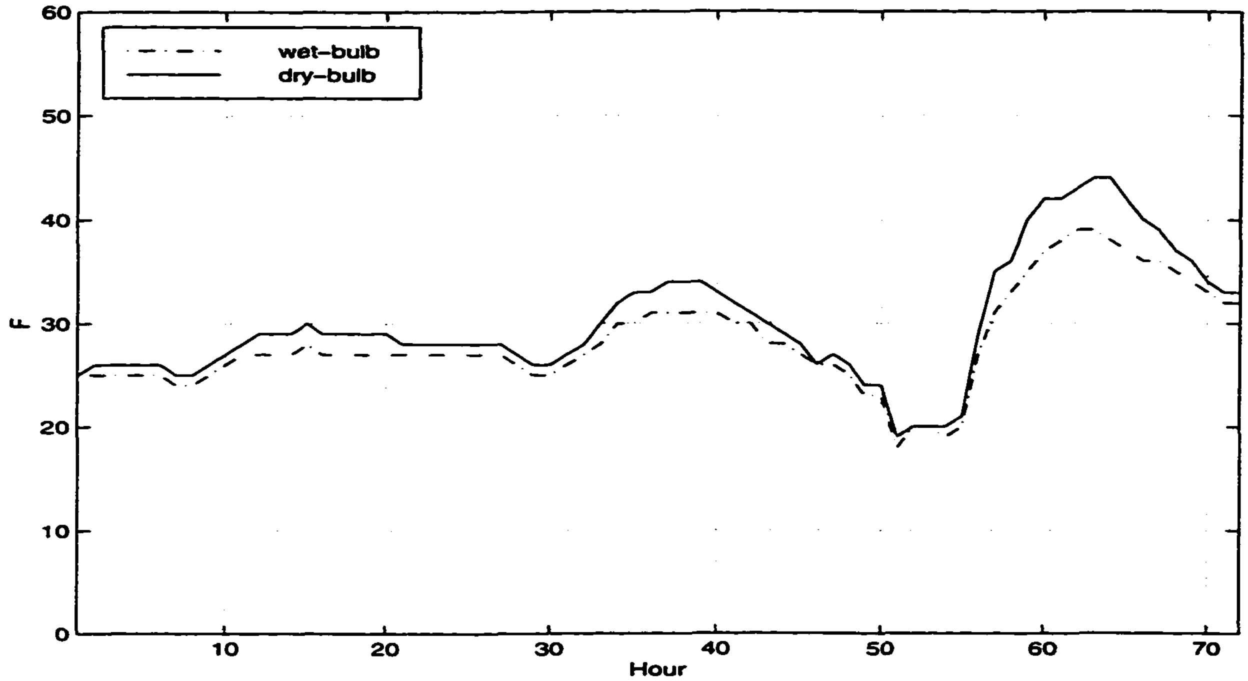


Figure 4.7 Outside air temperatures from 990223 through 990225

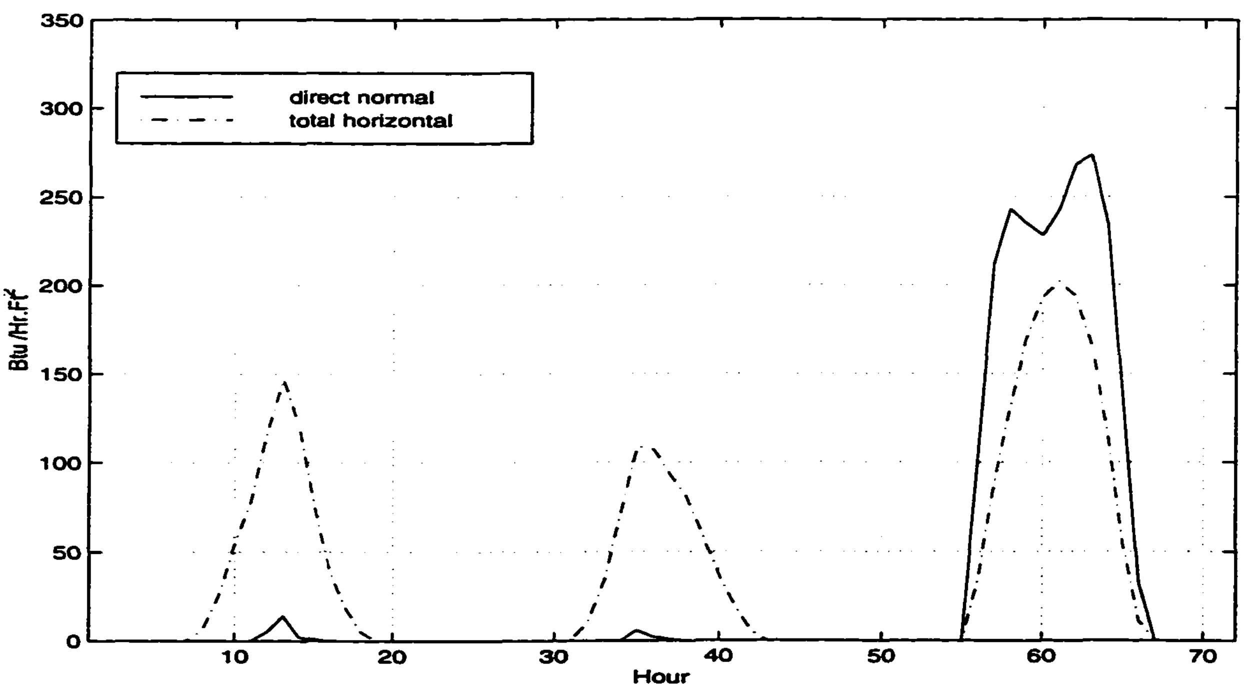


Figure 4.8 Solar fluxes from 990223 through 990225

The air handling unit was operated in air-side economizer mode. The chiller was not used for the test; all cooling was accomplished with outdoor air. The economizer was activated when the outdoor air dry-bulb temperature was below 65 °F. When it was active, it satisfied the cooling load with outside air (up to 100% of supply airflow) as long as the outside air temperature was less than 65 °F. The supply air temperature leaving the AHU was constant at 58 °F throughout the test. Electric heating coils were used for zone reheat. Return air was pulled back to the AHU by the return fan through the plenum.

The thermostat setpoints for all the test rooms were 73 °F and 72 °F for the cooling and the heating, respectively. Zone air flowrates for the exterior test rooms (east, south and west) were 700 CFM, and the zone air flowrate for the interior test room was 400 CFM. The baseboard heaters were used to provide internal sensible loading to the rooms. The baseboard heaters in the test rooms were scheduled as shown in Figure 4.9. The minimum outside air flowrates were scheduled with the economizer as shown in Figure 4.10. Although there is a minimum outside air flowrate schedule, outdoor air flowrates during the test never reached these minimum values.

The Dynamic Test with VAVRH System

The test was conducted from March 19, 1999 through March 22, 1999. The maximum, minimum and average dry bulb temperature at the site were 62°F, 27°F, and 41°F, respectively. Relative humidity values varied from a maximum of 91% to a minimum 20% with an average of 53%. Wind speed varied from 23.5 mph to 0.0 mph with an average of 5.8 mph. Sky conditions were sunny for the first 3 days and partly cloudy for the last day. Outside temperatures and solar data for these three days are presented in Figure 4.11 and Figure 4.12, respectively.

The air handling unit was operated in air-side economizer mode. The chiller was available for the test; however, most of cooling was accomplished with outdoor air. The control strategy of the economizer was the same as the dynamic test with CAVRH. The major difference between this test and the CAVRH dynamic test was to have a setback thermostat schedule. Electric baseboard heaters in the test rooms were used for the internal loads. The thermostat schedule is shown in Figure 4.13.

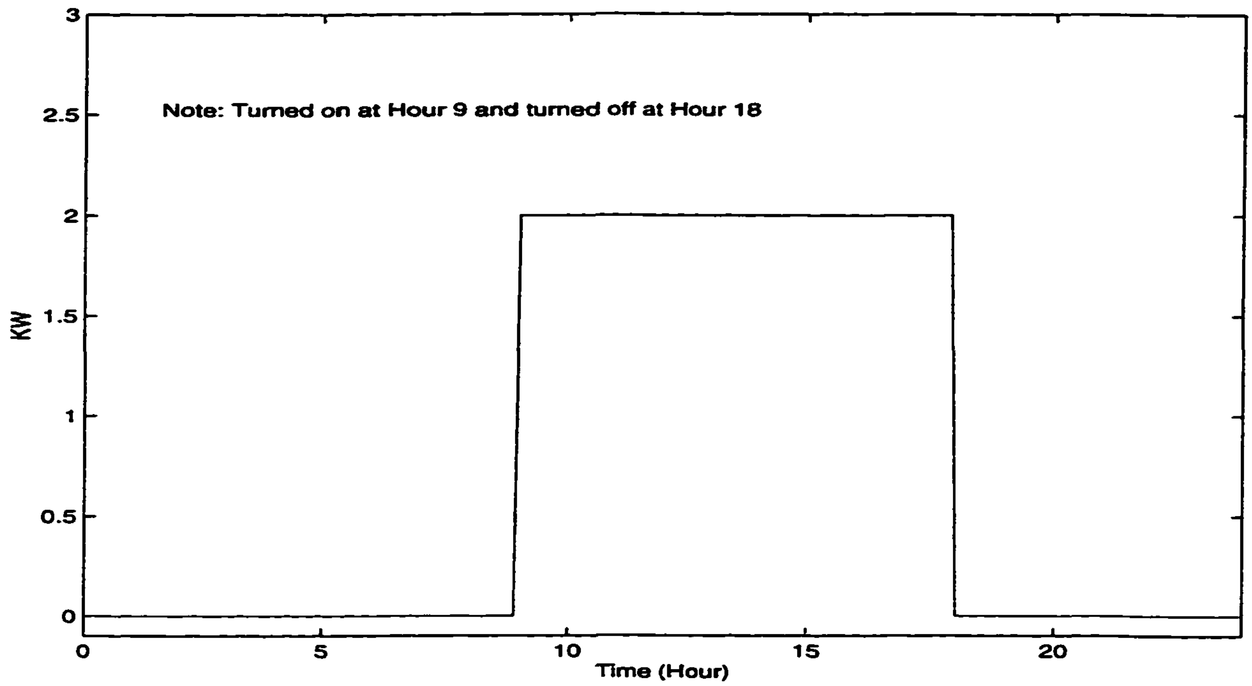


Figure 4.9 Each room's baseboard heaters schedule during the test period

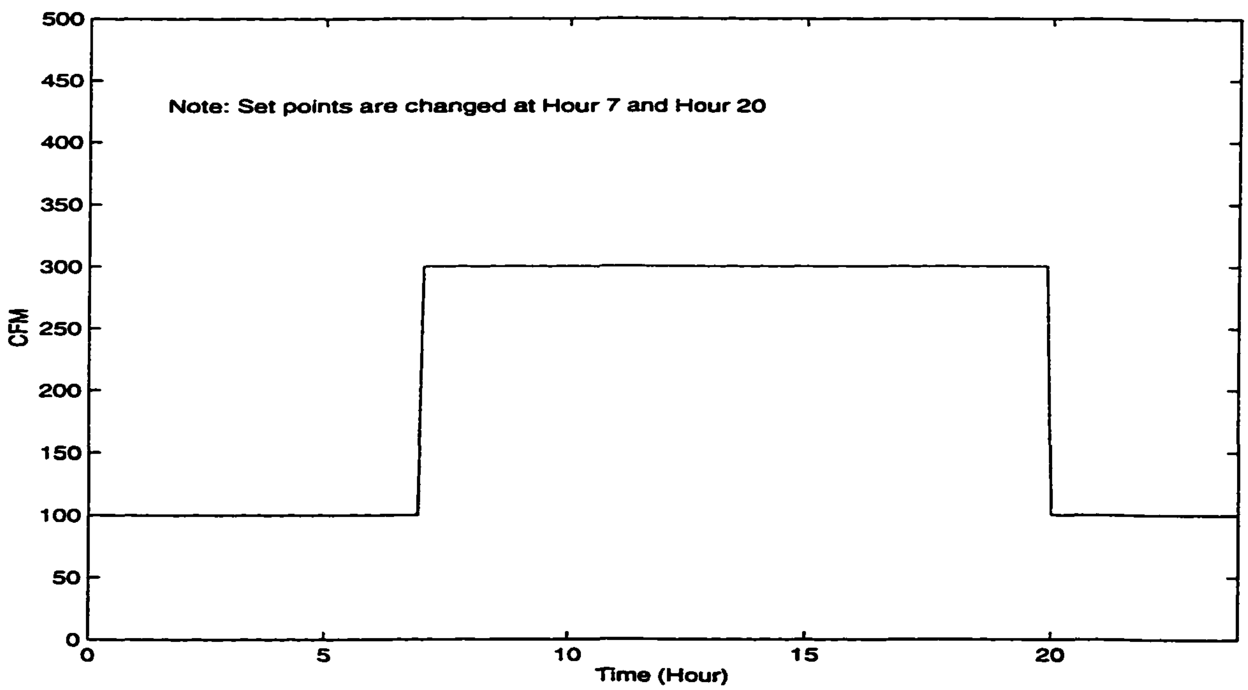


Figure 4.10 Minimum outside air flow rate schedule during the test period

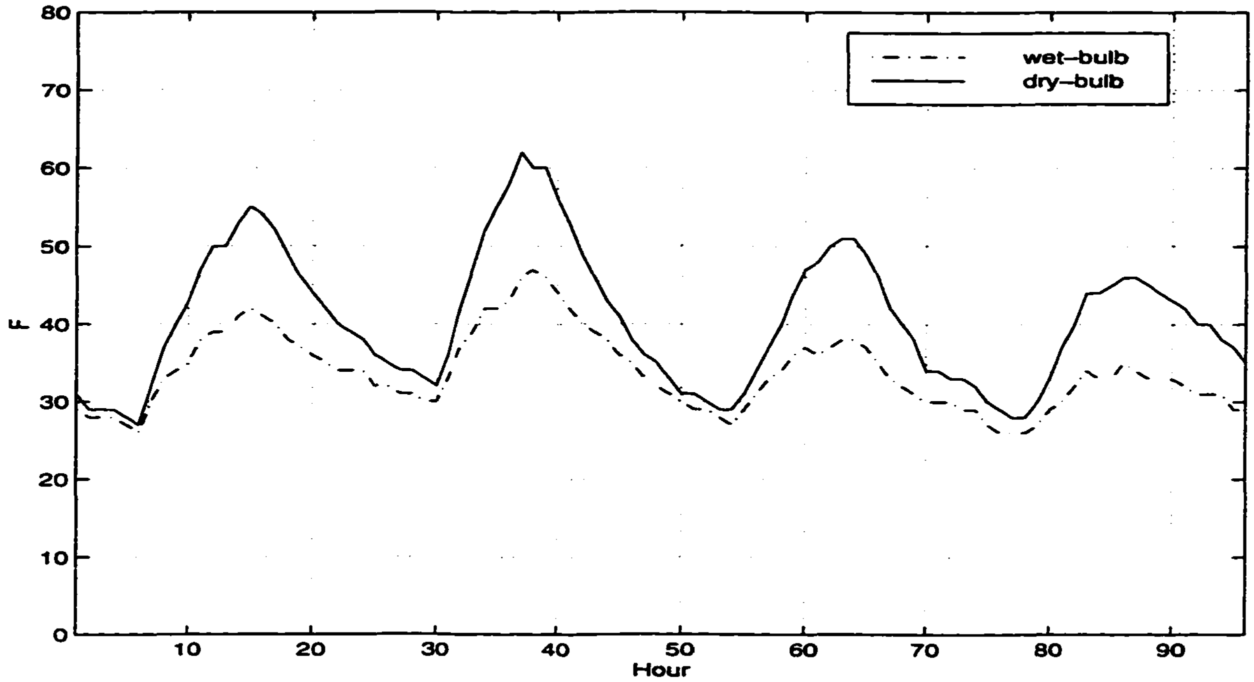


Figure 4.11 Outside air temperatures from 990319 through 990322

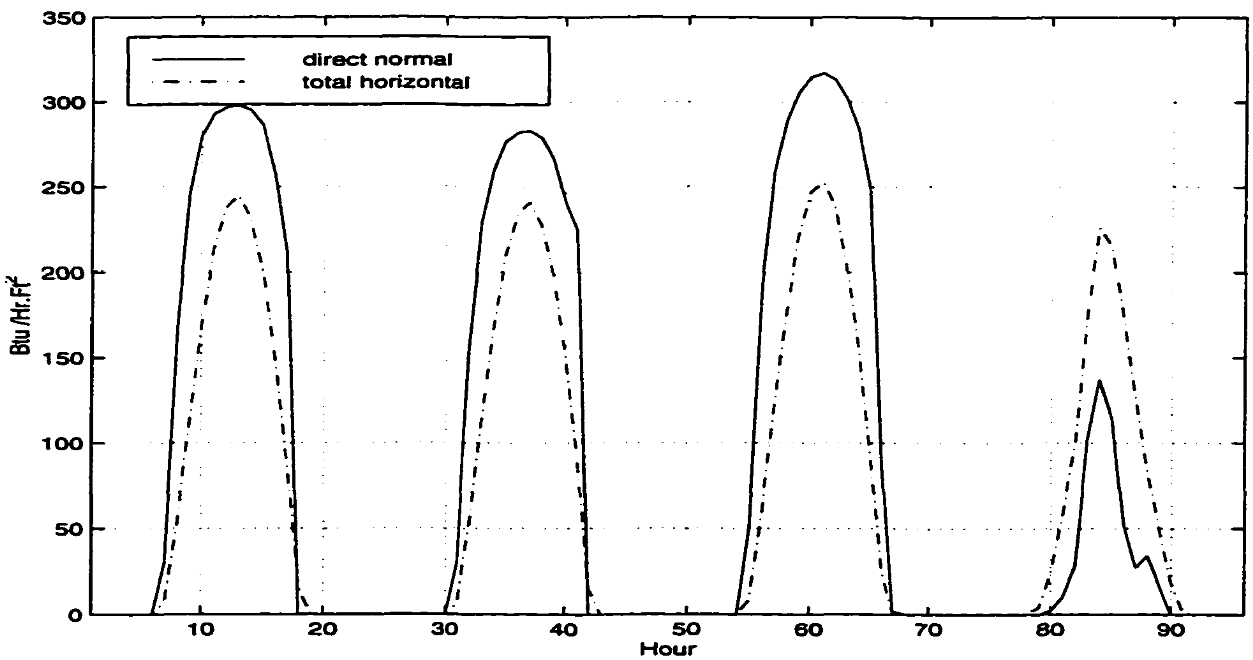


Figure 4.12 Solar fluxes from 990319 through 990322

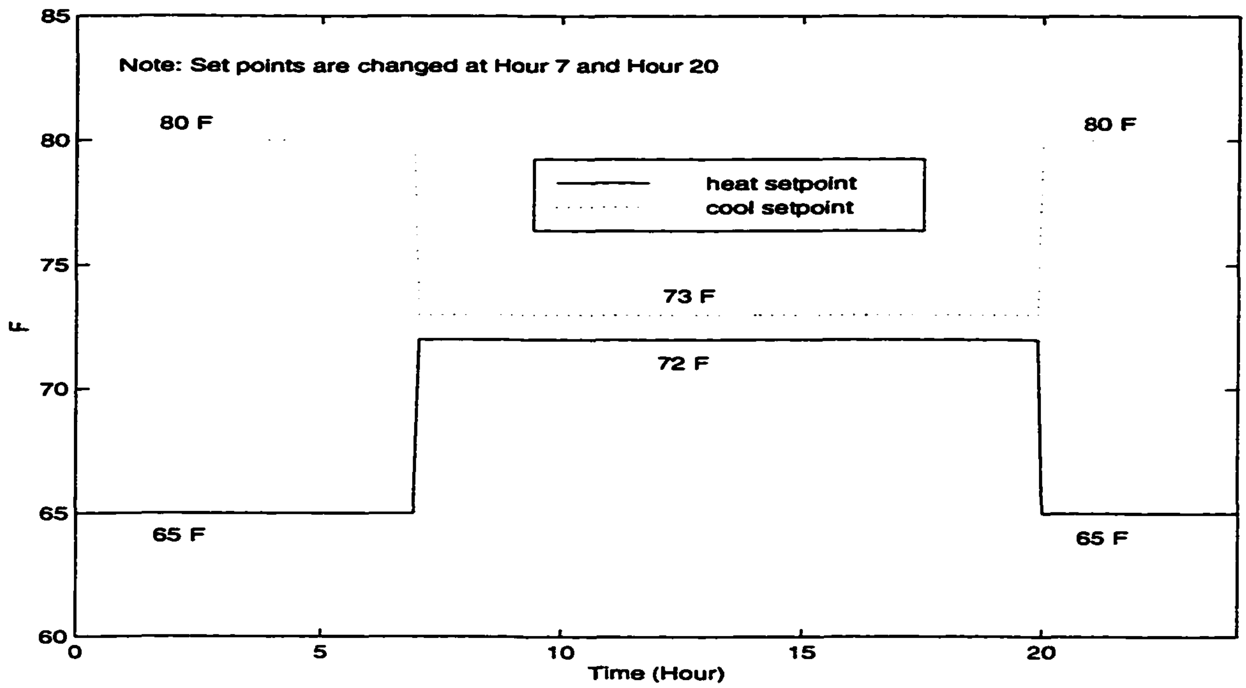


Figure 4.13 Each room's thermostat schedule during the test period

The baseboard heater schedule was the same as for the CAVRH test (see Figure 4.9).

Supply air temperature leaving the AHU was constant at 58 °F during the occupied period. The AHU fan was running during the occupied period. During the unoccupied period, the AHU fan would run only when any room had a demand for either heating or cooling in order to satisfy the thermostat setpoint. Electric heating coils were used for the zone reheat. Return air was pulled back to the AHU by the return fan through the plenum. The schedule for minimum outside air flow rates was the same as the CAVRH test (see Figure 4.10). Zone air flowrates for the exterior test rooms were allowed to vary from maximum 1000 CFM to minimum 450 CFM. The zone air flowrates for the interior test room were allowed to vary from maximum 550 CFM to minimum 270 CFM.

The Dynamic Test with 4PFCU System

The test was conducted from March 21, 1999 through March 23, 1999. The maximum, minimum and average dry bulb temperature at the site were 58°F, 26°F, and 40°F, respectively.

Relative humidity values varied from a maximum of 90% to a minimum 18% with an average of 46%. Wind speed varied from 16.4 mph to 0.0 mph with an average of 5.2 mph. Sky conditions were sunny for 2 days and partly cloudy for 1 day. Outside temperatures and solar data for these three days are presented in Figure 4.14 and Figure 4.15, respectively.

The major difference between this test and the non-dynamic test with 4FCU was the use of operation schedules. These included a night set-back room thermostat schedule and scheduled internal loads during typical occupancy periods for a building. Electric baseboard heaters in the test rooms were used to meet the scheduled internal loads. The thermostat schedule is shown in Figure 4.13. The baseboard heater time schedule was the same as other dynamic tests. However, for this test, only one stage (1 KW) of baseboard heater was used because of the limited cooling capacity of the FCU.

The fan speed of the FCUs was set at medium speed for the test period, 580 and 370 CFM for exterior rooms and an interior room, respectively. The fan was turned on only when cooling or heating demand existed in the rooms during the unoccupied period.

Test Having Daylight Control Strategy in the Building

Daylighting is the use of light from the sun and sky to complement or replace electric light. Appropriate fenestration and lighting controls are commonly used in commercial buildings to modulate daylight admittance and to reduce the need for electric lighting, while meeting the occupant's lighting quality and quantity requirements. Lighting and its associated cooling energy contribute from 30 to 40% of a commercial building's total energy usage according to Ernest (1997) the report, NBNL-39945, Ernest Orlando Lawrence Berkeley National Laboratory. Daylighting is the most cost effective strategy for targeting these uses, so many building energy simulation programs have been developed to model daylighting along with HVAC systems.

For the daylighting validation study, the VAVRH system was chosen. This test was conducted at the same time with VAVRH(1). The "B" test room were used for the daylighting study, and the "A" test rooms were used for VAVRH(1). Outside temperatures and solar data for these several days are presented in Figure 4.3 and Figure 4.4. These tests were conducted

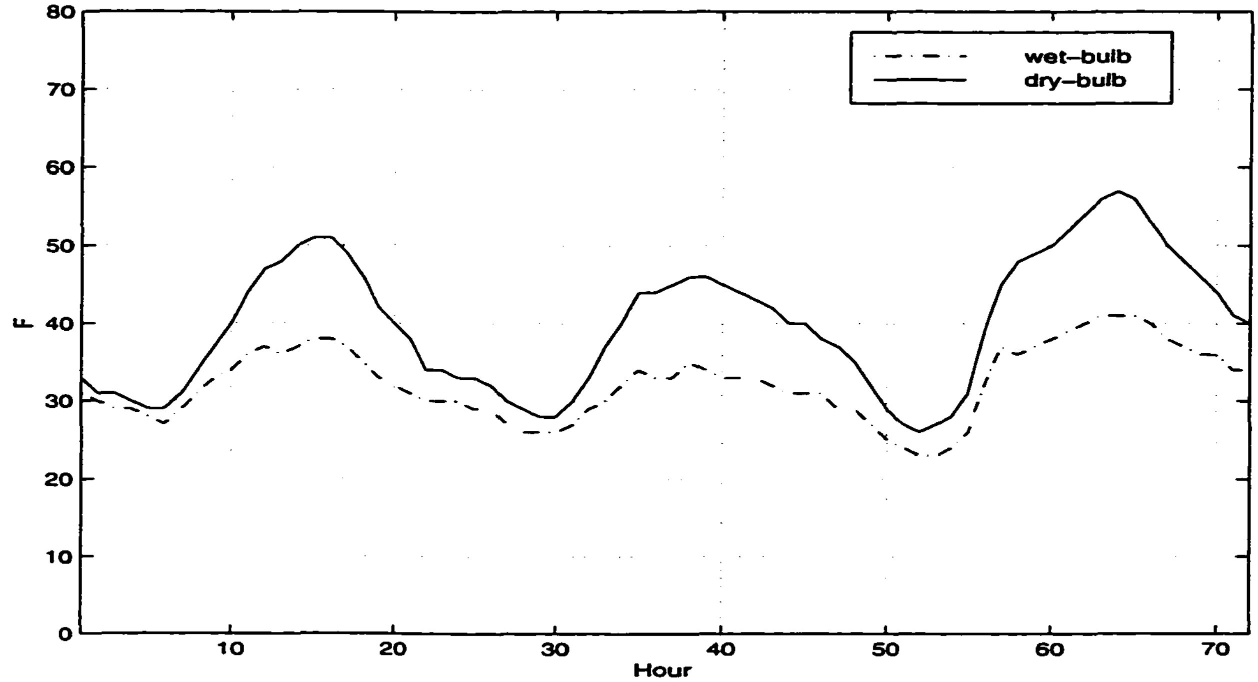


Figure 4.14 Outside air temperatures from 990321 through 990323

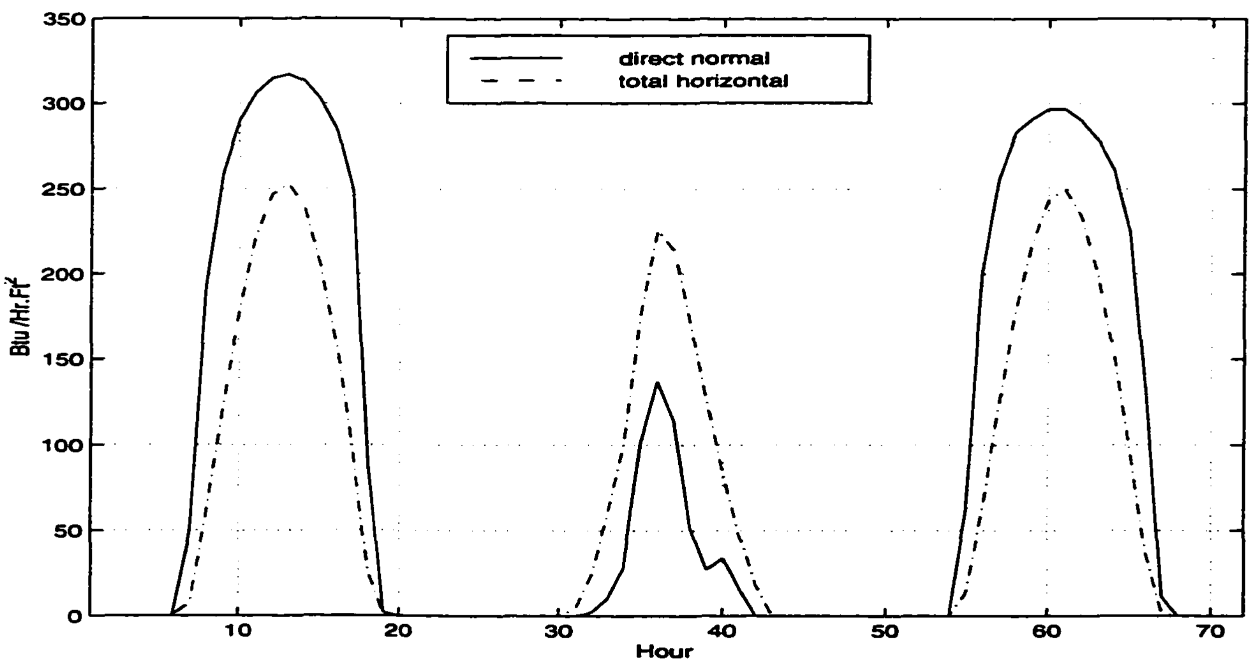


Figure 4.15 Solar fluxes from 990321 through 990323

from March 28 through March 31, 1999.

For the test, room set points were kept constant throughout the test at 73°F and 72°F for cooling and heating, respectively. Lights in the rooms were scheduled so that they were turned on at 6:00AM, about 1 hour before sunrise, and turned off at 8:00PM, about 1 hour after sunset. Ventilation air flow was set up to be equal to 30CFM throughout the test. The rest of the test conditions were the same as the non-dynamic VAVRH tests.

A daylighting sensor and a controller were installed in the ceiling of each room and the rooms' illumination was measured and controlled continuously by dimmable ballasts in order to maintain a minimum of 76 foot-candles during the test. Figure 4.16 shows the locations of the sensor and controller in each room.

Reference points are 10.4 foot distant from the window, 2.5 foot high from the floor. Specifications for the windows and surfaces of the rooms are described in Chapter 5, Computer Model. There were no blinds used in the exterior windows allow 100% daylight through the glass, and the windows in the interior walls were blocked with sheetrock so that the light cannot pass through the glass. Visible transmittance of the window glass is 0.73 and its inside reflectance is 0.16. The ceiling mounted lighting sensors were calibrated with a light meter. The range of the sensors is from 0 to 750 foot-candles.

The maximum lighting power for the test rooms are shown in Table 4.2. For the daylight control, the interior room did not use any daylight because there is no any exterior window in the room, but used 100 % of artificial light, 305W. The fraction values for the minimim powers are also given in Table 4.2.

Table 4.2 Lighting powers in the test rooms

Test rooms	A	B	Minimum %
East	481 W	487 W	30.2
South	478 W	497 W	31.8
West	477 W	449 W	26.5
Interior	328 W	305 W	-

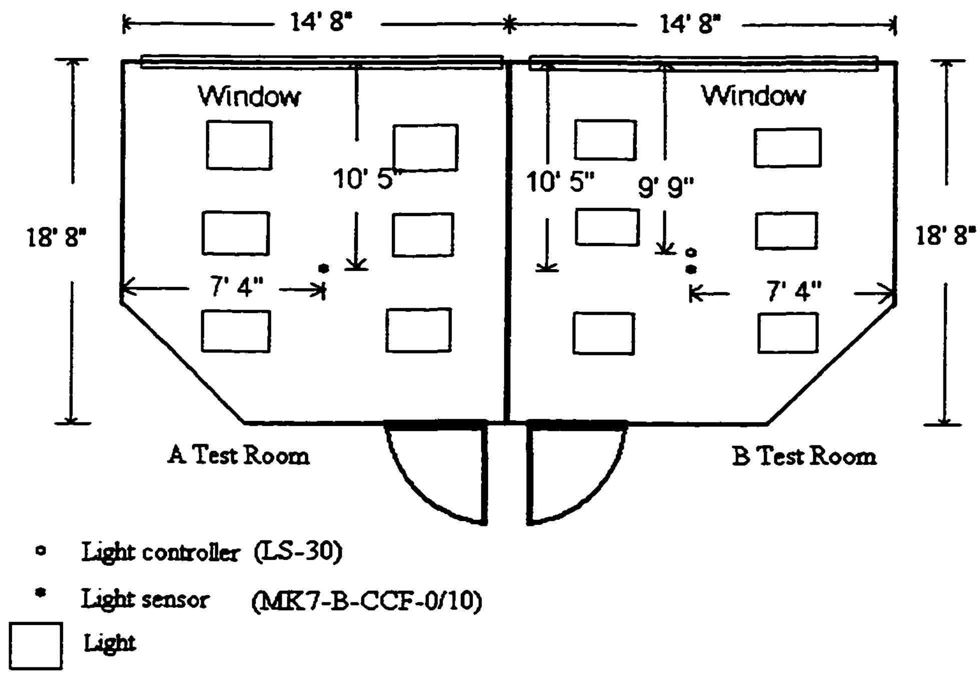


Figure 4.16 Layout of daylighting controller and sensor in each room

5 COMPUTER MODELS

This chapter describes the necessary information used in the computer models. The Energy Resource Station was modeled using DOE2, HAP and TRACE for the purposes of comparing thermal loads calculated by the programs to the thermal loads calculated from data collected by the building automation system. In general, the energy analysis programs divide the model input into four sections: a) LOADS, b) SYSTEM, c) PLANTS and d) ECONOMICS. For this study only the first two sections were extensively used. A minimal amount of plant input was specified, and no economics analysis was performed. Samples of the input files for DOE2, HAP and TRACE are presented in Appendices B, C and D, respectively.

A list of input parameters was created so that each computer model could be compared to the list and so that each computer model's input could be compared to the others. Before their simulation results can be compared to actual building performance data, it was necessary for their inputs to be verified as to whether they are the same as the actual building data.

Once the input parameters were verified the weather data collected at the site needed to be processed so that it could be used by the simulation programs. The site weather was measured during the testing periods. It was necessary to convert the weather data into various formats before they can be used by the simulation programs. Both DOE2 and HAP use TMY data format for their weather files, while TRACE uses its own data format. Modifying the TMY data is very important for this research because the prediction accuracy of the simulation software depends on the weather data. One of the important things is reconciling time conventions in the data because the TMY data uses apparent solar time while the site weather was based on local time.

Development of Input Files

This section describes the necessary information to create input files for the computer models. The information required by the computer models can be divided into three categories. They are information about the building structure, the operation schedules of the building, and the HVAC system configurations. While information about the building structure did not change, the other input categories changed according to the test being conducted.

Following sub-sections describe each room in the ERS including its size and orientation. In addition, they specify the material layers of each construction element in the room, which provide the computer model with information about the thermal properties of the construction element. In the same way, windows and doors in each room are identified, and their thermal properties are specified. The building operation schedule and HVAC system configurations were defined for each test in Chapter 4, Experimental Design.

Building Location

This specifies the location of the building and information about time.

- Latitude: 41.71 degrees North
- Longitude: 93.61 degrees West
- Altitude: 938.0 feet
- Time-zone: 6, central time zone in US

Building Shade

No surrounding objects block solar irradiation on the ERS. The surrounding ground cover is nearly all grass with a limited amount of concrete walkways approaching the building entrances.

Floor Plan

The floor plan is used to identify each space for the building model. In each computer model, it is necessary to identify location and orientation of the space. Figure 3.2 illustrates a simplified floor plan, and Figure 3.3 presents a 3-dimensional view of the building.

Construction Layer Description

This specifies the material layers of each construction element in the model. These include; the cross section of an exterior wall, interior wall, ceiling, door, underground floor and roof.

Layer Type Identification

Two different construction layers, bottom and top divide the exterior wall in a room. Top refers to the exterior wall above 8.5 feet (from ceiling to roof) and bottom refers to the exterior wall below 8.5 feet (from floor to ceiling). For the ERS, the top wall is an exterior wall for the plenum space of a room, and the bottom wall is an exterior wall for the conditioned space (or room).

Table 5.1 classifies construction layers used in the building. LAY-R* in the layer type in Table 5.1 is used for the roof of the building which is horizontal. LAY-W* is used for the exterior wall of the room which is vertical. LAY-P* is used for the interior wall of the room which is vertical. LAY-C1 is for the ceiling of the room, and LAY-F1 is for the floor of the room.

Layer Description

Layers for exterior walls and roofs are described from inside to outside. Layer type refers to the layer identification in the previous section. Table 5.2 describes thickness and thermal properties of materials used for the construction layers, where

T: thickness in inch

K: conductivity, Btu/hr-ft-°F

D: density, lb/ft^2

Cp: specific heat, Btu/lb-°F

R: resistance, hr-ft^2-°F/Btu.

The inside film resistance of walls, ceilings and floors, which is the combined convective and radiative air film-resistance for the inside wall surface, is 0.68. For the outside film resistance

Table 5.1 Identification of construction layers used in the ERS building

Layer type	Description
LAY-R1	Layers for the roof of all spaces except for the classroom
LAY-R2	Layers for the roof of the classroom
LAY-W1	Layers for the exterior wall in bottom of test rooms
LAY-W2	Layers for the exterior wall in top of test rooms
LAY-W3	Layers for the spandrel wall in bottom of computer room and office
LAY-W4	Layers for the exterior wall in top of computer room and office
LAY-W5	Layers for the exterior wall of the classroom
LAY-W6	Layers for the exterior wall in bottom of the other spaces
LAY-W7	Layers for the exterior wall in top of the other spaces
LAY-P1	Layers for the 6-inch interior partition wall of all spaces
LAY-P2	Layers for the 4-inch interior partition wall of all spaces
LAY-P3	Layers for the 1/8-inch interior glass partition wall of test rooms
LAY-P4	Layers for the door of all spaces
LAY-C1	Layers for the ceiling of all spaces
LAY-F1	Layers for the ground floor of all spaces

value is calculated by the simulation programs based on TMY weather data. Solar absorptances for the exterior walls and the roof are 0.6 and 0.29, respectively.

Window Types and Description

This section specifies the type of glass used in a window, and the size and location of the window. This is used to describe the window in an exterior wall or skylight in a roof. Each type of window has information about number of panes, shading coefficient, heat conductance of the total window (except for the outside film coefficient), width and height of the window. The windows in the exterior wall are located 3.5 feet above the floor level, and the skylight is on the roof of the media center. The glass conductance does not include the outside film coefficient but does include the frame. Table 5.3 identifies window type and illustrates its position, size, shading coefficient and conductance, where

W: width, feet

H: height, feet

P: number of panes

Table 5.2 Thickness and thermal properties used for construction layers

Layer type	Description	T	K	D	Cp	R
LAY-R1	Inside surface					
	2 in heavy weight concrete	2.00	0.7576	140	0.2	0.22
	4 in horizontal air space	4.00	-	-	-	0.87
	2 in heavy weight concrete	2.00	0.7576	140	0.2	0.22
	Vapor barrier	-	-	-	-	0.06
	4 in insulation	4.00	0.0133	1.5	0.38	25.06
	Single-ply membrane	-	-	70	0.35	0.44
	Washed river rock	1.00	0.8340	55	0.4	0.10
	Outside surface					
LAY-R2	Inside surface					
	22 gage steel deck	0.034	26.0	480	0.1	-
	4 in insulation	4.00	0.0133	1.5	0.38	25.06
	Single-ply membrane	-	-	70	0.35	0.44
	Washed river rock	1.00	0.8340	55	0.4	0.10
	Outside surface					
LAY-W1	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Vapor barrier	-	-	-	-	0.06
	3/8 in vertical air space	0.38	-	-	-	0.90
	1.5 in rigid insulation with foil face	1.50	0.0133	1.5	0.38	9.39
	4 in pre-cast conc.	4.00	0.7576	140	0.2	0.44
	Outside surface					
LAY-W2	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	3/8 in vertical air space	0.38	-	-	-	0.90
	1 in rigid insulation with foil face	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
	Outside surface					
LAY-W3	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Vapor barrier	-	-	-	-	0.06
	Metal stud framing with R13 batt with foil face	3.50	0.0250	0.6	0.2	12.96
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	4.75 in vertical air space	4.75				0.92
	1 in spandrel glass	1.00	-	-	-	2.08
	Outside surface					
LAY-W4	Inside surface					
	Metal stud framing with R13 batt with foil face	3.50	0.0250	0.6	0.2	12.96
	3/4 in vertical air space	0.75	-	-	-	0.90
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
	Outside surface					

Table 5.2 (Continued)

Layer type	Description	T	K	D	Cp	R
LAY-W5	Inside surface					
	3/4 in gypsum board	0.75	0.0926	50	0.2	0.67
	Vapor barrier	-	-	-	-	0.06
	Metal stud framing with R13 batt with foil face	3.50	0.0250	0.6	0.2	12.96
	1 3/8 in vertical air space	1.38	-	-	-	0.89
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
	Outside surface					
LAY-W6	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Vapor barrier	-	-	-	-	0.06
	Metal stud framing with R13 batt with foil face	3.50	0.0250	0.6	0.2	12.96
	3/4 in vertical air space	0.75	-	-	-	0.90
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	4 in pre-cast conc.	4.00	0.7576	140	0.2	0.44
	Outside surface					
LAY-W7	Inside surface					
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Metal stud framing with R13 batt with foil face	3.50	0.0250	0.6	0.2	12.96
	3/4 in vertical air space	0.75	-	-	-	0.90
	1 in rigid insulation	1.00	0.0133	1.5	0.38	6.26
	6 in pre-cast conc.	6.00	0.7576	140	0.2	0.66
	Outside surface					
LAY-P1	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Metal stud framing with fiberglas fill	3.50	0.0225	3.0	0.33	12.96
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
LAY-P2	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
	Metal stud framing with fiberglas fill	2.37	0.0225	3.0	0.33	8.78
	5/8 in gypsum board	0.63	0.0926	50	0.2	0.56
LAY-P3	1/8 in glass with steel frame	1/8	0.797	138	0.18	0.013
LAY-P4	Door	1.75	-	-	-	4.16
LAY-C1	Ceiling	0.75	0.033	18	0.32	1.89
LAY-F1	Carpet	-	-	-	0.34	1.23
	4 in heavy weight conc.	4.00	0.7576	140	0.20	0.44
	Perimeter insulation with a 2 inch wide	-	-	-	-	5.00

Table 5.3 Window identification and its characteristics with size

Type	Location	W	H	P	S	C
WIN-TEST	Exterior wall in test rooms	14.0	5	2	0.85	0.55
WIN-TYP1	Exterior wall east in the office	11.8	5	2	0.31	0.30
WIN-TYP2	Exterior wall south in the office	15.3	5	2	0.31	0.30
WIN-TYP3	Exterior wall south in the computer room	15.3	5	2	0.31	0.30
WIN-TYP4	Exterior wall west in the computer room	24.0	5	2	0.31	0.30
WIN-TYP5	Exterior wall south in the classroom	3.5	5	2	0.31	0.30
WIN-TYP6	Exterior wall west in the classroom	7.0	5	2	0.31	0.30
WIN-TYP7	Exterior wall north in the classroom	3.5	5	2	0.31	0.30
WIN-TYP8	Exterior wall east in the reception room	7.9	5	2	0.31	0.30
WIN-TYP9	Door in vest east and west	3.0	7.0	2	0.31	0.30
WIN-SKY	Roof of the media center	10.0	10	1	0.35	0.24

S: shading coefficient

C: heat conductance of the total window, Btu/hr-ft^2-°F.

Space Description

This section identifies each space. Once all spaces have been identified, then each surface of the space is described in terms of orientation, width, height and construction layer. Gross surface areas are presented in this section. Thus, the areas include door and/or window areas. Window data were presented in Table 5.3. The size of a door is 3 feet wide and 7 feet tall.

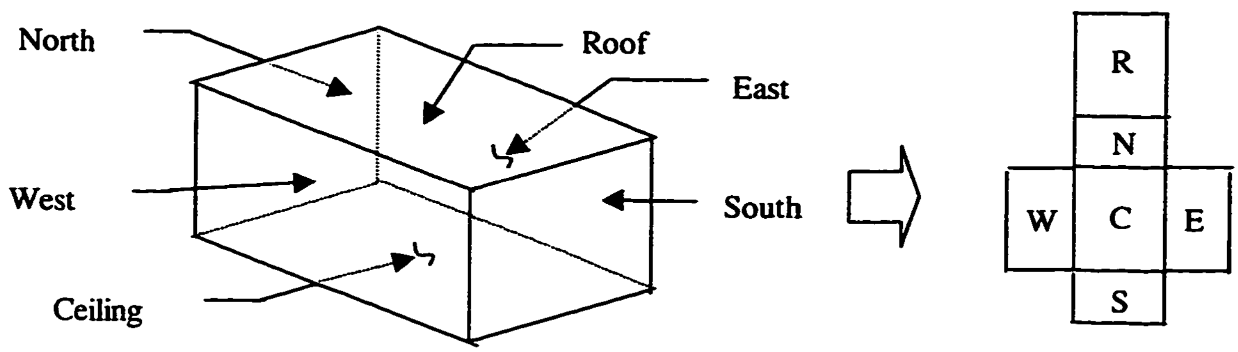
Space Identification and Description

Each space has at least six surfaces associated with it, but for simplification, it is assumed that all spaces have six surfaces. For a better understanding of the surface geometry, a capital letter representing the position of the surface is used. Figure 5.1 illustrates the surface arrangements with following symbols.

C: a horizontal surface used for the ceiling

E: a vertical surface used for the wall east

- Geometry presentation for plenum spaces



- Geometry presentation for conditioned spaces

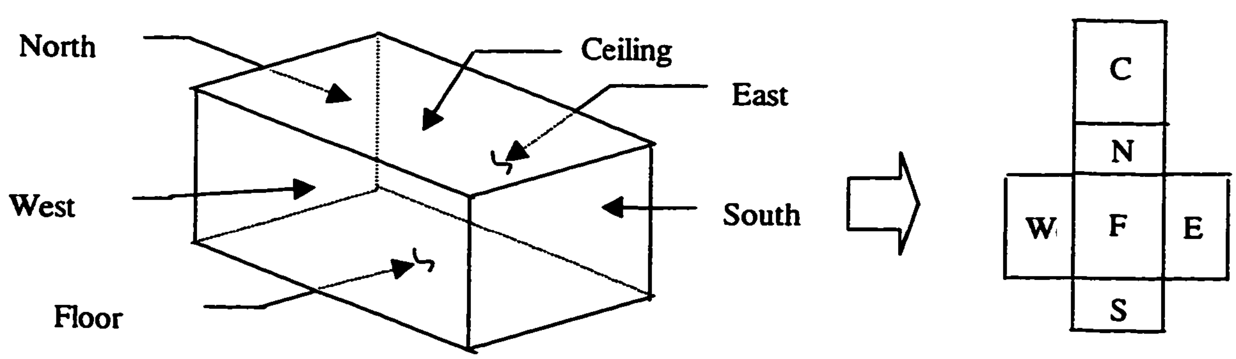


Figure 5.1 Geometry presentation of plenum and conditioned spaces

F: a horizontal surface used for the floor

N: a vertical surface used for the wall north

R: a horizontal surface used for the roof

S: a vertical surface used for the wall south

W: a vertical surface used for the wall west

Most of the rooms have a plenum space and a conditioned space. The mechanical room and storage room do not have plenum spaces. The ceiling height of most rooms is 8.5 feet, and the plenum height is 5.5 feet. Since the test rooms are matched pairs, information provided on each orientation applies to either room. Table 5.4 identifies a space as either plenum space or conditioned space. Plenum space is designated with the prefix "P". Table 5.5 describes the spaces identified in Table 5.4 with detailed information about the surfaces. All walls used in the building are vertical, and the ceiling, roof and floor are horizontal. This building is oriented for a true north/south. In the same way, the space identified in Table 5.5 was described by surface orientation such as north, east, south and west. For example, "P-EAST", a plenum space in the test room east is located on the east side of the building at FL+8.5. It is surrounded by six surfaces: one east-facing exterior wall, one interior wall north, one interior wall south, one interior wall west, one ceiling and one roof. Once the surface orientations are specified, detailed information about the six surfaces which make up "P-EAST" must be provided. This includes the size of the surface, the construction layer of the surface, and any windows or doors, if present.

For another example for a conditioned space called "SOUTHROOM", it is located on the south side of the building at FL+0.0. This space also is surrounded by six surfaces: one south-facing exterior wall that has a window, one north-facing interior wall that has a door, one east-facing interior wall, one west-facing interior wall that is adjacent to the computer room, one ceiling that is adjacent to the plenum space called "P-SOUTH", one floor.

Table 5.4 Identification of plenum and conditioned space

Space-ID	Description
P-EAST	Plenum in the test room east
P-SOUTH	Plenum in the test room south
P-WEST	Plenum in the test room west
P-INTE	Plenum in the test room interior
P-BREAK	Plenum in the break room, restroom of women and men
P-RECEPT	Plenum in the reception room
P-OFFICE	Plenum in the office
P-COMPUTE	Plenum in the computer center
P-CLASS	Plenum in the classroom
P-DISPLAY	Plenum in the display room
P-MEDIA	Plenum in the media center
EASTROOM	Conditioned space in the test room east
SOUTHROOM	Conditioned space in the test room south
WESTROOM	Conditioned space in the test room west
INTEROOM	Conditioned space in the test room interior
BREAKROOM	Conditioned space in the break room, restrooms of women and men
RECEPTION-RM	Conditioned space in the reception room
OFFICE	Conditioned space in the office
COMPUTE-RM	Conditioned space in the computer center
CLASSROOM	Conditioned space in the classroom
DISPLAY-RM	Conditioned space in the display room
STORAGE-RM	Conditioned space in the storage room, elec.room
MEDIA-CENTER	Conditioned space in the media center
MECH-ROOM	Conditioned space in the mechanical room

Table 5.5 Description of the space and details of its six surfaces

Space	Orientation	Width (ft)	Height (ft)	Layer	Window	Door
P-EAST	R	17.74	15.50	LAY-R1	-	-
	C	17.74	15.50	LAY-C1	-	-
	N	17.74	5.50	LAY-P2	-	-
	E	15.50	5.50	LAY-W2	-	-
	S	17.74	5.50	LAY-P2	-	-
	W	15.50	5.50	LAY-P1	-	-
P-SOUTH	R	15.50	17.74	LAY-R1	-	-
	C	15.50	17.74	LAY-C1	-	-
	N	15.50	5.50	LAY-P2	-	-
	E	17.74	5.50	LAY-P2	-	-
	S	15.50	5.50	LAY-W2	-	-
	W	17.74	5.50	LAY-P1	-	-
P-WEST	R	17.74	15.50	LAY-R1	-	-
	C	17.74	15.50	LAY-C1	-	-
	N	17.74	5.50	LAY-P2	-	-
	E	15.50	5.50	LAY-P1	-	-
	S	17.74	5.50	LAY-P2	-	-
	W	15.50	5.50	LAY-W2	-	-
P-INTE	R	15.50	17.74	LAY-R1	-	-
	C	15.50	17.74	LAY-C1	-	-
	N	15.50	5.50	LAY-P2	-	-
	E	17.74	5.50	LAY-P2	-	-
	S	15.50	5.50	LAY-P2	-	-
	W	17.74	5.50	LAY-P1	-	-
P-BREAK	R	10.66	36.60	LAY-R1	-	-
	C	10.66	36.60	LAY-C1	-	-
	N	10.66	6.00	LAY-P2	-	-
	E	36.60	6.00	LAY-W7	-	-
	S	10.66	6.00	LAY-P2	-	-
	W	36.60	6.00	LAY-P2	-	-
P-RECEPT	R	17.74	13.00	LAY-R1	-	-
	C	17.74	13.00	LAY-C1	-	-
	N	17.74	5.50	LAY-P2	-	-
	E	13.00	5.50	LAY-W4	-	-
	S	-	-	-	-	-
	W	-	-	-	-	-
P-OFFICE	R	16.40	12.10	LAY-R1	-	-
	C	16.40	12.10	LAY-C1	-	-
	N	-	-	-	-	-
	E	12.10	5.50	LAY-W4	-	-
	S	16.40	5.50	LAY-W4	-	-
	W	12.10	5.50	LAY-P1	-	-
P-COMPUTE	R	16.30	25.10	LAY-R1	-	-
	C	16.30	25.10	LAY-C1	-	-
	N	16.30	5.50	LAY-P2	-	-
	E	25.10	5.50	LAY-P1	-	-
	S	16.30	5.50	LAY-W4	-	-
	W	25.10	5.50	LAY-W4	-	-
P-CLASS	R	22.20	34.67	LAY-R2	-	-
	C	22.20	34.67	LAY-C1	-	-
	N	22.20	1.00	LAY-W5	-	-
	E	-	-	-	-	-
	S	22.20	1.00	LAY-W5	-	-
	W	34.67	1.00	LAY-W5	-	-
P-DISPLAY	R	17.83	17.74	LAY-R1	-	-
	C	17.83	17.74	LAY-C1	-	-
	N	17.83	5.50	LAY-P2	-	-
	E	17.74	5.50	LAY-P1	-	-
	S	-	-	-	-	-
	W	-	-	-	-	-
P-MEDIA	R	30.00	60.80	LAY-R1	-	-
	C	30.00	57.20	LAY-C1	-	-
	N	-	-	-	-	-
	E	-	-	-	-	-
	S	-	-	-	-	-
	W	6.00	5.50	LAY-W7	-	-
EASTROOM	C	17.74	15.50	LAY-C1	-	-
	F	17.74	15.50	LAY-F1	-	-
	N	17.74	8.50	LAY-P2	-	-
	E	15.50	8.50	LAY-W1	WIN-TEST	
	S	17.74	8.50	LAY-P2	-	-
	W	15.50	8.50	LAY-P3	-	LAY-P4

Table 5.5 (Continued)

Space	Orientation	Width (ft)	Height (ft)	Layer	Window	Door
SOUTHROOM	C	15.50	17.74	LAY-C1	-	-
	F	15.50	17.74	LAY-F1	-	-
	N	15.50	8.50	LAY-P3	-	LAY-P4
	E	17.74	8.50	LAY-P2		-
	S	15.50	8.50	LAY-W1	WIN-TEST	
	W	17.74	8.50	LAY-P1	-	-
WESTROOM	C	17.74	15.50	LAY-C1	-	-
	F	17.74	15.50	LAY-F1	-	-
	N	17.74	8.50	LAY-P2	-	-
	E	15.50	8.50	LAY-P3	-	LAY-P4
	S	17.74	8.50	LAY-P2	-	-
	W	15.50	8.50	LAY-W1	WIN-TEST	
INTEROOM	C	15.50	17.74	LAY-C1	-	-
	F	15.50	17.74	LAY-F1	-	-
	N	15.50	8.50	LAY-P2	-	-
	E	17.74	8.50	LAY-P2	-	-
	S	15.50	8.50	LAY-P3	-	LAY-P4
	W	17.74	8.50	LAY-P1	-	-
BREAKROOM	C	10.66	36.60	LAY-C1	-	-
	F	10.66	36.60	LAY-F1	-	-
	N	10.66	8.00	LAY-P2	-	-
	E	36.60	8.00	LAY-W6	-	-
	S	10.66	8.00	LAY-P2	-	-
	W	36.60	8.00	LAY-P2	-	LAY-P4
RECEPTION-RM	C	17.74	13.00	LAY-C1	-	-
	F	17.74	13.00	LAY-F1	-	-
	N	17.74	8.500	LAY-P2	-	-
	E	13.00	8.50	LAY-W4	WIN-TYP8	
	S	17.74	8.50	LAY-P2	-	-
	W	-	-		-	-
OFFICE	C	16.40	12.10	LAY-C1	-	-
	F	16.40	12.10	LAY-F1	-	-
	N	16.40	8.50	LAY-P2	-	LAY-P4
	E	12.10	8.50	LAY-W3	WIN-TYP1	-
	S	16.40	8.50	LAY-W3	WIN-TYP2	-
	W	12.10	8.50	LAY-P1	-	-
COMPUTER-RM	C	16.30	25.10	LAY-C1	-	-
	F	16.30	25.10	LAY-F1	-	-
	N	16.30	8.50	LAY-P2	-	-
	E	25.10	8.50	LAY-P1	-	LAY-P4
	S	16.30	8.50	LAY-W3	WIN-TYP3	-
	W	25.10	8.50	LAY-W3	WIN-TYP4	-
CLASSROOM	C	22.20	34.67	LAY-C1	-	-
	F	22.20	34.67	LAY-F1	-	-
	N	22.20	9.00	LAY-W5	WIN-TYP7	-
	E	34.16	9.00	LAY-P1	-	LAY-P4
	S	22.20	9.00	LAY-W5	WIN-TYP5	-
	W	34.67	9.00	LAY-W5	WIN-TYP6	-
DISPLAY-RM	C	17.83	17.74	LAY-C1	-	-
	F	17.83	17.74	LAY-F1	-	-
	N	17.83	8.50	LAY-P2	-	-
	E	17.74	8.50	LAY-P1	-	-
	S	17.83	8.50	LAY-P2	-	LAY-P4
	W	17.74	8.50	LAY-P2	-	-
STORAGE-RM	C	10.55	25.30	LAY-C1	-	-
	F	10.55	25.30	LAY-F1	-	-
	N	10.55	14.00	LAY-W6	-	-
	E	25.30	14.00	LAY-W6	-	-
	S	10.55	14.00	LAY-P2	-	-
	W	15.30	14.00	LAY-P2	-	LAY-P4
MEDIA-CENTER	R	10.50	10.50	LAY-R1	WIN-SKY	-
	C	30.00	57.20	LAY-C1	-	-
	F	30.00	60.80	LAY-F1	-	-
	N	-	-	-	-	-
	E	-	-	-	-	-
	S	-	-	-	-	-
	W	6.00	8.50	LAY-W6	WIN-TYP9	-
MECH-ROOM	R	66.30	30.60	LAY-R1	-	-
	F	66.30	30.60	LAY-F1	-	-
	N	57.80	14.00	LAY-W7	-	-
	E	25.30	14.00	LAY-P2	-	-
	S	57.80	14.00	LAY-P2	-	LAY-P4
	W	25.30	14.00	LAY-W7	-	-

Development of Verification Reports

These reports were used to verify the input data that was created by each computer model. The reports included physical and thermal property data of the building, geographical and weather data of the site, and set points of the HVAC systems and rooms. Information in these reports should be matched among the three models: DOE2, HAP and TRACE.

Verification of Physical and Thermal Property Data

This report was created to confirm whether every model had the same input information for the size of rooms, orientations of the rooms and walls and construction types.

First the summary of spaces occurring in the model was used to verify number of spaces, number of exterior walls, and space information: name, height, area.

Second the details of exterior surfaces occurring in the model was used to verify number of exterior surfaces and surface information: name, height, width, azimuth angle, tilt angle and U-value.

Third the details of interior surfaces occurring in the model was used to verify number of interior surfaces and surface information: name, area and U-value.

Finally the details of windows occurring in the model was used to verify number of windows and window information: name, height, width, shading coefficient and U-value.

Verification of Geographical and Weather Data

This report was used to examine whether each model used the same weather conditions for its model. Geographical data was used to verify latitude, longitude, altitude and time zone.

Hourly weather data was used to verify information for month, day, hour, outside air-dry bulb temperature, wet-bulb temperature, direct normal solar irradiation, and total horizontal solar irradiation.

Verification of Set Points

This report was used to examine whether each model used the same information for the thermostat set points, design room air flow rates, supply air temperature and outside air flow rates.

First the zone report was used to verify information for month, day, hour, zone temperature and design air flow rate. The system report was used to verify information for month, day, hour, design supply air flow rate, design outside air flow rate, temperatures of air entering and leaving cooling coil, and return air temperature.

Development of Simulation Weather

In order to best match actual building energy usage with predicted energy use, the weather data used by the building energy software must be modified to reflect actual weather conditions at the site. A weather station plus solar instrumentation was installed at the ERS to collect the site weather data. This weather station collects dry bulb temperature, relative humidity, wind speed, wind direction, and atmospheric pressure. The solar instrument measures direct normal solar flux and global horizontal solar flux. Data collection is performed by the building automation system on a one minute interval basis. The collected data are stored on the hard disk of the desktop computer and periodically downloaded to magnetic tape permanent storage.

The ERS weather data files must be converted to various formats before they can be used by the simulation software. This conversion process includes changing to appropriate units and calculating hourly values. Once the conversion work was performed, the hourly data set was used to modify the original TMY data set for Des Moines, Iowa.

Both DOE-2 and HAP use TMY data format for their weather files, while TRACE uses its own data format. Modifying the TMY data is very important for this research project because the prediction accuracy of the simulation software depends on the weather data. Raw weather data needs several steps of modification to produce the needed weather data format. One of these steps is reconciling time conventions in the data. The TMY format uses time indices 1-24 where 1 is 1:00 am apparent solar time and 24 is 12:00 midnight apparent solar time. Solar radiation data for a particular hour represents solar flux received during the prior one hour period (e.g., solar data for hour #10 represents the flux received between 9:00 and 10:00 apparent solar time). Therefore, adhering to this convention is important because ultimately angles of incidence are paired with the data to determine solar fluxes on the building surfaces. Calculations to determine solar fluxes for a particular time on the building surfaces are performed by the simulation programs.

Since solar time does not coincide with local standard time, two corrections are required to convert standard time to solar time. First, there is a constant correction for the difference in longitude between the observer's meridian (longitude) and the meridian on which the local standard time is based. For the ERS building, the meridian is 90 °W (Central time zone). The sun takes 4 minutes to traverse 1° of longitude. The second correction is from the equation of time, which takes into account the perturbations in the earth's rate of rotation which affect the time the sun crosses the observer's meridian. The difference in minutes between solar time and standard time is

$$Solartime - Standardtime = 4(Lst - Lloc) + E \tag{5.1}$$

where Lst is the standard meridian (90°W) for the local time zone. $Lloc$ is the longitude of the location in question (93.7 °W). If daylight saving time is in effect, then one must subtract 1 hour to obtain the standard time. The equation of time E (in minutes) is determined from

$$E = 229.2(0.000075 + 0.001868cos(B) - 0.032077sin(B) - 0.014615cos(2B) - 0.04089sin(2B)) \tag{5.2}$$

where B = (n - 1) and n = day of the year.

As noted earlier, the solar instruments are calibrated to produce a solar power flux measurement (Btu/hr-ft^2). The solar data are collected on a 1-minute interval basis. At the end of the test period, these data are converted to an energy flux by integrating the power flux data over a specific time period. This time period is one hour since this is what is required for the TMY format. It should also be noted that the value of the energy flux which has occurred during the 1-hour period must be based on solar time rather than local time as is the convention used in the TMY format.

Both the DOE-2 and HAP programs use the TMY data format. TMY data contains much more information than is required by either program. The TMY data actually used by DOE-2 and HAP programs are marked with "O" in Table 5.6. The weather data processing procedure is outlined in Figure 5.2. To execute the above tasks, various FORTRAN programs were written. The program listings are included in the Appendix E.

Standard TRACE weather files are derived from data collected by either the U.S. Department of Commerce Climate Center (USDCCC) or the National Oceanic and Atmospheric Administration (NOAA). Using NOAA data or USDCCC data, the 8,760 hours of data is modified by a data reduction program to produce 12 "typical days", which represent the effective weather profile for one month. Therefore, the building thermal loads calculated by TRACE are for each "typical day". Each day consists of 24 hours of weather data.

In this research project the TRACE weather files were modified by replacing the "typical" data with actual weather data for one day. For example, weather data collected at the ERS for March 1 was substituted in the TRACE weather file for the "typical" day in March. This provides a way of comparing the heating and cooling loads calculated by TRACE to be compared with the building data collected on March 1. The TRACE program assumes the 21^{st} day of the month for purpose of solar angle calculation.

Hourly weather data required by the TRACE program for energy simulation includes dry bulb and wet bulb temperatures, humidity ratio, wind speed, barometric pressure and a cloud cover modifier. The cloud cover modifier represents the amount of clear sky not obscured by clouds. Thus a clear sky has a modifier of 1 while a completely overcast sky has a modifier of 0. Another way to express this is

$$CCM = 1 - SC \tag{5.3}$$

where CCM is the cloud cover modifier and SC is the fraction of sky which is covered by clouds. An approximation for estimating SC, which was suggested by Lamas et al. (1994), is given by

$$SC = (\frac{I_{DF}}{I_{TH}})^2 \tag{5.4}$$

where I_{DF} is the diffuse irradiation on a horizontal surface and I_{TH} is the total irradiation on a horizontal surface.

Table 5.6 TMY (Typical Meteorological Year) data format

Contents of TMY data format	DOE2	HAP
WBAN station number		
Year of observation (00 ~ 99 = 1900 ~ 1999)	O	O
Month of observation (01 ~ 12)	O	O
Day (01 ~ 31)	O	O
Solar time at end of hourly observation 0001 ~ 2400	O	O
Local standard time corresponding to the solar time	O	
Extraterrestrial radiation kJ/m^2 based on solar constant = $1{,}377J/m^2$.	O	
Direct normal radiation $kJ/\ m^2$	O	
Diffuse radiation kJ/ m		
Net radiation		
Tilt radiation		
Observed radiation		
Engineering corrected radiation		
Standard year corrected radiation in $kJ/\ m^2$	O	O
Additional radiation data		
Minutes of sunshine hours		
Time of surface observation (01 ~23)	O	
Ceiling height in meters times ten		
Sky condition		
Visibility in hundreds of meters		
Weather flags to set the rain and snow		
Atmospheric pressure reduced to sea level in tenths of millibars		
Station atmospheric pressure in tenths of millibars	O	O
Dry-bulb temperature in tenths of °C (-700 ~ 0600)	O	O
Dew point temperature in tenths of °C	O	O
Wind direction in degrees	O	
Wind speed in tenths of m/s (0000 ~ 1500)	O	
Total sky cover (tenths) (00 ~ 10)	O	
Total opaque sky cover (tenths)	O	
Snow cover flag; 0 = none, 1 = some		

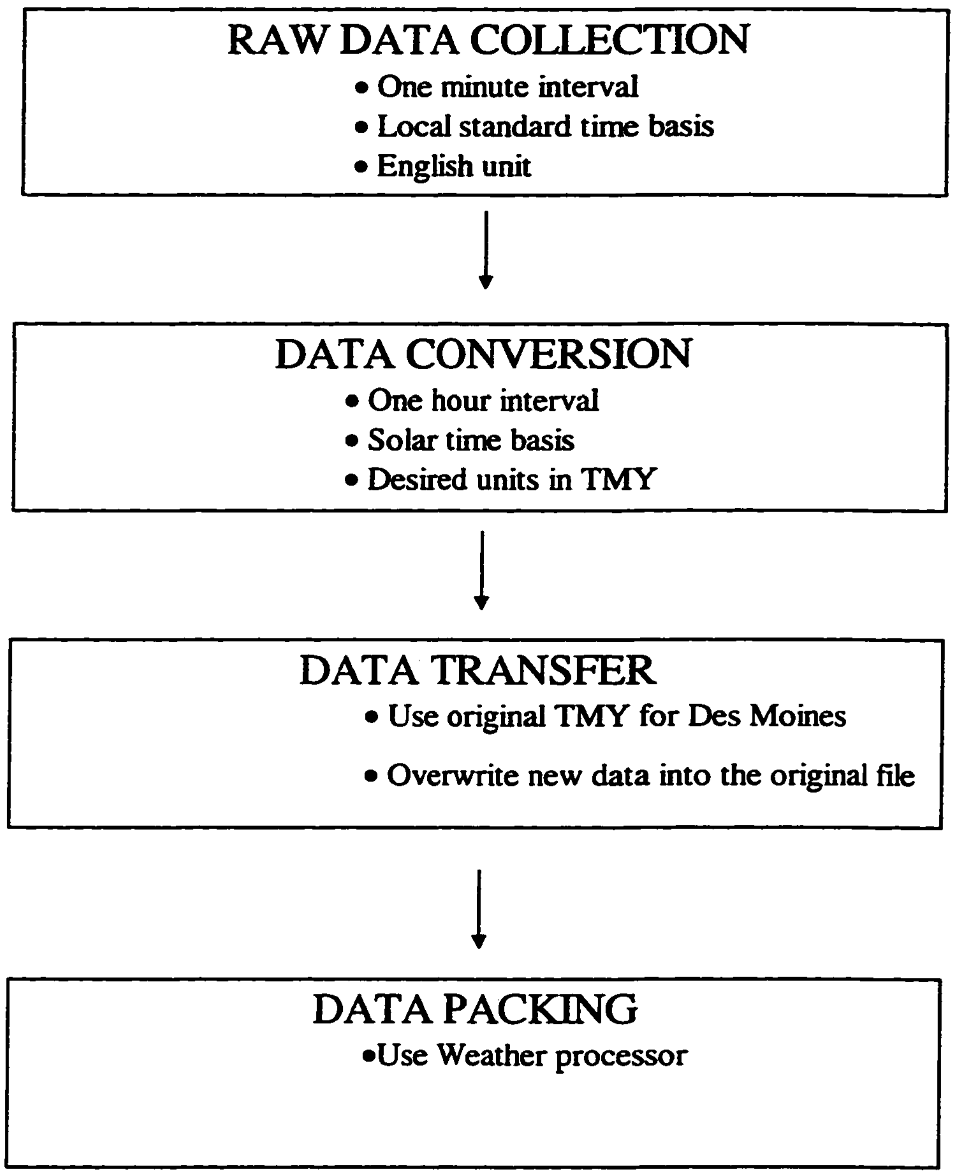


Figure 5.2 Weather data processing flow diagram

Values for the total horizontal irradiation comes from the pyranometer measurements. The diffuse horizontal irradiation is calculated by subtracting the direct horizontal irradiation from the total horizontal irradiation. The direct horizontal irradiation is calculated using the pyrheliometer data (direct normal irradiation) multiplied by the cosine of the angle of incidence between the sun rays and a horizontal surface. These calculations are included in the FORTRAN weather processing program.

6 EXPERIMENTAL DATA ANALYSIS AND ENERGY CALCULATION

For many of the tests conducted for this research, both the "A" and "B" test rooms (and systems) were configured to be same. This provided an opportunity to gather data on both systems operating under "identical" conditions. This also provided some assurance that if something went wrong with one system data from the other system could still be used for the study.

For some tests both systems could not be used due to the limited resources at the ERS. For example, only the "B" test rooms are equipped with fan coil units. Also, only the "B" test rooms have dimmable ballasts used for the daylighting tests.

For tests where both systems were configured the same, experimental data show slight differences in the system operating parameters between the two systems. For example, a test configuration might have specified a constant outdoor air flow rate of 300 CFM. The outdoor air flow rate measured on system "A" might indicate 290 CFM while the value measured on system "B" might indicate 310 CFM. Since the focus of this research was on the comparisons between the computer programs and a given system, it was not necessary to have a "perfect" match between the "A" and "B" systems. In order to provide the best possible comparison with the computer programs, one system was chosen and the model inputs were matched to that system's operating conditions (310 CFM outside air, for example).

The first section of this chapter describes how the experimental data were analyzed to determine the validity of the data. Once the experimental data were analyzed, then heating and cooling energy rates were calculated using the data. The second section of the chapter describes how the cooling and heating energy rates were computed.

Validation of Experimental Data

These experimental data are divided into two categories: building performance data and weather data. Sensors located in the HVAC systems and test rooms had been calibrated and double checked before the tests. Weather instruments including the solar instruments also had been calibrated and checked periodically before the tests. The solar tracker was checked at least three times a day during each test to assure that the pyheliometer was tracking the sun correctly.

Even though the calibration work had been performed well, still there was the possibility that the experimental data could be erroneous because of physical problems associated with the hardware in the building or the HVAC systems. For example, a heating water valve might not be completely closed if there was a blocking member in the valve stem even though the controller commanded the valve to be closed. This kind of problem only can be detected by examining associated parameters in the measured data. The following sections describe how the experimental data were analyzed.

Building Performance Data

The data trended by the building automation system were examined to check whether the set points of the building and HVAC systems were being controlled as desired. One nice way to detect problems in the system operation or errors in the measurement is to use a graphical presentation. The graphical presentation gives a visual image of the building operation making it easier to identify the system operation and to spot anomalies in the trend data.

The room temperatures were examined for the whole test period. Also the sum of zone supply air flow rates (measured by the flow sensors in the TABs) were compared to the supply air flow rate discharged from the central air handling unit. Another comparison was to check the energy balance for the heating coil or the cooling coil. The energy balance compared the heat transfer rates between the air-side and the water-side of a coil. When electric coils were used in the TAB, the energy balance compared the air-side heat transfer rate with the electric power of the heating coil. If erroneous data were found in the experimental data, that test was rejected and the problems were addressed before a new test was run.

For the purpose of ERS data analysis, MATLAB and LATEX programs were developed to calculate statistical summaries and to create various plots using the experimental data. Some of the plots are presented in Figure 6.1 to Figure 6.4. The sample outputs are included in Appendix F.

Figure 6.1 shows how the temperatures associated with one of the AHUs were controlled during the test period for February 5, 1999.

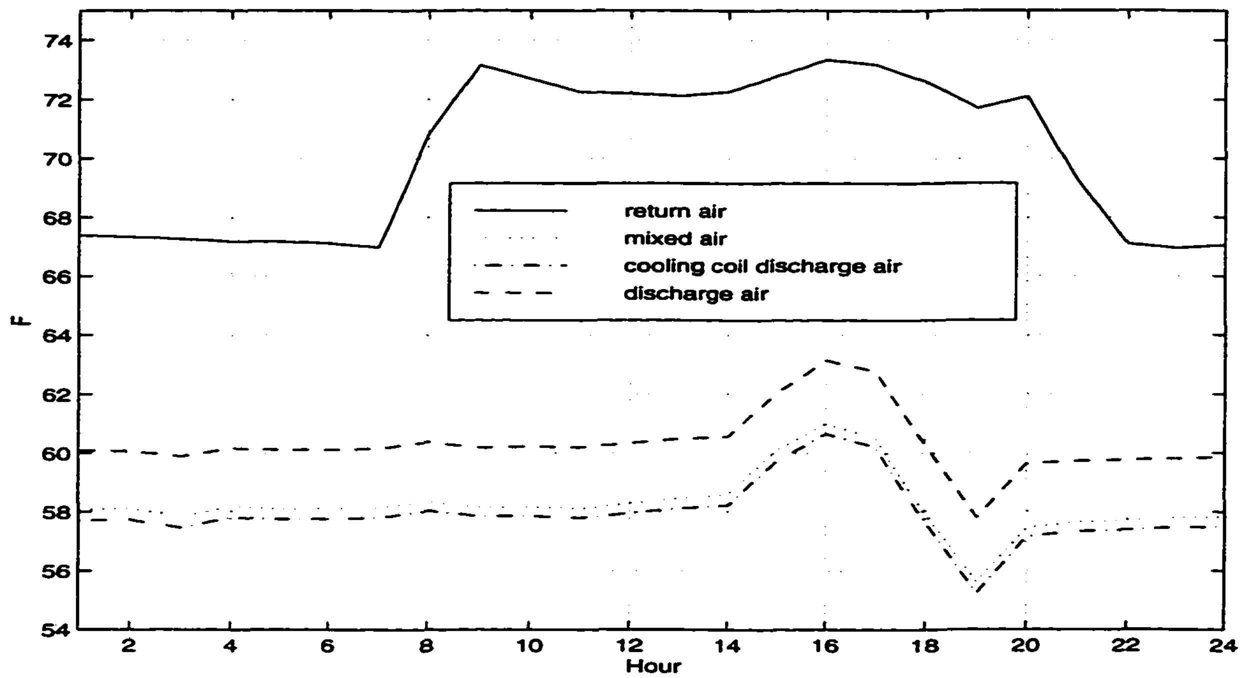


Figure 6.1 Measured AHU's air temperatures for February 5, 1999

Originally the set point of the AHU discharge air temperature was specified to be maintained constant at 60°F throughout the test period, but we can see there was a jump at hour 16 while the set point, 60°F was kept very well for most of the hours. The reason the set point was not kept for all hours is because the test was using outside-air economizer control without the chiller. When the outdoor air temperature became too warm, the AHU discharge air temperature went out of control.

Figure 6.2 illustrates the relative accuracy of the air flow rate sensors during the test.

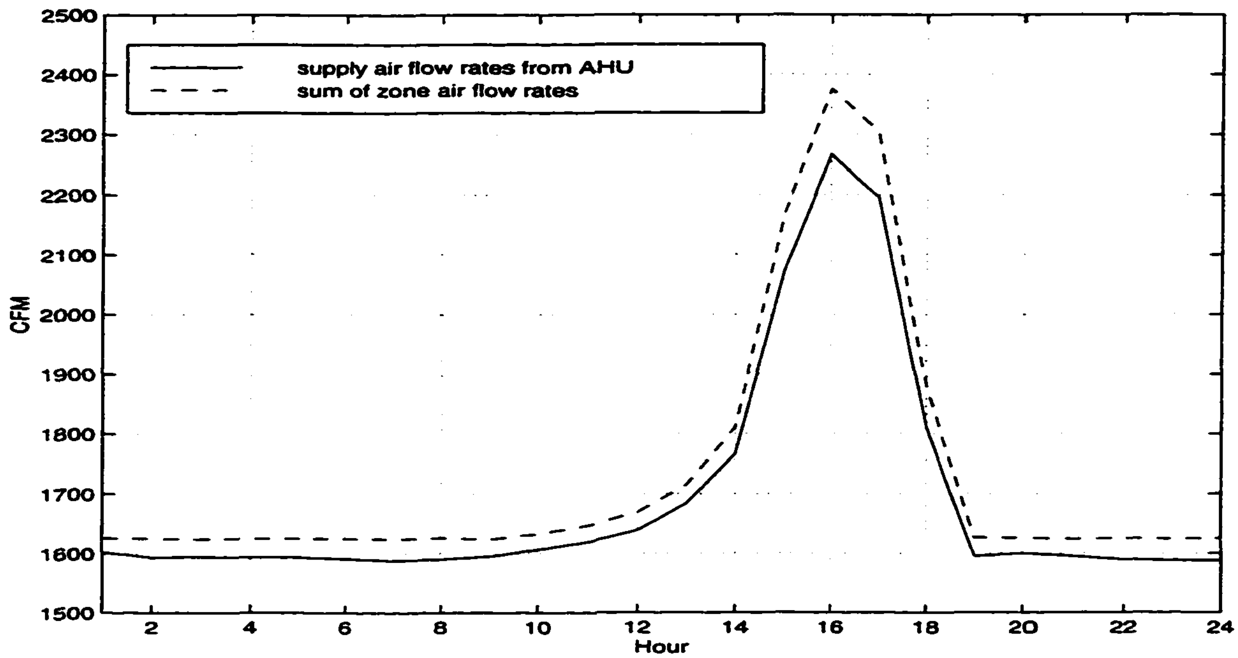


Figure 6.2 Comparison of AHU's supply air flow rates versus sum of zone air flow rates for February 5, 1999

The air flow rate measured at each TAB was summed and compared to the AHU discharge air flow rate measurements. Percent errors ranged from 1.8% to 4.4% for a wide range of air flow rates. These results are good. However, when we compare the magnitude of air flow rates each to other, the sum of zone air flow was greater than that of AHU's. Physically this situation is not possible. The AHU's air flow should always be equal to or possibly greater than the sum of zones' because of the possibility of some duct air leakage.

Figure 6.3 shows that the room temperatures were controlled during the test period. The rooms' temperatures were maintained from 65°F to 75°F, based on the thermostat schedule utilized during the test period. The thermostat set points for heating and cooling were 72°F and 73°F for the occupied period, respectively. For the unoccupied period, the set points were 65°F and 80°F, respectively. The throttling range for these set points were 1.5°F. Considering the above conditions for the set points, we can say that the room temperatures were controlled very well for the test period. Figure 6.4 displays the zone reheat energy rates for the south test room based on the air-side energy balance and the electric power to the reheat coils.

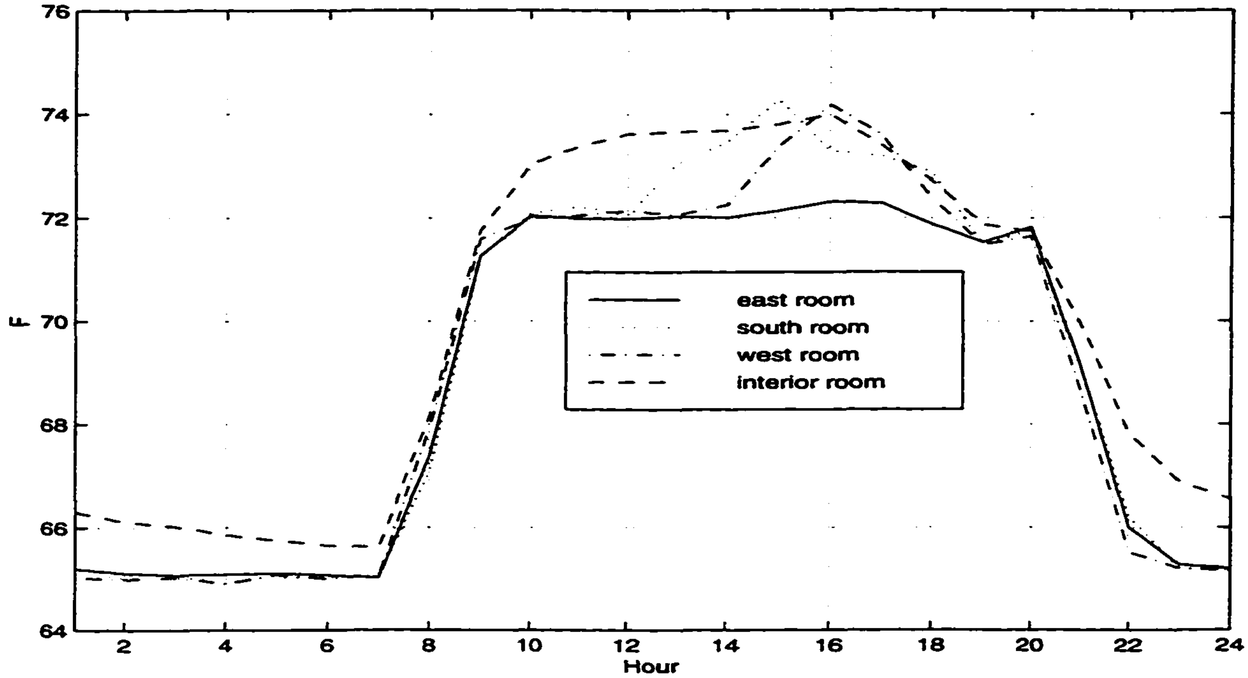


Figure 6.3 Measured room's air temperatures for February 5, 1999

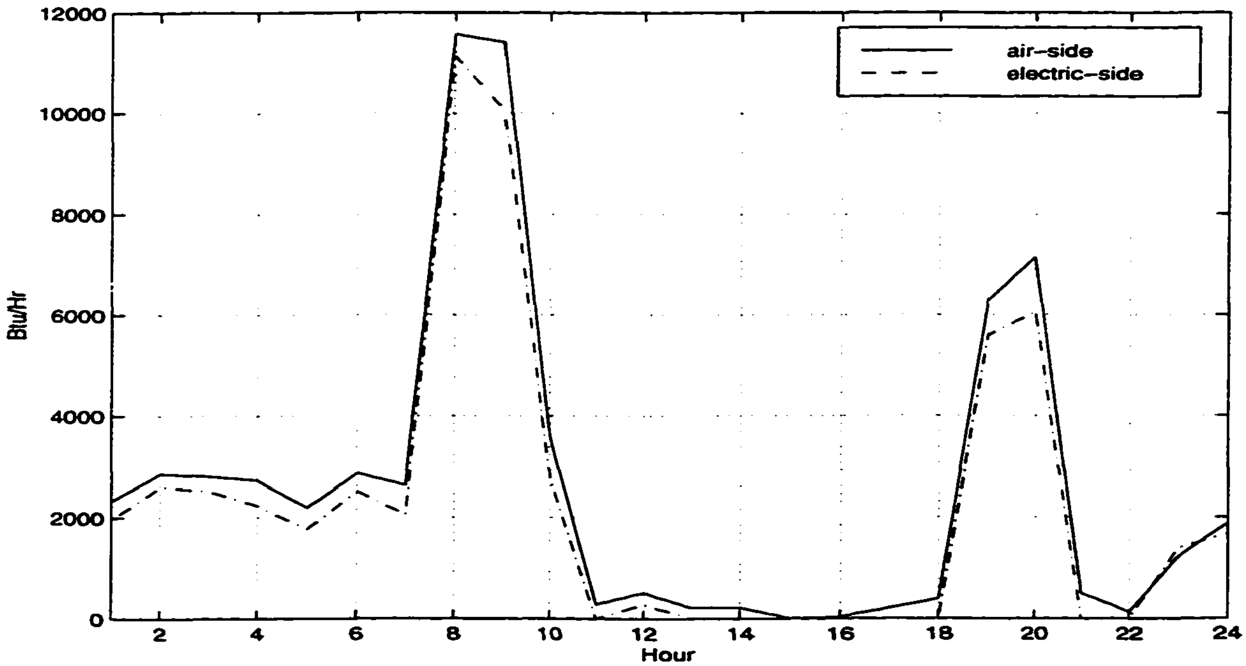


Figure 6.4 Comparison of zone reheat energy rates between air-side and electric side for February 5, 1999

The results are quite good. The air-side energy rates are slightly greater than the electric energy rates, but it is acceptable considering the errors in the air flow rate sensors.

Everything associated with experimental data analysis is directly connected to computer model because the computer model needs to have information that real building and HVAC systems used for their controls.

Weather Data

The measured solar data from the pyrheliometer and pyranometer were compared with the results calculated by the ASHRAE clear sky model [1995 ASHRAE Applications Handbook, Chapter 30, Solar Energy Utilization]. A clear day in January was selected for the test since the equations are based on a clear sky. Data comparison was made for two hours during January 28, 1997 from 11:20 AM through 1:15 PM. Data were collected every 5 minutes. The measured normal direct radiation was about 5% higher than the calculation results, while the measured global radiation for the horizontal surface was almost the same as the calculation results. The measured values were 0.04% lower than the calculated values.

For the clear sky model, the normal direct radiation, I_{DN}, at the site on the clear day was calculated using the following equation:

$$I_{DN} = A/exp(B/sin(\beta)) \tag{6.1}$$

where A = 380Btu/hr.ft^2, the apparent extraterrestrial irradiation at mass = 0, and B = 0.141, the atmospheric extinction coefficient, are function of the date and take into account the seasonal variation of the earth-sun distance and the air's water vapor content. The values of the parameters A and B were from the literature [Table 1, Chapter 30, ASHRAE Applications Handbook]. The solar altitude, β, is obtained from the following equation:

$$sin(\beta) = cos(l)cos(h)cos(d) + sin(l)sin(d) \tag{6.2}$$

where l is the latitude, and h is the hour angle, and d is the declination.

For the clear sky model, the global radiation for the horizontal surface, I_{TH} on the clear day was calculated by the following equation:

$$I_{TH} = I_{DN} sin(\beta) + CI_{DN} \tag{6.3}$$

where $C = 0.103$ is the dimensionless parameter, which is the ratio of diffuse on a horizontal surface to direct normal radiation. The parameter C is assumed to be constant for an average clear day for the month. The coefficient C is introduced from ASHRAE Cooling and Heating Load calculation Manual (1993). The comparison results are illustrated in the Table 6.1 and Figure 6.5.

Hourly solar fluxes vary along the time of day and the day of year. For example, at noon on a clear day of January at the site, the direct normal irradiation values are greater than those of the total horizontal irradiation values because the sun's altitude angle is so low ($I_{TH} = I_{DN}sin(\beta) + I_{DF}$), where I_{TH} is total horizontal irradiation, and I_{DN} is direct normal irradiation, and I_{DF} is diffuse component of the irradiation, and β is the solar altitude angle. On the contrary this situation is reverse in June because the solar altitude is much greater than in January. This implies that the total direct normal irradiation value at noon in June cannot be greater than the total horizontal irradiation value. Using this idea, the measured solar data could be checked by this clear sky model to determine if the measured data were reliable or not. For this purpose a solar fluxes calculation program was developed. The MATLAB program listings are included in Appendix G.

Figure 6.6 presents solar altitude angles as a function of month in the site (43° North Latitude). In January solar altitude angle is the lowest, about 28°, and this angle is the highest, about 72° in June. Figure 6.7 presents direct normal irradiation as a function of solar altitude angles. We can see that maximum direct normal irradiation can be obtained at noon in March and September in the site. Figure 6.8 presents total horizontal irradiation as a function of solar altitude angles. The maximum total horizontal irradiation occurs at noon in June at the site. Figure 6.9 shows how the two components of solar fluxes on a surface vary depending on the time of day and the day of the year at the site. The program was useful to verify the measured solar data because sometimes the power to the solar tracker would fail causing the pyheilometer to not track the sun. Obviously, this situation provided strange results.

Table 6.1 Solar fluxes comparison between measurement and calculation

local time	solar time	GNDC[a] Btu/h-ft^2	GNDM[a] Btu/h-ft^2	differ %	GHRC[a] Btu/h-ft^2	GHRM[a] Btu/h-ft^2	differ %
11:20	10:53	281.37	297.55	5.75	160.90 •	156.94	-0.02
11:25	10:58	282.14	299.13	6.02	162.56	158.92	-0.02
11:30	11:03	282.84	299.44	5.87	164.09	160.48	-0.02
11:35	11:08	283.48	299.74	5.73	165.50	161.89	-0.02
11:40	11:13	284.05	300.24	5.70	166.78	162.73	-0.02
11:45	11:18	284.56	300.24	5.51	167.93	163.63	-0.03
11:50	11:23	285.01	300.24	5.35	168.96	163.91	-0.03
11:55	11:28	285.40	300.78	5.39	169.86	164.28	-0.03
12:00	11:33	285.73	299.95	4.98	170.63	164.17	-0.04
12:05	11:38	286.00	299.69	4.78	171.27	164.83	-0.04
12:10	11:43	286.22	299.34	4.58	171.78	165.26	-0.04
12:15	11:48	286.38	299.34	4.52	172.16	165.57	-0.04
12:20	11:53	286.49	300.18	4.78	172.41	166.06	-0.04
12:25	11:58	286.54	299.36	4.47	172.53	165.98	-0.04
12:30	12:03	286.54	299.49	4.52	172.52	167.12	-0.03
12:35	12:08	286.48	277.98	-2.97	172.39	167.89	-0.03
12:40	12:13	286.37	299.59	4.62	172.12	168.40	-0.02
12:45	12:18	286.20	299.03	4.48	171.72	168.36	-0.02
12:50	12:23	285.97	298.44	4.36	171.20	168.15	-0.02
12:55	12:28	285.69	297.10	3.99	170.54	167.29	-0.02
13:00	12:33	285.36	297.33	4.19	169.76	166.96	-0.02
13:05	12:38	284.96	296.31	3.98	168.85	166.00	-0.02
13:10	12:43	284.50	295.60	3.90	167.81	165.01	-0.02
13:15	12:48	283.99	294.89	3.84	166.64	163.57	-0.02
For an hour		285.33	299.85	5.09	169.72	164.30	-0.03

GNDC: direct normal radiation calculated by the equation.
GNDM: direct normal radiation measured from the pyrheliometer.
GHRC: global radiation calculated by the equation for the horizontal surface.
GHRM: global radiation measured from the pyranometer for the horizontal surface.

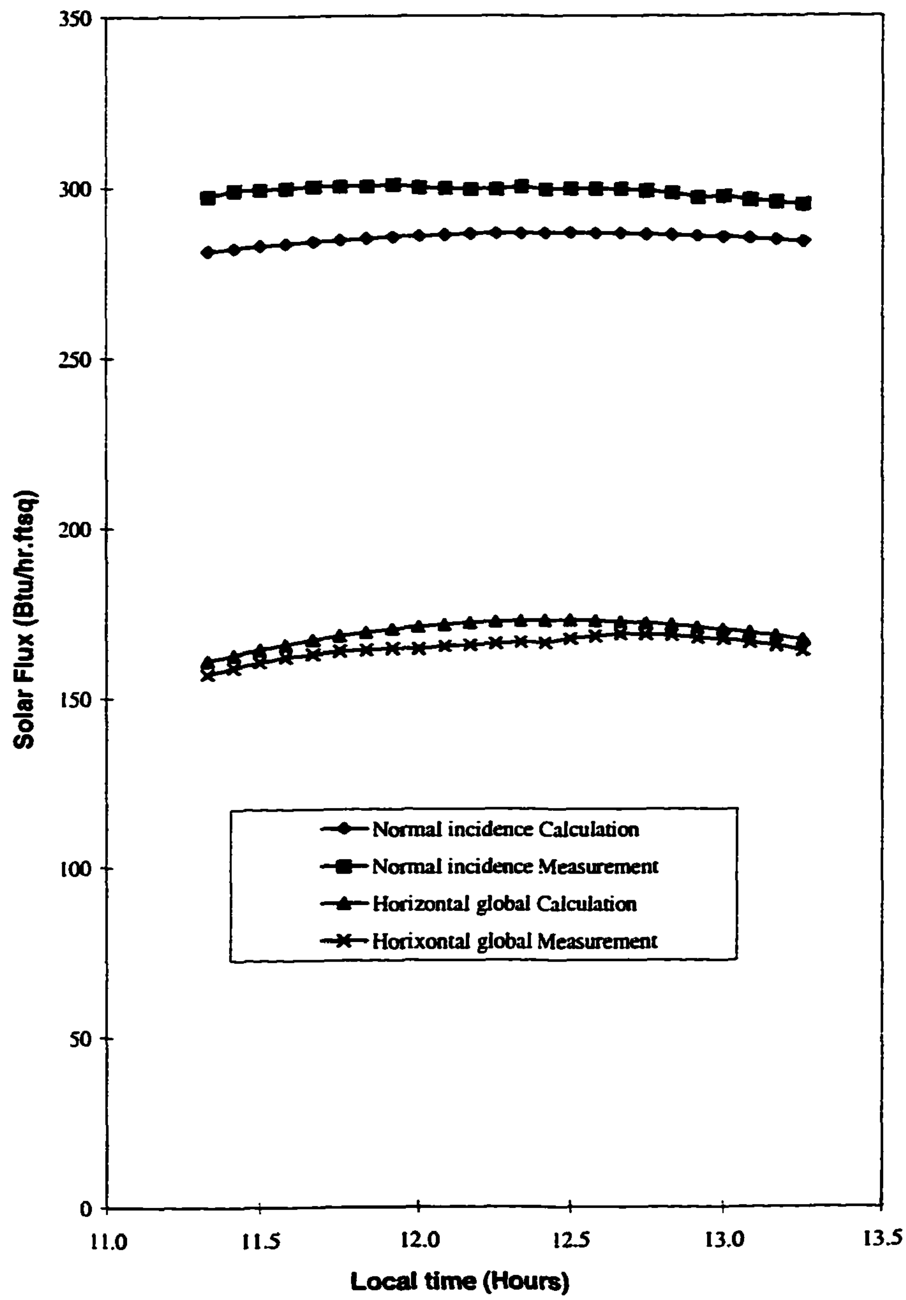


Figure 6.5 Solar fluxes comparison between measurement and calculation

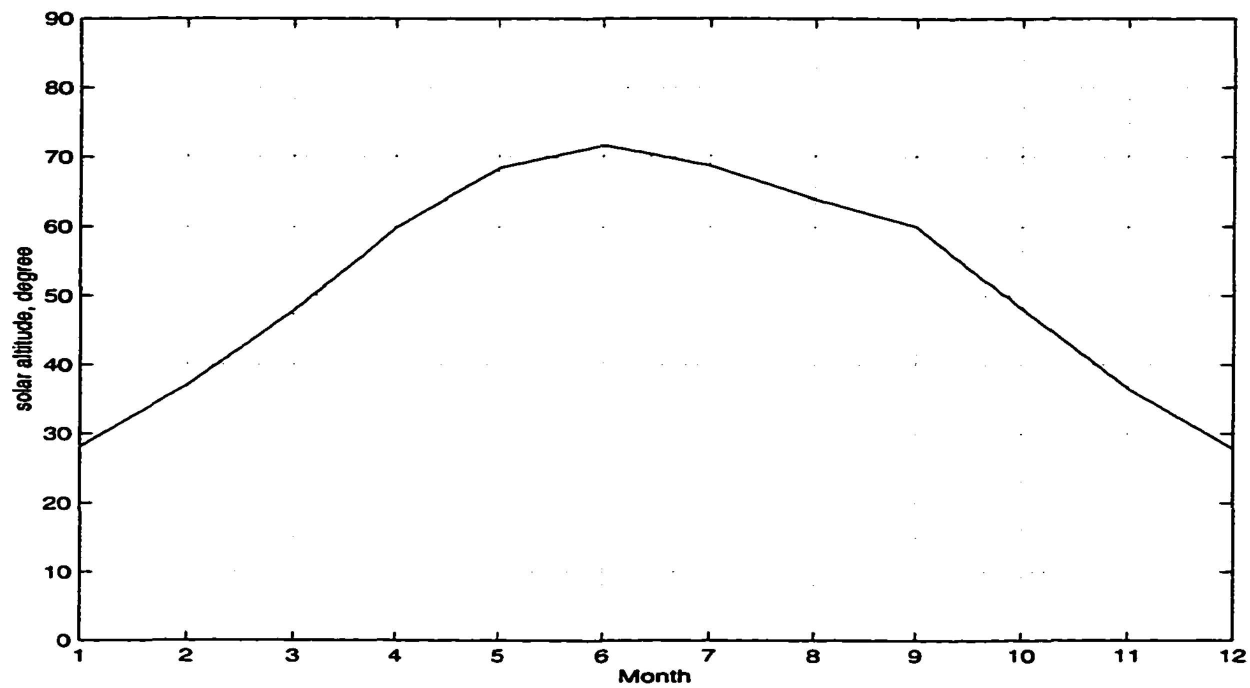


Figure 6.6 Solar altitude angles as a function of month in the site (43° North Latitude)

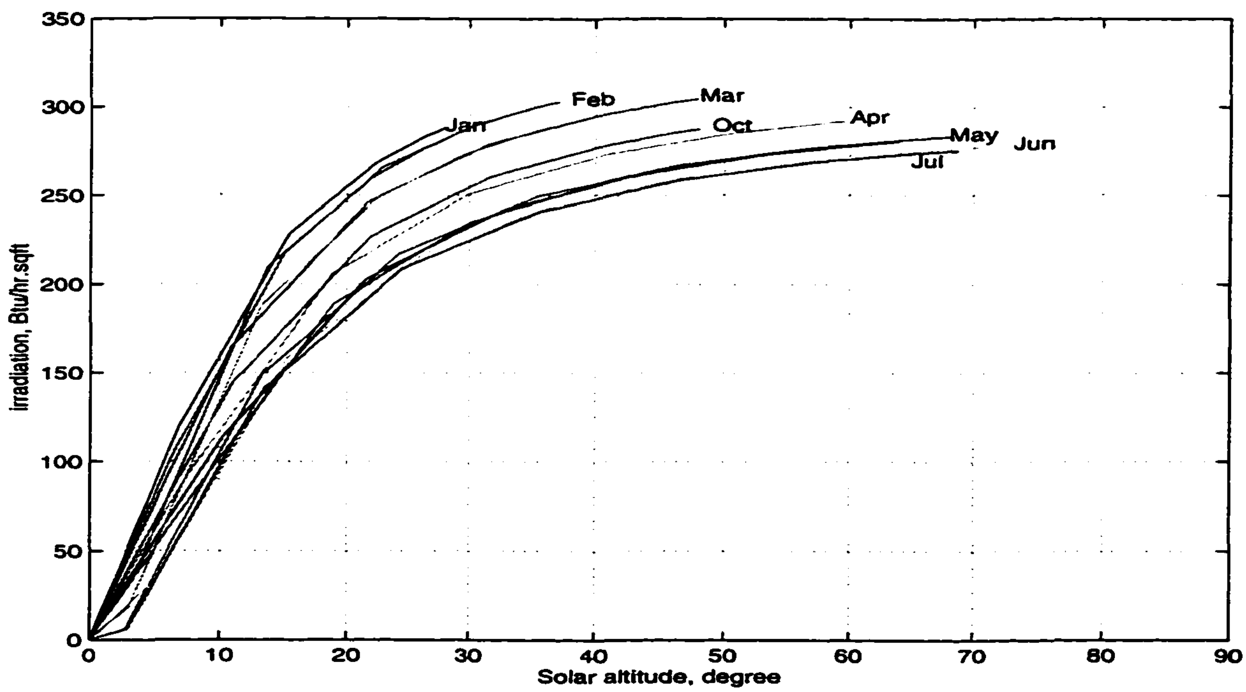


Figure 6.7 Direct normal irradiation as a function of solar altitude angles at the site

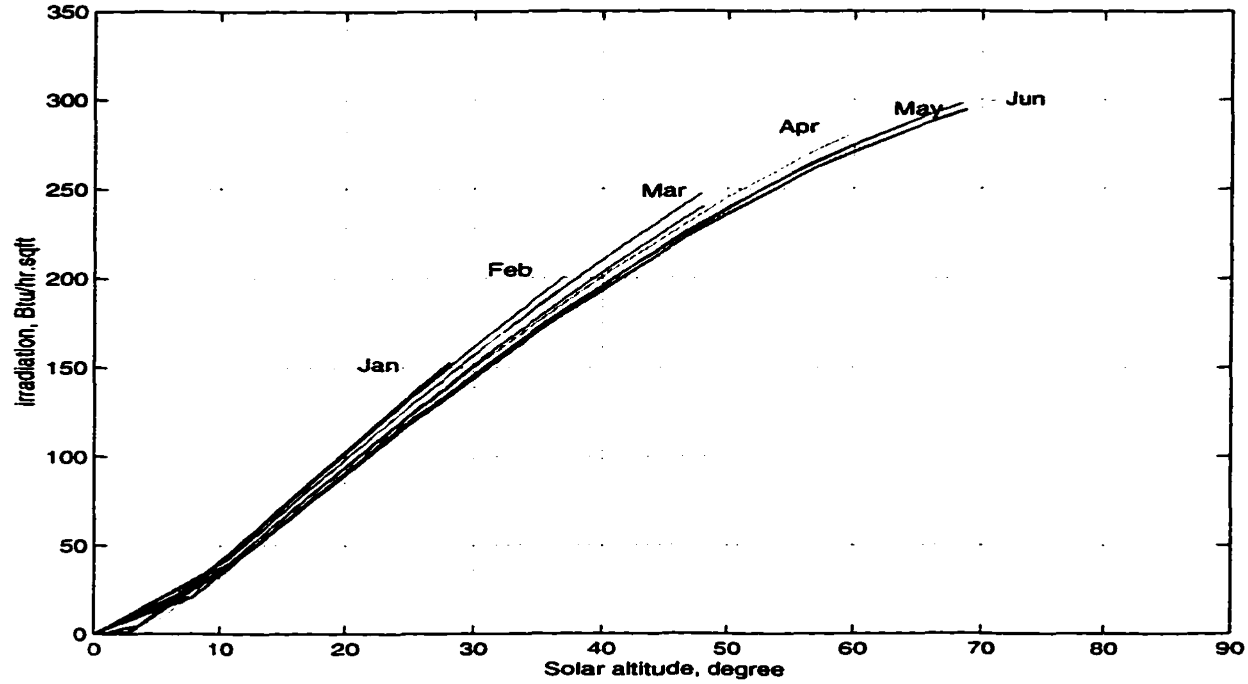


Figure 6.8 Total horizontal irradiation as a function of solar altitude angles in the site

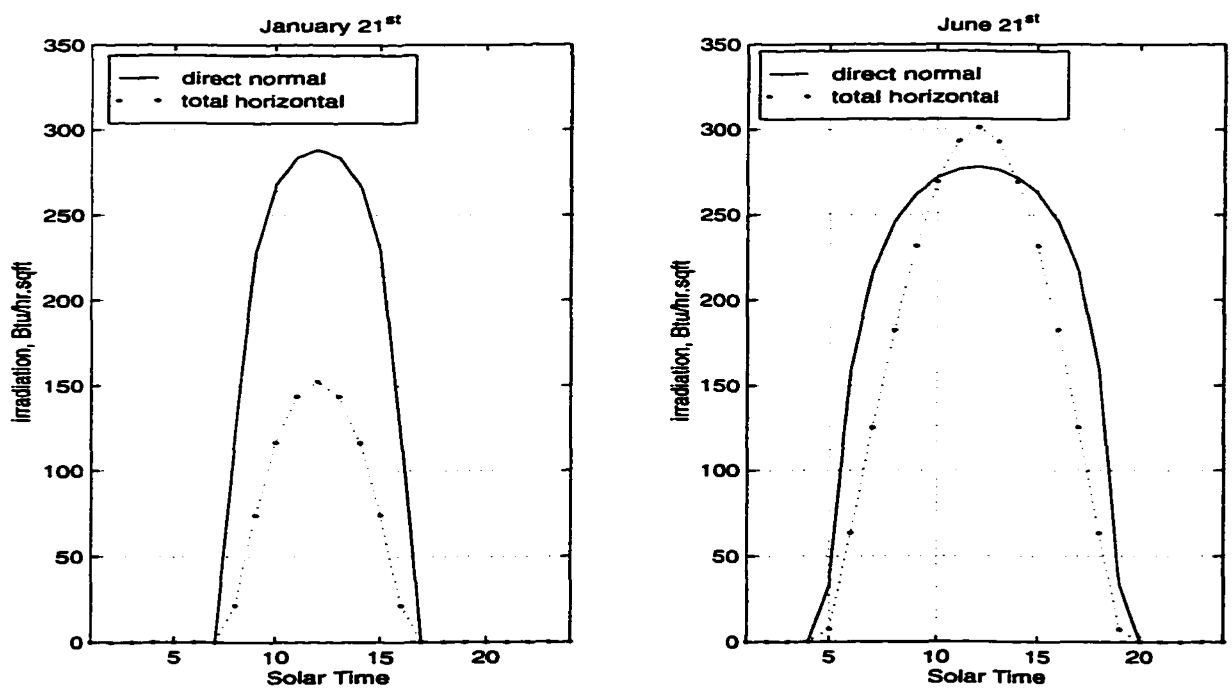


Figure 6.9 Comparison of total horizontal irradiation and direct normal irradiation on January 21^{st} and June 21^{st} in the site

Energy Calculation and Estimation of Propagation of Error

Using quantities that were measured directly (e.g. temperature, flow rate, power, etc.) from various sensors, energy rates were calculated by applying energy balances on various system components such as the main cooling coil and the terminal heating devices.

The cooling energy rates were calculated using water-side data for the cooling coil in the AHU—the two temperatures of the chilled water entering and leaving the cooling coil, and the chilled water flow rate. The reheat energy rates were calculated at the zone level by taking electric power input to the terminal box in the zone. When 4PFCU system was used for tests, an air-side energy balance was applied at the zone level to calculate heating and cooling coil loads.

When the energy rates were calculated using the data measured from individual sensor, uncertainty analysis was used to estimate the magnitude of the error due to measurement errors in the individual sensor. Uncertainty values for temperature sensors and watt transducers were estimated by obtaining standard deviations using statistical methods. Uncertainty values for flow rate sensors were obtained from manufacturer's literature that came with the instrumentation.

Once the uncertainty values for individual sensors were determined, uncertainty value (propagation error) for cooling or reheat energy rates was calculated using the method of propagation of errors. The following equation was used.

$$u(q) = \sqrt{\sum_{i=1}^{n} (\frac{\partial q}{\partial x_i})^2 u(x_i)^2} \tag{6.4}$$

where $q = q(x_1, x_2, \ldots, x_n)$, and $u(x_1), u(x_2), \ldots, u(x_n)$ are uncertainty values for $x_1, x_2, \ldots, x_n$, respectively. Specific values and equations to determine energy rates are discussed in following sections.

Zone Reheat Energy Rate Calculation

Although the air handling units in the ERS contain hot water coils, all heating during the test period was accomplished at the zone (or room). Heat was added either at the TAB or the FCU depending on the system being tested. All tests except FCU tests used electric heat for the terminal heating. Perimeter rooms (exterior rooms) had three stages of electric heater in the TABs, and the interior room had two stages of electric heaters in the TAB.

During the tests the trend data included the status of each stage of electric heat. The trend data shows 1/0 for on/off, respectively. For each 1-minute set of trend data, the load on the electric reheat coil was calculated using

$$q_{e_i} = \sum_{j=1}^{k} S_{ij} P_{ij} \tag{6.5}$$

where i = time index for each minute, q_{e_i} = instantaneous reheat energy rate, j = 1,2,3; stage index of the electric heater in a zone (1 or 2 for an interior room, and 1,2 or 3 for exterior rooms), S_{ij} = status of each stage of electric heater, 0 for off, and 1 for on, P_{ij} = power of electric heater for each stage.

The hourly heating energy rate for each room (or zone) was calculated by summing the electric heat power for the times when the status indicated each was on. The summation was for a one-hour period. This yields the hourly heating energy rate for each zone. The equation can be expressed as follows.

$$q_e = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{k} S_{ij} P_{ij} \tag{6.6}$$

where q_e = hourly reheat energy rate for a zone,

i = time index for instantaneous time,

j = stage index for the electric heater,

S_{ij} = status of each stage of electric heater, 0 for off, and 1 for on, for instantaneous time

P_{ij} = power of electric heater for each stage, for instantaneous time

n = frequency of power measurement in an hour,

k = number of stages of the electric heater in a zone, 2 for an interior room, and 3 for exterior rooms.

Power for each stage of heat was different from the nominal value because the voltage of the electric heaters varied slightly during the day. For example, the nominal value of power of the first stage of electric heater in an exterior room was 1.667 KW while the actual measured power for the first stage heater had an average value of 1.635 KW. The measured power was used for the energy rate calculation. The uncertainty value in the measured power was obtained from multiple measurements of the heater power. The uncertainty value, $u(q_e)$ for q_e is given by

$$u(q_e) = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{k}(\frac{\partial q_{e_i}}{\partial P_{i_j}})^2 u(P_{i_j})^2} = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{k}(S_{i_j})^2 u(P_{i_j})^2} \tag{6.7}$$

where $u(P_j)$ is standard deviation that was estimated by statistical method using the experimental data. Eight replications were made to determine the standard deviation value for each stage of the electric heater. The standard deviation value for each stage, $u(P_j)$ was calculated by

$$u(P_j) = \sqrt{\sum_{n=1}^{8}(P_{j_n} - \bar{P}_j)^2} \tag{6.8}$$

where P_{j_n} = power measured for n = 1, 2, ... ,8; $\bar{P}_j$ = mean of measured powers; j =1, 2 for interior room, and j =1, 2, 3 for exterior rooms. Table 6.2 presents a statistical summary of the electric heater power measurements for each stage.

Table 6.2 Statistical summary of electric heater power measurement for each stage

Stage, j = 1 ~ 3	Nominal power (KW)	Mean power, $\bar{P}$(KW)	$u(P)$ (KW)
For exterior test rooms			
1	1.667	1.635	0.0339
2	1.667	1.682	0.0584
3	1.667	1.538	0.0516
For interior test room			
1	1.000	0.965	0.0070
2	1.000	0.965	0.0070

Power values were converted to units of Btu/Hr by multiplying by 3412. The total heating energy rate for each hour is the sum of the zone energy rates at the same hour. The daily heating energy is the sum of the hourly total heating energy rates.

Trend data for the tests also included the supply air temperature leaving the air handling unit, the discharge air temperature from each TAB, and the volumetric flow rate of air for each TAB. For each 1-minute set of trend data, the reheat energy rate was calculated using

$$q_{a_i} = 1.09CFM_i * (EAT_i - LAT_i) \tag{6.9}$$

Then the hourly reheat energy rate becomes

$$q_a = \frac{1.09}{n} \sum_{i=1}^{n} CFM_i * (EAT_i - LAT_i) \tag{6.10}$$

where q_{a_i} is instantaneous energy rate in Btu/hr. q_a is the hourly energy rate in Btu/Hr. 1.09 is the density-specific heat product for air at 60 °F (which includes a conversion factor from minutes to hours). CFM is the supply airflow rate in cubic feet per minute. EAT is the entering air temperature to the electric heating coil. and LAT is the leaving air temperature out of the electric heating coil in °F. These calculations also were averaged over a one-hour period to yield the hourly reheat energy for each zone. These results were not used directly for comparison purpose to the simulated results from the computer models. but were used to check the reheat energy calculations based on the electric power measurements. All calculations were performed by the MATLAB program. and the program listings are included in Appendix H.

FCU Energy Rate Calculation

The FCUs in the ERS have both cooling and heating coils in them. Hourly heating loads were computed using the air-side energy equation 6.10 at the zone level. but the conversion factor was changed from 1.09 to 1.08 because of the different air density (from 60°F to 72°F). The fan coil units were operated with a constant fan speed setting thus providing a fixed CFM. Trend data for the temperature of the air entering the bottom of the FCU and the discharge air temperature were used in the calculation. The discharge air temperature was measured using an average temperature of two temperature sensors to increase the accuracy.

Using equation 6.4 to estimate the uncertainty of the hourly heating coil loads. the uncertainty value for the heating coil loads becomes

$$u(q_a) = \frac{1}{n}\sqrt{\sum_{i=1}^{n}((\frac{\partial q_{a_i}}{\partial CFM_i})^2 u(CFM_i)^2 + (\frac{\partial q_{a_i}}{\partial LAT_i})^2 u(LAT_i)^2 + (\frac{\partial q_{a_i}}{\partial EAT_i})^2 u(EAT_i)^2)} \tag{6.11}$$

$$= \frac{1}{n}\sqrt{1.08\sum_{i=1}^{n}((EAT_i - LAT_i)^2 u(CFM_i)^2 + (LAT_i)^2(CFM_i)^2 u(EAT_i)^2 + (CFM_i)^2(EAT_i)^2 u(LAT_i)^2)} \tag{6.12}$$

where i = time index for instantaneous time, $u(q_a)$ = uncertainty value for hourly heating rate, CFM_i = volumetric air flow rate in cfm, EAT_i = entering air temperature in °F to the FCU, values were ± 10 CFM, ± 0.5°F and ± 0.5°F for CFM, entering and leaving air temperatures, respectively. The hourly system heating load was computed, as before, by summing the zone heating loads. The daily heating energy was then computed from the hourly system loads.

The hourly zone cooling load was calculated using the air-side energy equation applied to the fan coil unit. The procedure used was exactly the same as used to compute the hourly heating loads. Fundamentally, equation 6.10 only accounts for the sensible heat transfer. Because there was no latent load in the test rooms, the sensible load is the total load and equation 6.10 applies. The hourly system cooling loads were computed by summing the zone cooling loads at the same hour, and the daily cooling energy was computed by summing the hourly system cooling loads.

Cooling Load Calculations

The hourly system cooling load for AHU was computed by applying the water-side energy equation to the chilled water coil in the AHU. Trend data for the entering and mixed water temperatures as well as the chilled water flow rate were used in the calculation. The chilled water temperature sensors were calibrated using a temperature-controlled water bath and NIST standard thermometers. Their accuracy was ±0.5°F. The pumps serving the AHUs were fixed speed pumps, and the chilled water flow rate was controlled by a three way valve. The flow meters were calibrated at the factory by the sensor manufacturer, and their accuracy was ±0.09 gpm for 0 ~ 18 gpm.

The system cooling load was averaged over a one-hour time period to yield the hourly system cooling load. For each 1-minute set of trend data, the load on the cooling coil was calculated using

$$q_{w_i} = 497.6GPM_i * (MWT_i - EWT_i) \tag{6.13}$$

Then hourly system cooling energy rate becomes

$$q_w = \frac{497.6}{n} \sum_{i=1}^{n} GPM_i * (MWT_i - EWT_i) \tag{6.14}$$

where q_{w_i} is instantaneous cooling energy rate in Btu/hr, q_w is hourly cooling energy rate in Btu/hr, 497.6 is the density-specific heat product for chilled water at 40 °F (which includes where q_{w_i} is instantaneous cooling energy rate in Btu/hr, q_w is hourly cooling energy rate in Btu/hr, 497.6 is the density-specific heat product for chilled water at 40 °F (which includes a conversion factor from minutes to hours), GPM is the water flow rate in gallon per minute, EWT is the entering water temperature to the cooling coil, and MWT is the mixing water temperature that is mixing the three way valve, mixing the water leaving the cooling coil with the water bypassed through the three-way valve. The three-way valve was installed in the inlet of the cooling coil, and the flow meter was located upstream of the three-way valve.

Uncertainty value for hourly system cooling loads were computed in a similar way as for the FCU. Using the concept of the equation 6.4 to estimate uncertainty of the hourly system cooling coil loads, the uncertainty value for the hourly cooling coil loads becomes

$$u(q_w) = \frac{1}{n}\sqrt{497.6\sum_{i=1}^{n}((MWT_i - EWT_i)^2 u(GPM_i)^2 + (EWT_i)^2(GPM_i)^2 u(MWT_i)^2 + (GPM_i)^2(MWT_i)^2 u(EWT_i)^2)} \qquad (6.15)$$

where i = time index for instantaneous time, $u(q_w)$ = uncertainty value for hourly cooling rate in Btu/Hr, GPM_i = volumetric water flow rate in gpm, MWT_i = mixing water temperature in °F , EWT_i = entering water temperature in °F, and $u(GPM_i), u(MWT_i), u(EWT_i)$ are uncertainty values for GPM, mixing and entering water temperatures, respectively. The uncertainty values were ± 0.09 gpm, ± 0.5°F and ± 0.5°F for GPM, mixing and entering water temperatures, respectively. The daily cooling energy was computed by summing the hourly system cooling loads.

7 RESULTS AND DISCUSSIONS

In this chapter the results from the computer simulations are compared with the experimental results from the ERS. The comparisons are discussed in four sections. Section one presents the comparisons for the non-dynamic test cases. In section two the dynamic test cases are presented. The daylighting study is presented in section three. Finally, an overall comparison is made for all tests. This is presented in the fourth section.

For all tests, comparisons are made between the hourly cooling and heating energy rates as calculated from ERS data and as predicted by the computer models. Depending on the specific tests and the output information available from the simulation programs, comparisons are made at the system level and at the zone (or room) level. For example, for the VAVRH and CAVRH tests all three programs (DOE2, HAP and TRACE) are compared with the ERS data for the hourly system cooling and heating energy rates. For the hourly zone reheat energy rates, only the DOE2 and HAP program results are compared with the ERS data because the TRACE program does not provide hourly heating energy rates at the zone level.

For tests involving variable air volume system operation, comparisons are made between measured air flow rates and air flow rates predicted by the simulation programs. For tests involving changes in the room thermostat set point, comparisons are made between measured room temperature and temperatures predicted by the models. Daylighting tests include comparisons between measured and predicted energy usage by the lights and measured and predicted room illuminance levels.

In the final section, comparisons between simulation results and ERS data are made to examine how well the simulation programs predict system cooling energy rates and heating energy rates depending on building operation characteristics, the HVAC system used, and combination of these two.

Every comparison is performed graphically and statistically to quantify the differences between the measurements and the predictions. Statistical parameters used for analysis are described in Table 7.1. Results from the propagation of error analysis are included with the ERS data. Units that were used for statistical summary are Btu/Hr for energy rates, CFM for air

Table 7.1 Summary of descriptive statistics used for the analysis

Descriptive statistics	Acronyms	Equations
Mean of predictions	MEAN(P)	$\bar{P} = \frac{1}{n}\sum_{t=1}^{n} P_t$
Mean of measurements	MEAN(M)	$\bar{M} = \frac{1}{n}\sum_{t=1}^{n} M_t$
Smallest of predictions	MIN(P)	$P_{min} = Min(P_t)$
Smallest of measurements	MIN(M)	$M_{min} = Min(M_t)$
Largest of predictions	MAX(P)	$P_{max} = Max(P_t)$
Largest of measurements	MAX(M)	$M_{max} = Max(M_t)$
Difference between P_t and M_t	DT	$D_t = P_t - M_t$
Smallest of differences	MIN(DT)	$D_{min} = Min(D_t)$
Largest of differences	MAX(DT)	$D_{max} = Max(D_t)$
Mean of differences	MEAN(DT)	$\bar{D} = \frac{1}{n}\sum_{t=1}^{n} D_t$
Root mean square error	RMSE	$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(D_t)^2}$
Standard error of mean of differences	STDE($\bar{DT}$)	$\sigma_{\bar{D}} = \sqrt{\frac{1}{(n)(n-1)}\sum_{t=1}^{n}(D_t - \bar{D})^2}$
Error percent of mean of predictions	ERR(%)	$EP_{\bar{P}} = \frac{(\bar{M}-\bar{P})}{\bar{M}} * 100$

P_t: predicted value at hour t.
M_t: measured value at hour t.

flows and °F for temperatures throughout the chapter, respectively. A listing of the MATLAB programs used to compute the statistical summary is included in Appendix I.

Tests Having Non-dynamic Characteristics of the Building

The tests used 3 different HVAC systems, CAVRH, VAVRH and 4PFCU. The purpose of these tests was to provide thermal performance data that were used to evaluate how well the computer models predict building energy rates for the cases where buildings have non-dynamic characteristics in the building operation. During each test, the building operation parameters such as room temperature and outside air flow rate were kept constant. There were no internal loads used in the test rooms.

Comparison of CAVRH(1) System

The test was conducted during the first week of August, 1998. The building required cooling energy and heating energy during the test period. Actual hourly cooling energy and heating energy rates were compared with the simulation results at the system level. For these comparisons, all three programs, DOE2, HAP and TRACE were used. The comparison results for the system cooling energy rate are presented in Table 7.2 and Figure 7.1. All three programs under-predicted the actual cooling energy rates by 3.6%, 18.7% and 15.8% for DOE2, HAP and TRACE, respectively. The DOE2 results most closely match the experimental results. The cooling energy rates predicted by HAP and TRACE are similar to each other. Considering the uncertainty of the actual data, ± 11.6% (± 5942 Btu/Hr), HAP and TRACE fall just outside the range of experimental uncertainty.

The comparison results for the system heating energy rate are presented in Table 7.3 and Figure 7.2. All three programs over-predicted their heating energy rates by 10.8%, 11.1% and 10.4% in DOE2, HAP and TRACE, respectively. The experimental uncertainty in the heating energy rate is ± 3%. While all three programs have about the same mean error, the TRACE program shows the greatest root mean square error.

Actual hourly zone reheat energy rates were compared with only two simulation programs, DOE2 and HAP because TRACE does not provide this information at the zone level. There are four zones (rooms), east, south, west and interior in the test building. The comparison results for these four zones are presented in Table 7.4 through Table 7.7 and Figure 7.3 through Figure 7.6.

For the comparison of the east zone as shown in Table 7.4 and Figure 7.3, the programs over-predicted their heating energy rates by 13.7% and 15.9% for DOE2 and HAP, respectively. The uncertainty value for the actual data is ± 3.4% (± 249 Btu/Hr) since the test used electric heating for the terminal heating. Except the morning hours when the sun shines through the

Table 7.2 Statistical summary of system cooling energy rate prediction in CAVRH(1)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	49390	41656	43168	51248±5942
MEAN(DT)	1859	9592	8081	-
MEAN ERROR(%)	3.6	18.7	15.8	±11.5
STDE(DT)	242	229	286	-
RMSE	2491	9720	8316	-
MIN(DT)	-1560	6684	3193	-
MAX(DT)	5744	12565	12419	-
MIN	43007	35804	36960	45595±5893
MAX	52379	45029	47280	55259±6093

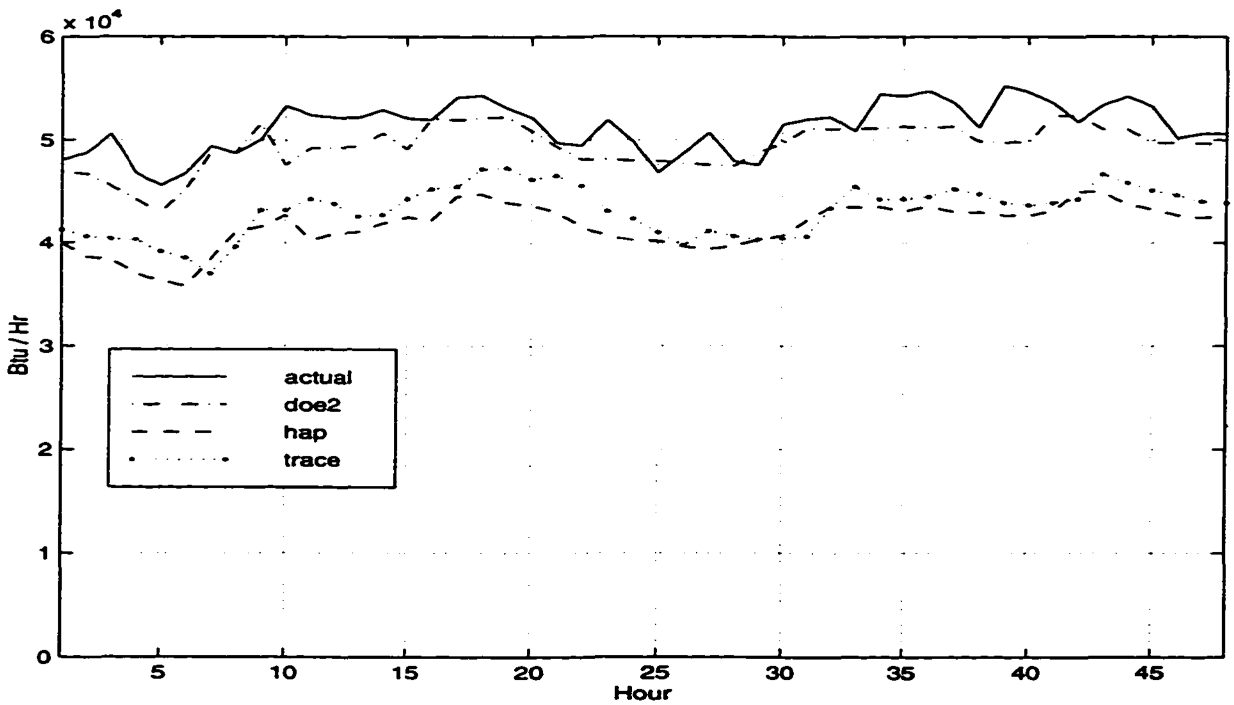


Figure 7.1 System cooling energy rate for CAVRH(1) from 980801 through 980802

Table 7.3 Statistical summary of system heating energy rate prediction in CAVRH(1)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	30137	30229	30038	27201±808
MEAN(DT)	-2936	-3028	-2837	-
MEAN ERROR(%)	-10.8	-11.1	-10.4	±3.0
STDE(DT)	301	315	446	-
RMSE	3587	3718	4169	-
MIN(DT)	-9746	-9408	-7769	-
MAX(DT)	1822	1411	3721	-
MIN	22075	24020	18260	19967±570
MAX	34808	33550	35730	31713±961

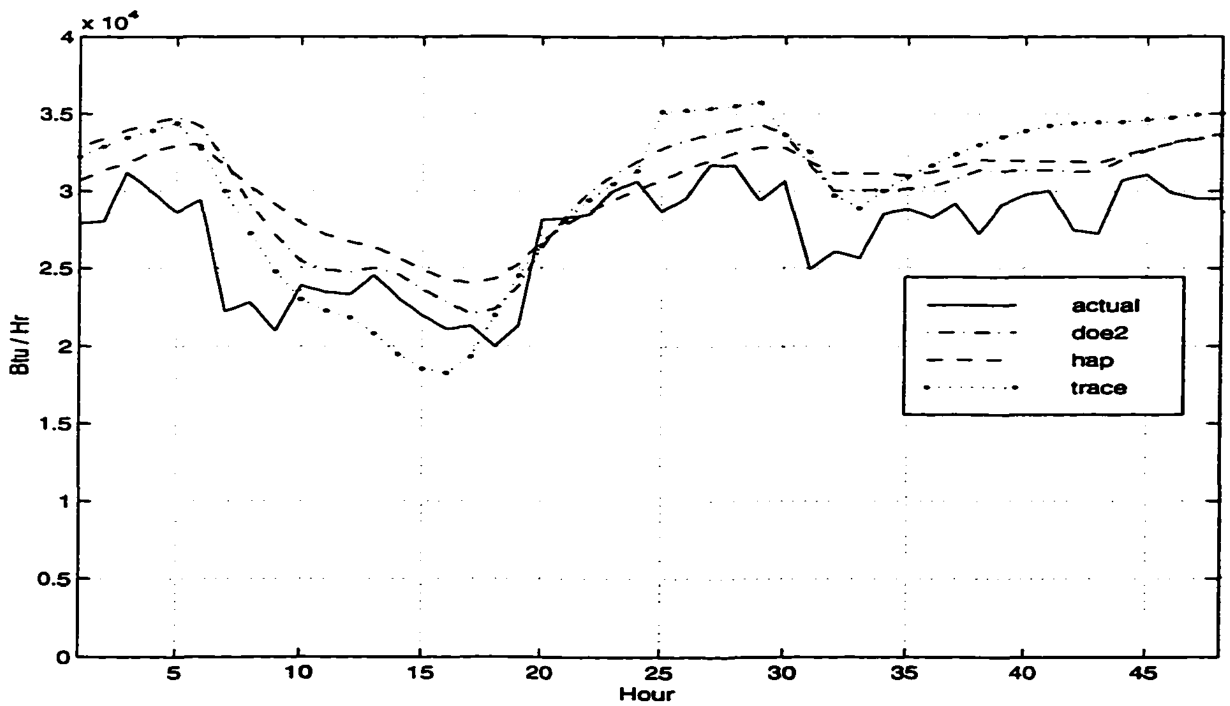


Figure 7.2 Total reheat energy rate for CAVRH(1) from 980801 through 980802

Table 7.4 Statistical summary of east room heating energy rate prediction in CAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	8331	8493	7330±249
MEAN(DT)	-1001	-1163	-
MEAN ERROR(%)	-13.7	-15.9	±3.4
STDE(DT)	195	225	-
RMSE	1670	1932	-
MIN(DT)	-7216	-7841	-
MAX(DT)	1431	533	-
MIN	3001	5799	465±16
MAX	10265	9758	9021±307

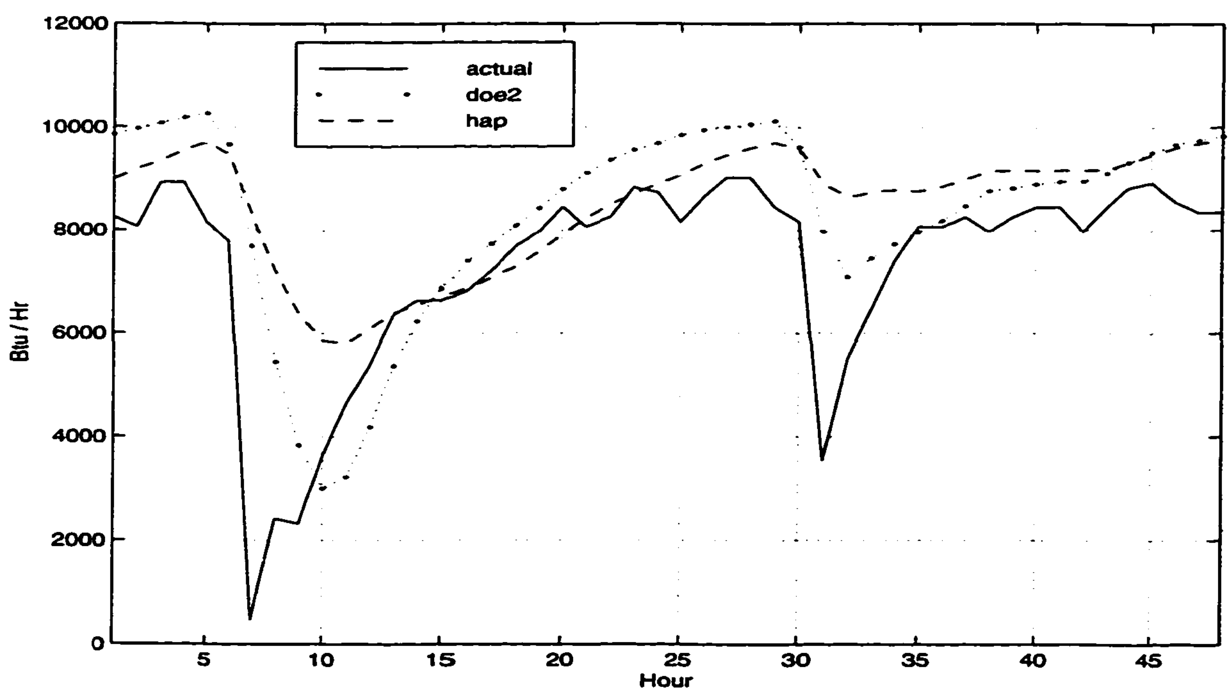


Figure 7.3 East room reheat energy rate for CAVRH(1) from 980801 through 980802

east-facing windows, most of the hours show good predictions from the programs.

The comparison of the south room is presented in Table 7.5 and Figure 7.4. The programs over-predicted their heating energy rates by 31.5% and 31.1% for DOE2 and HAP, respectively. The experimental uncertainty is 3.4%. Though out the test, the programs always over-predicted their energy rates with similar magnitude for every hour. Although the models over estimate the heating energy, the general trends agree with the building data.

The comparison of the west room is presented in Table 7.6 and Figure 7.5. The programs under-predicted their heating energy rates by 4.3% and 3.8% for DOE2 and HAP, respectively. Considering the uncertainty of the actual data (± 3.4%), the prediction results were pretty good. As recognized in the east room, the west room also showed a larger difference between models and measured data during the late afternoon when the sun shown through the west-facing class. However, in this case, DOE2 more closely matched the experimental results.

The comparison of the interior room is presented in Table 7.7 and Figure 7.6. The programs over-predicted their heating energy rates by 3.9% and 1.9% for DOE2 and HAP, respectively. The uncertainty in the experimental data is 0.6%.

Comparison of VAVRH(1) System

The test was conducted during late March, 1999. In addition to the purpose of the CAVRH(1) test, this test was designed to investigate how supply air flow to each room varies depending on the room's heating or cooling loads during the day. The building required cooling energy and heating energy during the test period. Comparisons were made in the same way as the CAVRH(1) test.

The comparison results for the system cooling energy rate are presented in Table 7.8 and Figure 7.7. All three programs under-predicted their cooling energy rates by 4.9%, 20.4% and 15.5% for DOE2, HAP and TRACE, respectively. The DOE2 predicted cooling energy rate most closely matches the experimental results. HAP and TRACE predicted similar cooling energy rates. Considering the uncertainty of the ERS data, ± 19.4% (± 5566 Btu/Hr), HAP results are just outside the range.

Table 7.5 Statistical summary of south room heating energy rate prediction in CAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	9012	8985	6855±231
MEAN(DT)	-2157	-2129	-
MEAN ERROR(%)	-31.5	-31.1	±3.4
STDE(DT)	90	75	-
RMSE	2243	2191	-
MIN(DT)	-3341	-3253	-
MAX(DT)	-788	-1029	-
MIN	5843	6886	4476±152
MAX	10246	9897	8161±277

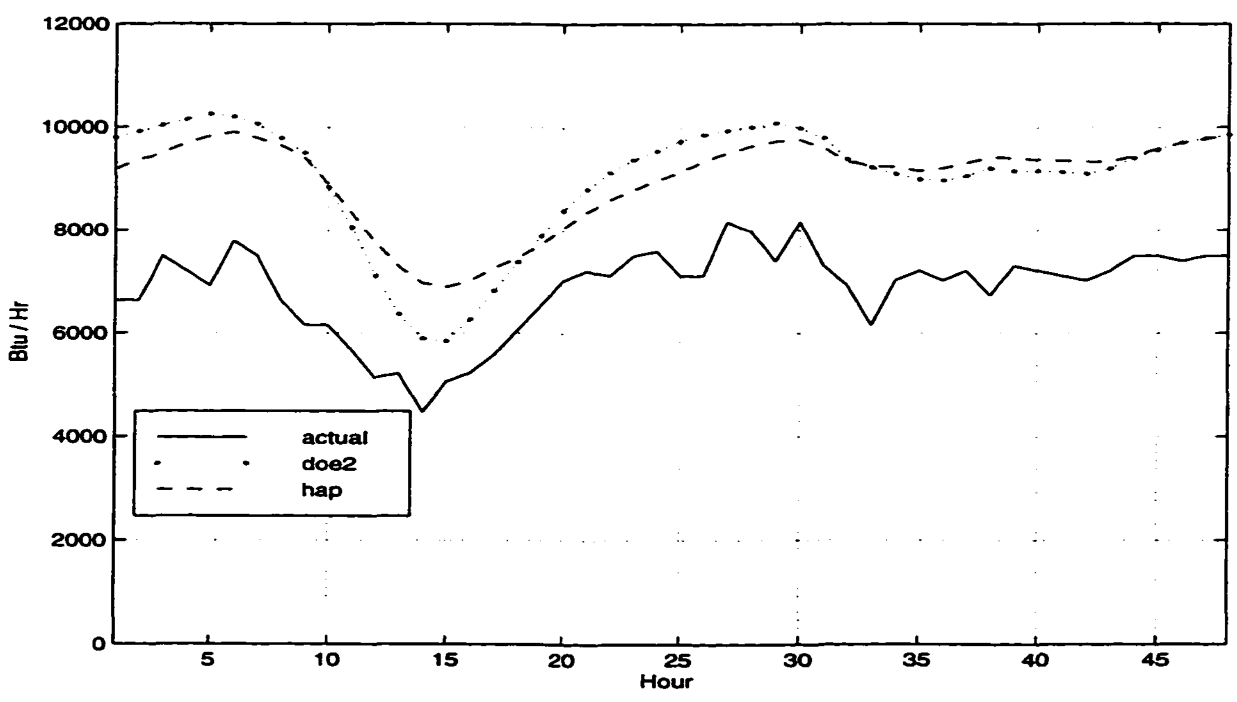


Figure 7.4 South room reheat energy rate for CAVRH(1) from 980801 through 980802

Table 7.6 Statistical summary of west room heating energy rate prediction in CAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	8539	8580	8922±303
MEAN(DT)	383	343	-
MEAN ERROR(%)	4.3	3.8	±3.4
STDE(DT)	129	158	-
RMSE	966	1136	-
MIN(DT)	-1360	-3090	-
MAX(DT)	3717	1995	-
MIN	2751	5422	2332±79
MAX	9948	9760	10535±355

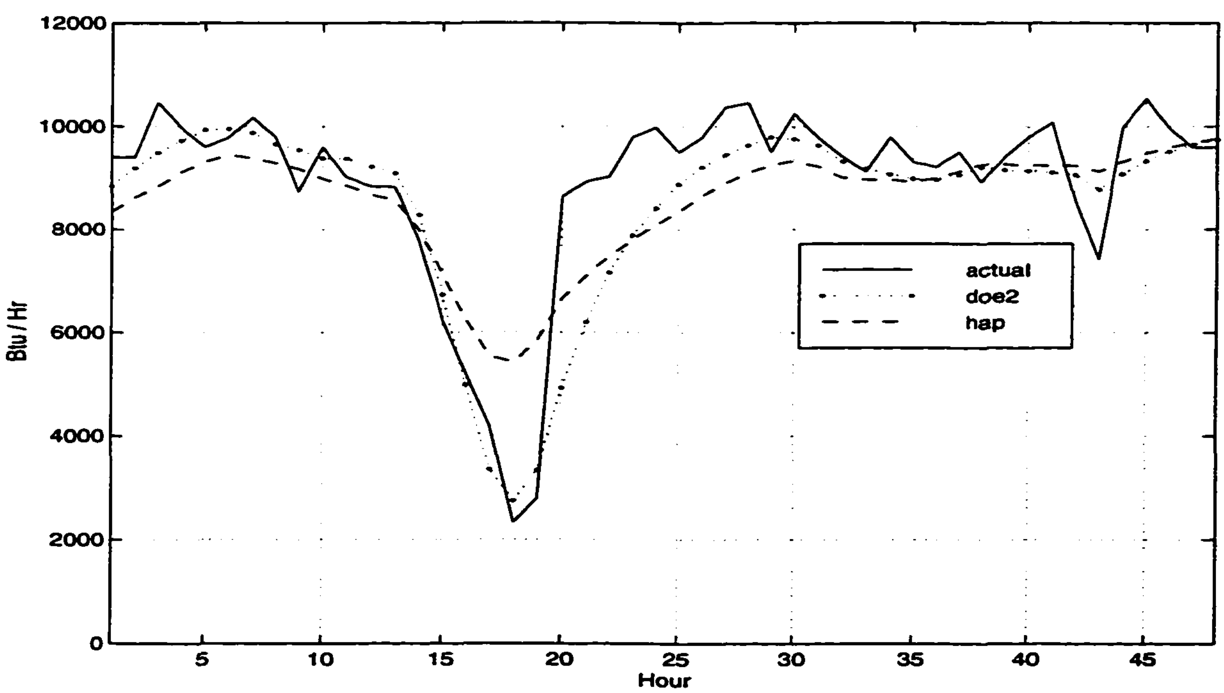


Figure 7.5 West room reheat energy rate for CAVRH(1) from 980801 through 980802

Table 7.7 Statistical summary of interior room heating energy rate prediction in CAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	4255	4172	4094±25
MEAN(DT)	-161	-78	-
MEAN ERROR(%)	-3.9	-1.9	±0.6
STDE(DT)	31	27	-
RMSE	264	203	-
MIN(DT)	-705	-563	-
MAX(DT)	272	313	-
MIN	4157	4143	3622±24
MAX	4379	4195	4500±27

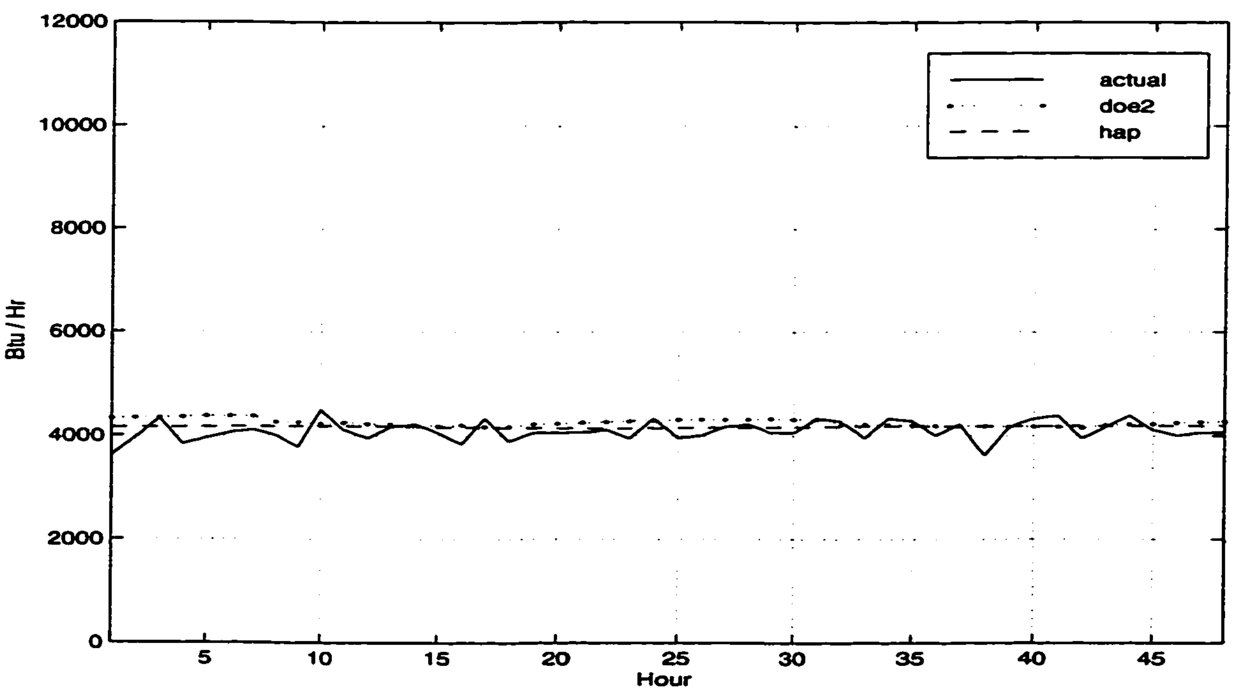


Figure 7.6 Interior reheat energy rate for CAVRH(1) from 980801 through 980802

Table 7.8 Statistical summary of system cooling energy rate prediction in VAVRH(1)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	27345	22895	24300	28763±5566
MEAN(DT)	1418	5868	4463	-
MEAN ERROR(%)	4.9	20.4	15.5	±19.4
STDE(DT)	199	183	202	-
RMSE	2401	6133	4877	-
MIN(DT)	-3085	2598	-87	-
MAX(DT)	6189	10518	10456	-
MIN	25236	20066	21840	27241±5539
MAX	31347	25462	28320	34700±5589

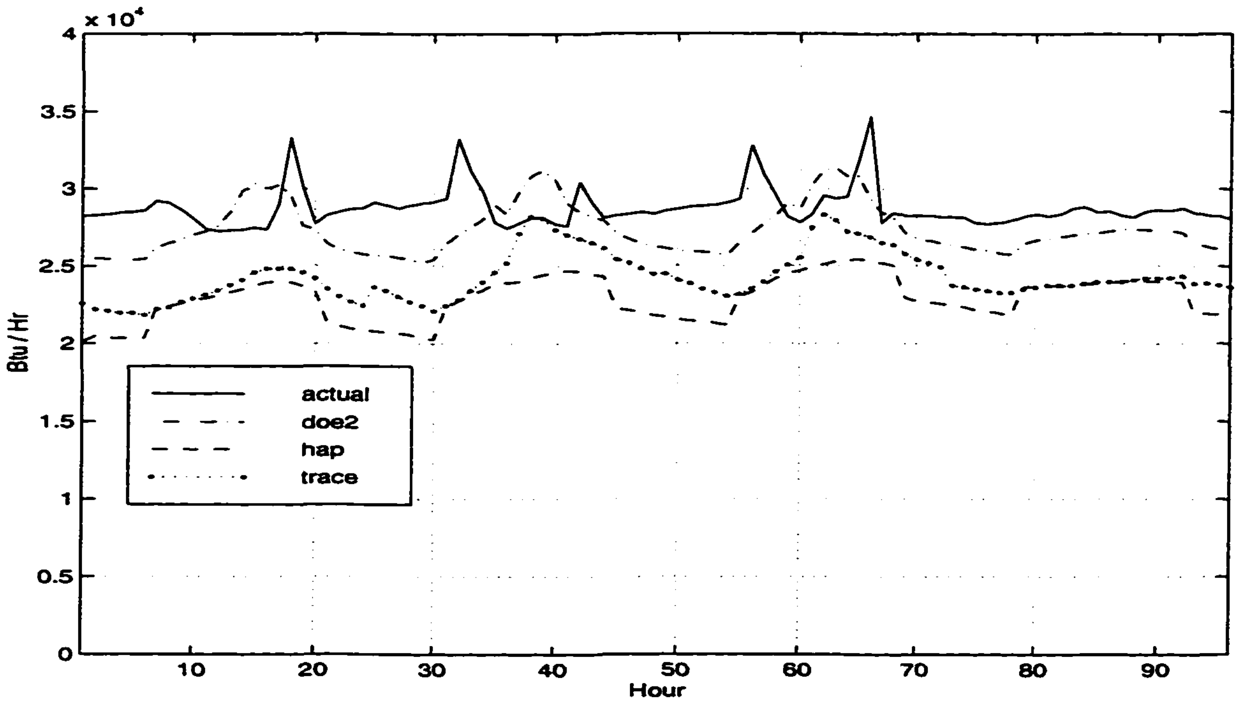


Figure 7.7 System cooling energy rate for VAVRH(1) from 990328 through 990331

The comparison results for the system heating energy rate are presented in Table 7.9 and Figure 7.8. On average all three programs over-predicted the system heating energy rates by 8.1%, 8.0% and 4.3% for DOE2, HAP and TRACE, respectively. The uncertainty in the experimental data was ± 2.9%.

The comparison results for the zones are presented in Table 7.10 through Table 7.13 and Figure 7.9 through Figure 7.12. For the comparison of the east zone, as shown in Table 7.10 and Figure 7.9, the programs predicted their heating energy rates very well for DOE2 and HAP. The programs under-predicted their energies slightly by 3.8% and 2.2% for DOE2 and HAP, respectively; however the uncertainty in the ERS data is ± 3.4%. This situation is the reverse of what happened in CAVRH(1).

The comparison of the south room is presented in Table 7.11 and Figure 7.10. The programs predicted their heating energy rates well with their percent error values, 10.1% and 8.9% for DOE2 and HAP, respectively. These are much better than in CAVRH(1), which were -31.5% and -30.1% for DOE2 and HAP, respectively.

The comparison of the west room is presented in Table 7.12 and Figure 7.11. The programs under-predicted their heating energy rates by 14.1% and 12.5% for DOE2 and HAP, respectively.

The comparison of the interior room is presented in Table 7.13 and Figure 7.12. The programs under-predicted their heating energy rates by 2.3% and 7.9% for DOE2 and HAP, respectively. Considering the uncertainty of the actual data, the prediction results were pretty good. The results are similar to the CAVRH(1).

For the comparisons of air flow rate, the actual data were compared with the simulation results. Figure 7.13 through Figure 7.17 show the results graphically, and Table 7.14 through table 7.18 present the statistical results. The comparison of AHU supply air flow rates is presented in Table 7.14 and Figure 7.13. DOE2 and TRACE showed a variation of the air flow rate for one hour in last each three day, but HAP did not show any variation of air flow throughout the test. The comparison of each zone's air flow rate is presented in Table 7.15 through Table 7.18 and Figure 7.13 through Figure 7.17. DOE2 program showed more variation in the south room while the experimental results showed more variation in the west

Table 7.9 Statistical summary of system heating energy rate prediction in VAVRH(1)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	18539	18571	19318	20183±585
MEAN(DT)	1645	1612	866	-
MEAN ERROR(%)	8.1	8.0	4.3	±2.9
STDE(DT)	279	439	345	-
RMSE	3182	4572	3468	-
MIN(DT)	-3507	-6751	-7536	-
MAX(DT)	9376	8177	7361	-
MIN	5971	9873	6590	6014±127
MAX	27850	25500	27870	31795±968

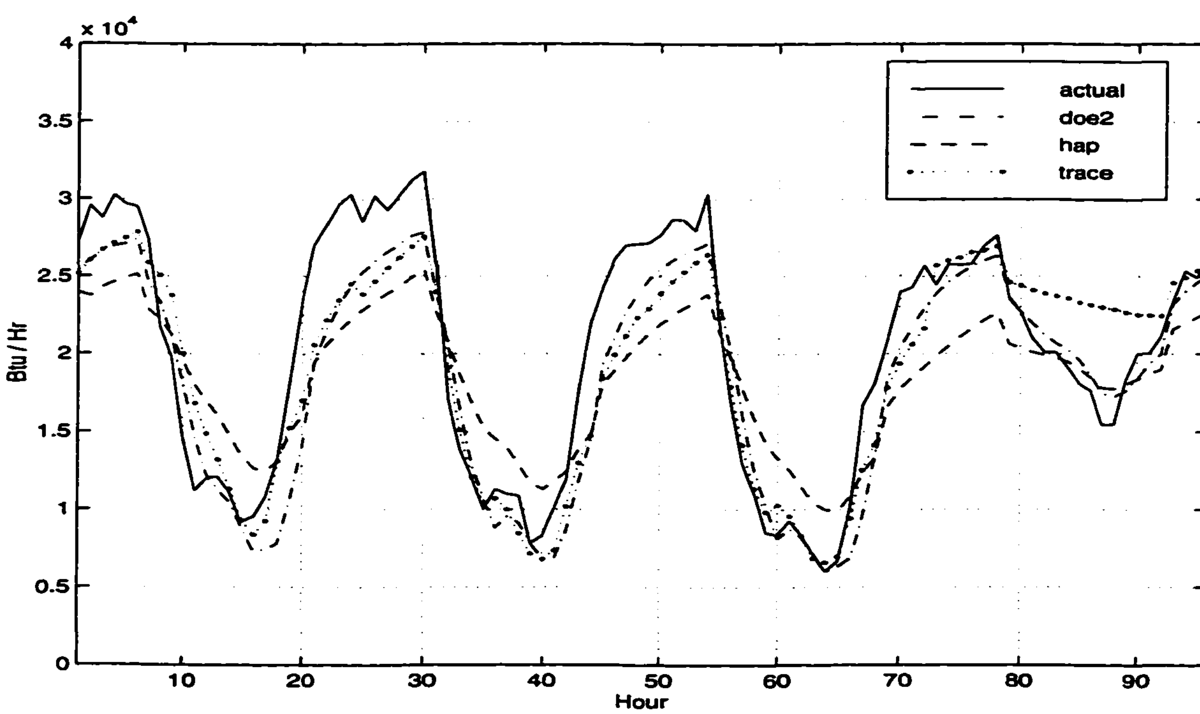


Figure 7.8 Total reheat energy rate for VAVRH(1) from 990328 through 990331

Table 7.10 Statistical summary of east room heating energy rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	5222	5308	5429±184
MEAN(DT)	206	121	-
MEAN ERROR(%)	3.8	2.2	±3.4
STDE(DT)	114	165	-
RMSE	1132	1612	-
MIN(DT)	-4025	-4845	-
MAX(DT)	2045	2090	-
MIN	0	2635	0
MAX	8052	7592	9021±307

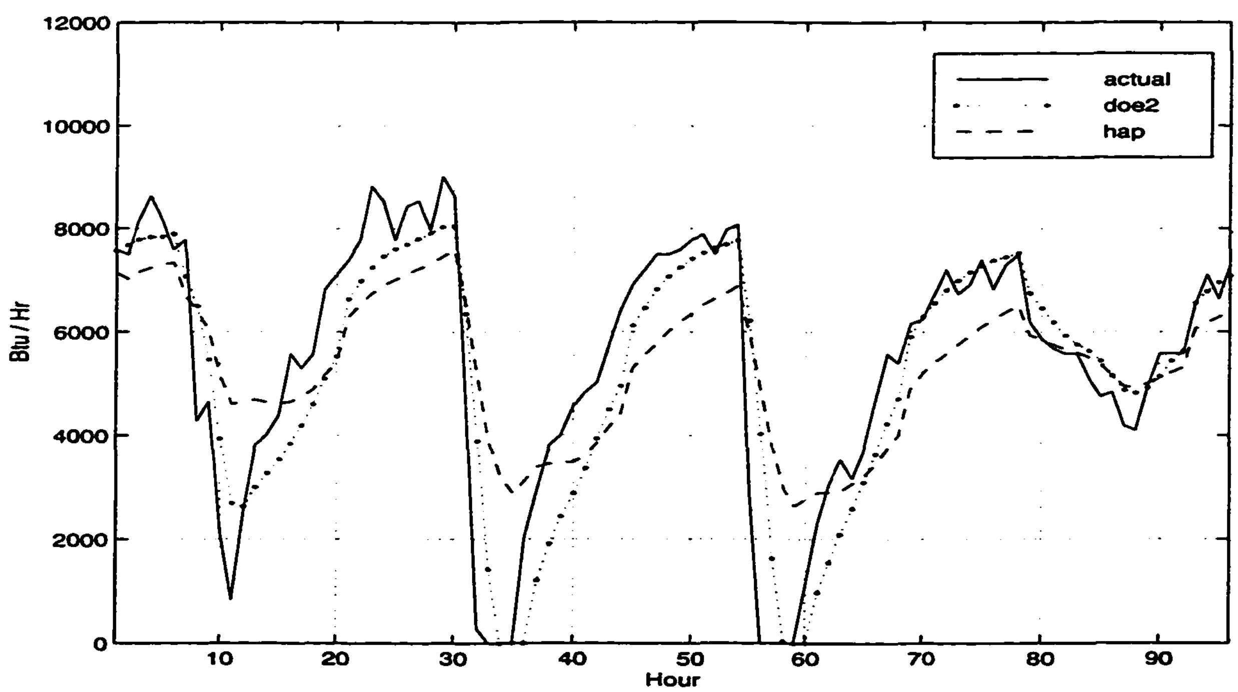


Figure 7.9 East room reheat energy rate for VAVRH(1) from 990328 through 990331

Table 7.11 Statistical summary of south room heating energy rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	4601	4661	5116±174
MEAN(DT)	514	455	-
MEAN ERROR(%)	10.1	8.9	±3.4
STDE(DT)	121	178	-
RMSE	1283	1798	-
MIN(DT)	-1897	-3335	-
MAX(DT)	4370	2937	-
MIN	0	1168	0
MAX	7906	7110	9978±339

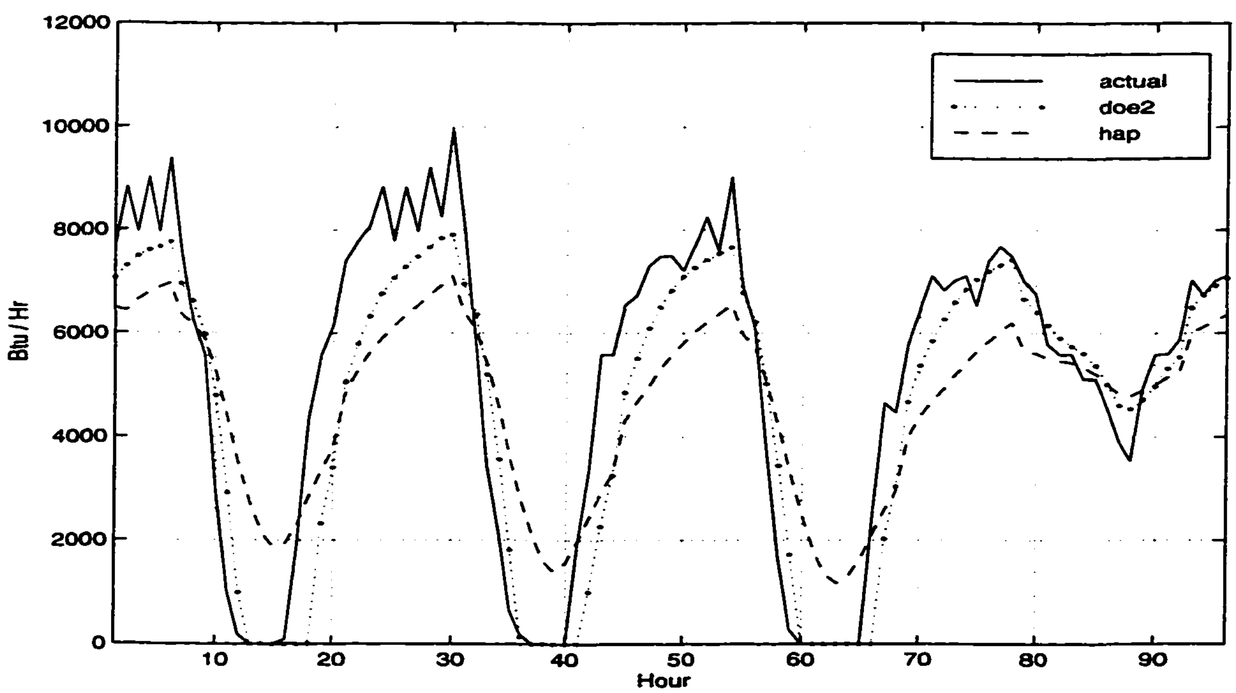


Figure 7.10 South room reheat energy rate for VAVRH(1) from 990328 through 990331

Table 7.12 Statistical summary of west room heating energy rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	5134	5228	5974±203
MEAN(DT)	840	746	-
MEAN ERROR(%)	14.1	12.5	±3.4
STDE(DT)	134	186	-
RMSE	1551	1964	-
MIN(DT)	-1670	-3183	-
MAX(DT)	4628	3769	-
MIN	0	1899	0
MAX	7804	7077	10074±342

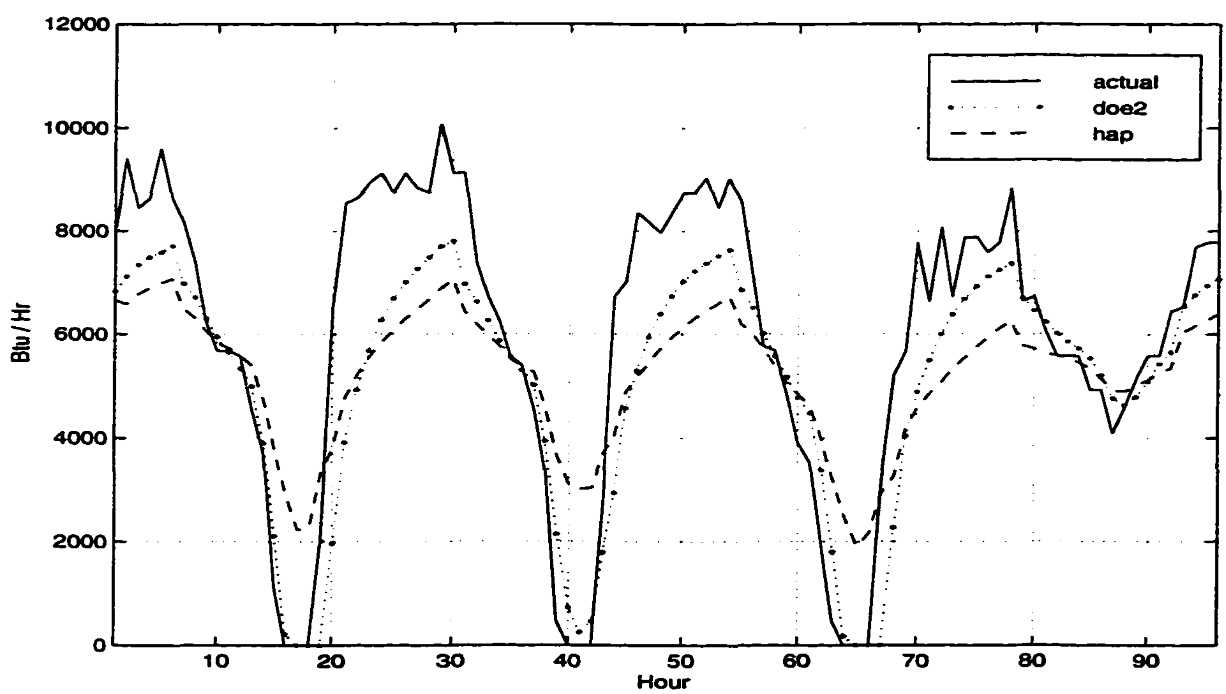


Figure 7.11 West room reheat energy rate for VAVRH(1) from 990328 through 990331

Table 7.13 Statistical summary of interior room heating energy rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	3581	3375	3664±24
MEAN(DT)	84	290	-
MEAN ERROR(%)	2.3	7.9	±0.7
STDE(DT)	23	22	-
RMSE	237	361	-
MIN(DT)	-412	-281	-
MAX(DT)	652	746	-
MIN	3206	3083	2853±20
MAX	4088	3750	4390±26

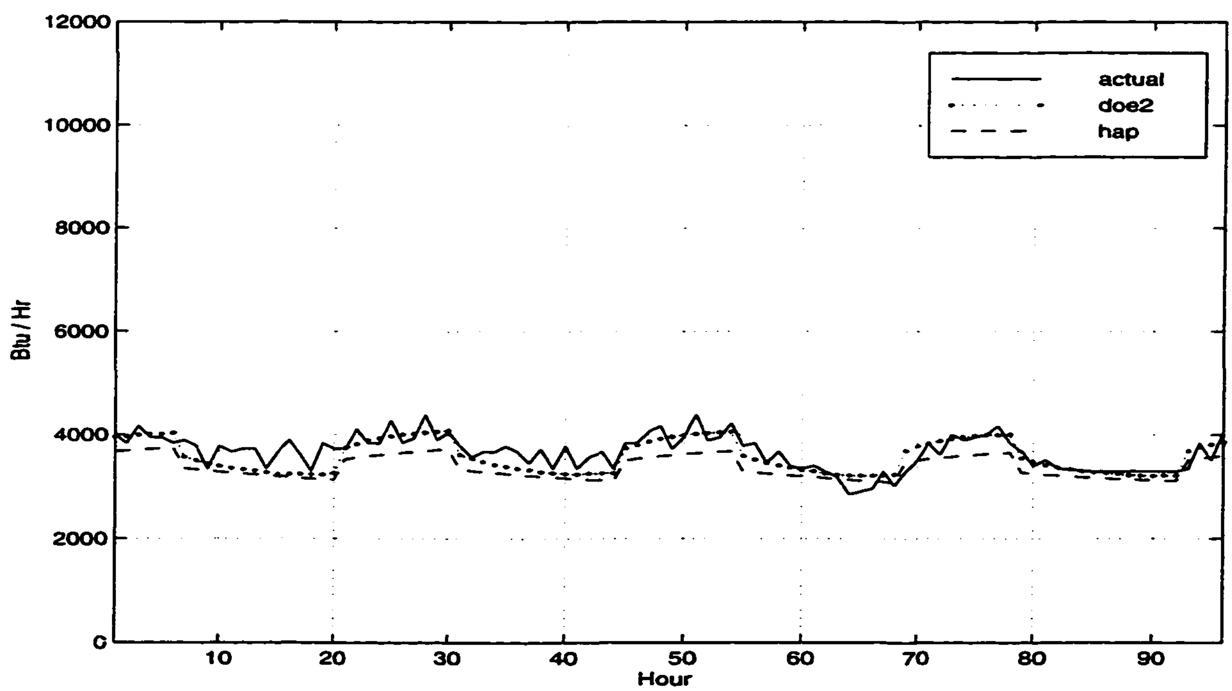


Figure 7.12 Interior room reheat energy rate for VAVRH(1) from 990328 through 990331

Table 7.14 Statistical summary of AHU supply air flow rate prediction in VAVRH(1)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	1636	1620	1626	1647±50
MEAN(DT)	11	27	21	-
MEAN ERROR(%)	0.7	1.6	1.3	±3.0
STDE(DT)	8	8	8	-
RMSE	75	80	80	-
MIN(DT)	-111	-16	-81	-
MAX(DT)	301	381	381	-
MIN	1620	1620	1620	1604±50
MAX	1743	1620	1749	2001±50

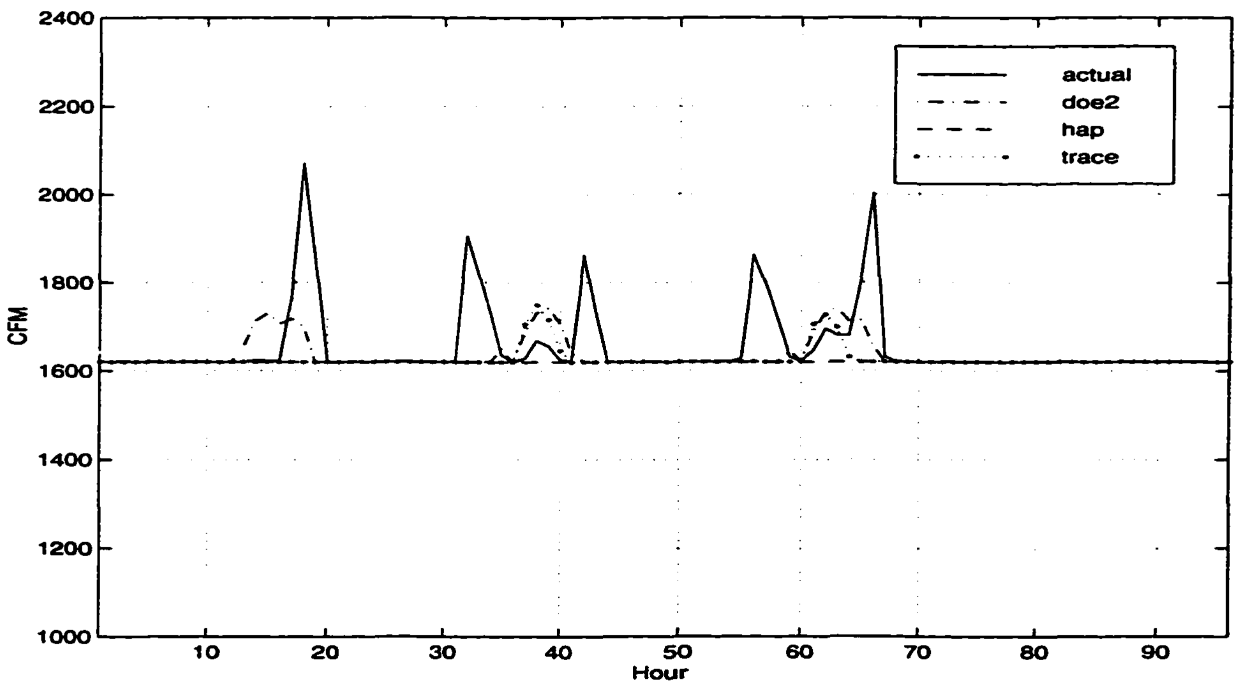


Figure 7.13 AHU supply air flow rate for VAVRH(1) from 990328 through 990331

Table 7.15 Statistical summary of east room supply air flow rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	451	450	462±50
MEAN(DT)	11	12	-
MEAN ERROR(%)	2.5	2.6	±10.8
STDE(DT)	5	5	-
RMSE	50	50	-
MIN(DT)	-16	-1	-
MAX(DT)	285	285	-
MIN	450	450	449±50
MAX	481	450	735±50

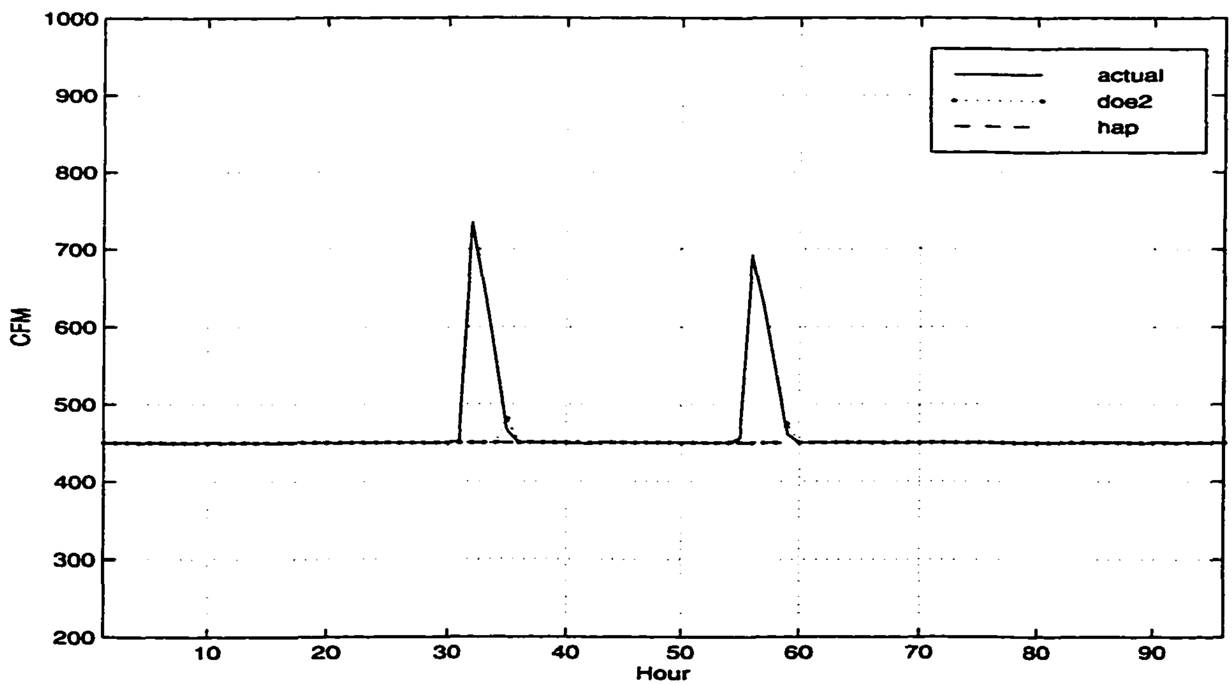


Figure 7.14 East room supply air flow rate for VAVRH(1) from 990328 through 990331

Table 7.16 Statistical summary of south room supply air flow rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	462	450	453±50
MEAN(DT)	-9	3	-
MEAN ERROR(%)	-2.1	0.7	±11.0
STDE(DT)	2	1	-
RMSE	26	12	-
MIN(DT)	-108	-1	-
MAX(DT)	2	76	-
MIN	450	450	449±50
MAX	574	450	526±50

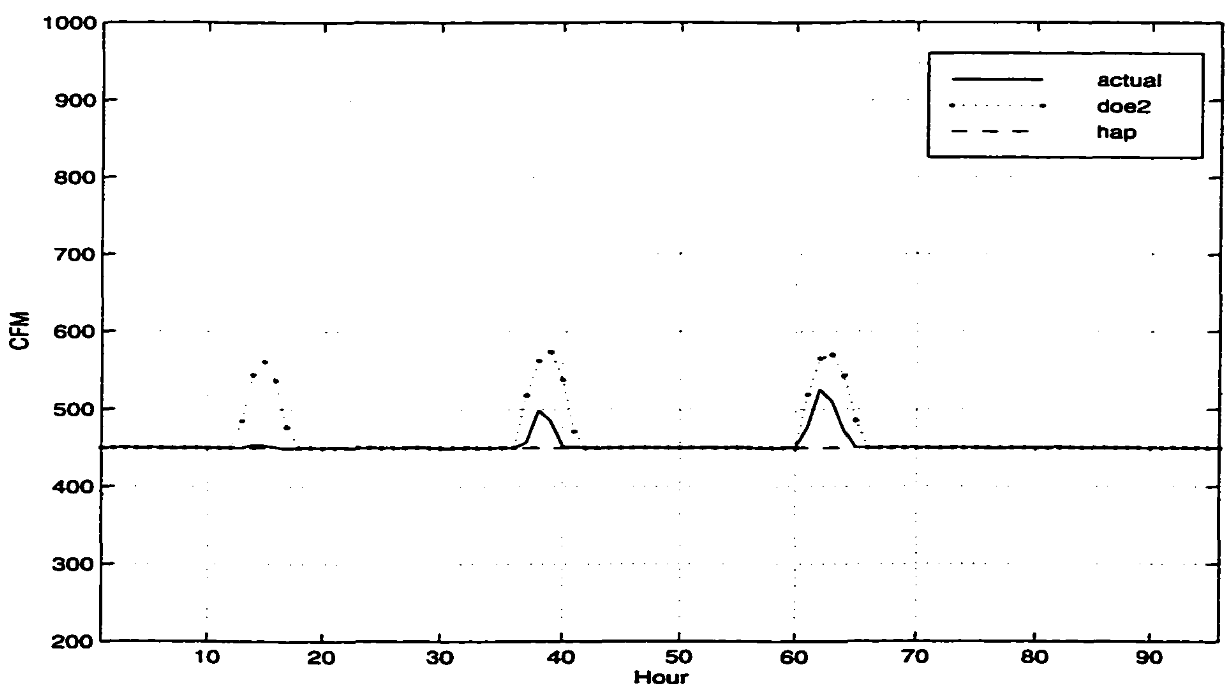


Figure 7.15 South room supply air flow rate for VAVRH(1) from 990328 through 990331

Table 7.17 Statistical summary of west room supply air flow rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	453	450	469±50
MEAN(DT)	16	19	-
MEAN ERROR(%)	3.5	4.0	±10.6
STDE(DT)	7	7	-
RMSE	66	75	-
MIN(DT)	-1	-1	-
MAX(DT)	371	451	-
MIN	450	450	449±50
MAX	530	450	901±50

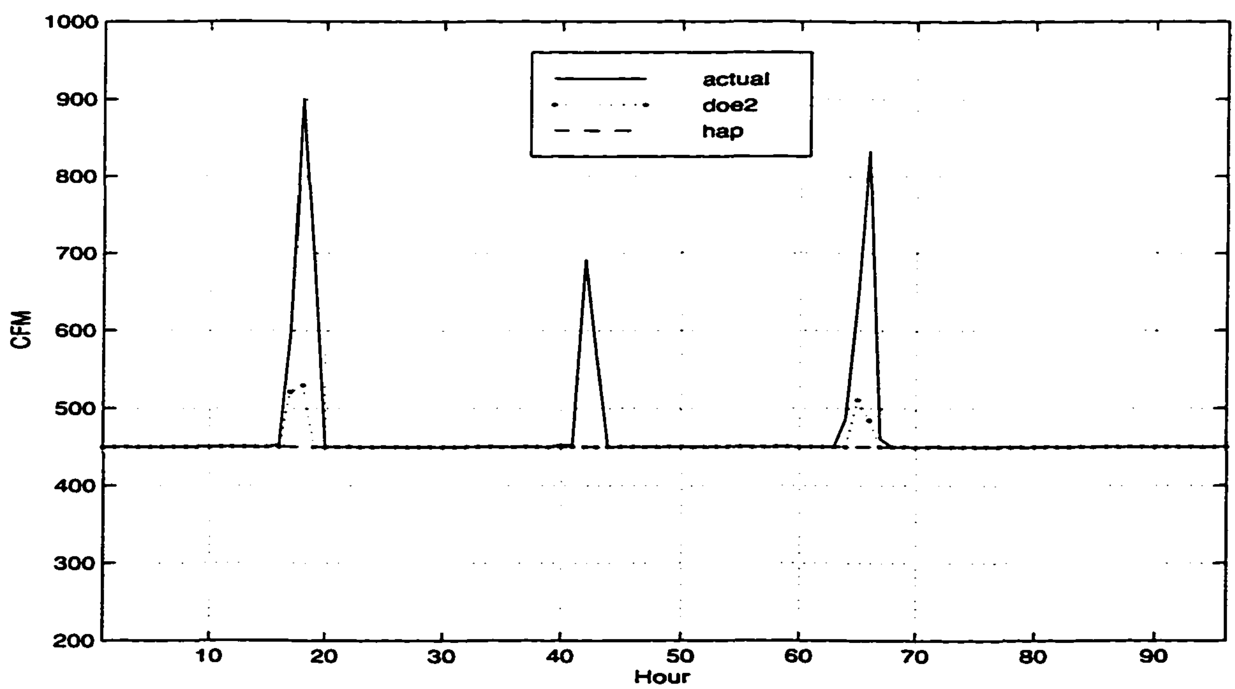


Figure 7.16 West room supply air flow rate for VAVRH(1) from 990328 through 990331

Table 7.18 Statistical summary of interior room supply air flow rate prediction in VAVRH(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	270	270	270±50
MEAN(DT)	0	0	-
MEAN ERROR(%)	0.0	0.0	±18.5
STDE(DT)	0	0	-
RMSE	0	0	-
MIN(DT)	-1	-1	-
MAX(DT)	1	1	-
MIN	270	270	269±50
MAX	270	270	271±50

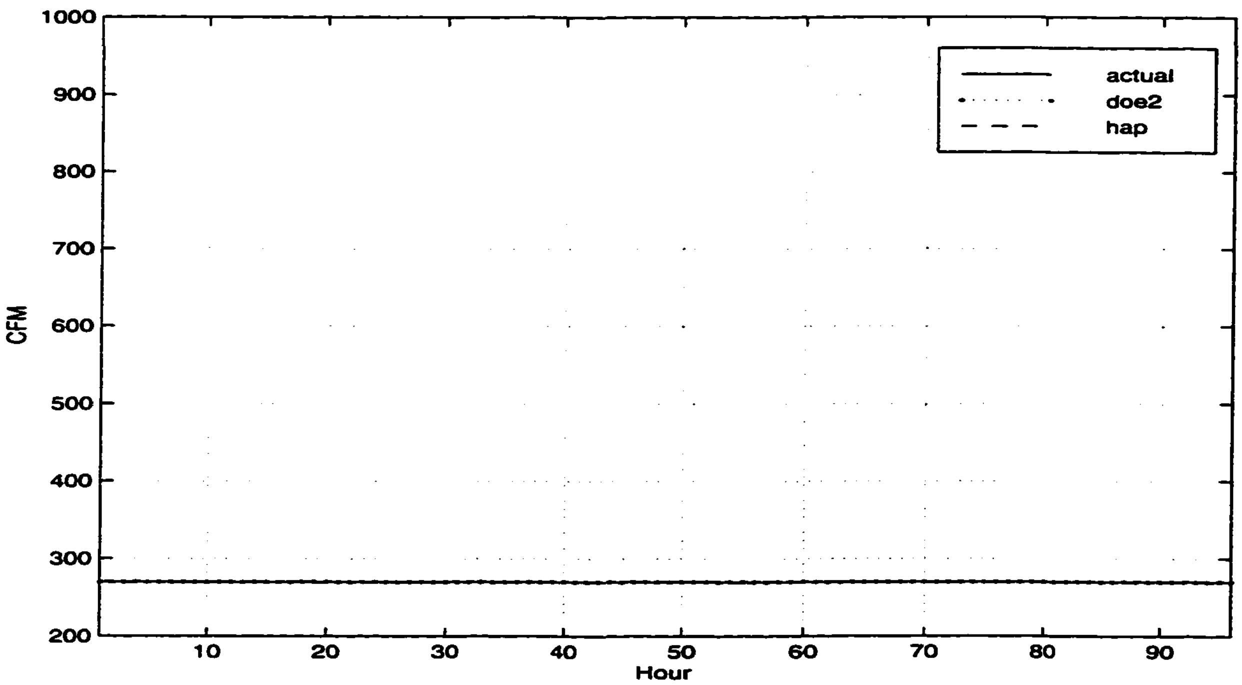


Figure 7.17 Interior supply air flow rate for VAVRH(1) from 990328 through 990331

room. In retrospect, this test was not a very good test for a VAV system since there was not much variation in zone cooling loads during the test.

Comparison of 4PFCU(1) System

The test was conducted during mid-March, 1999. One of the purposes of this test was to examine how the system responds to building envelope load alone, so no ventilation air was allowed throughout the test period. Figure 7.18 $\sim$ 7.19 present comparisons cooling and heating energy rates at the system level with numerical information in Table 7.19 $\sim$ 7.20. TRACE predicted both cooling and heating well. HAP showed differences in both cooling and heating energy predictions. The uncertainty for the measured data was large because energy calculations were made by taking the air-side energy balance. Considering the uncertainty of the measurement, the DOE2 program energy predictions were good.

Figure 7.20 $\sim$ 7.23 present comparisons of zone heating energy rates with numerical information in Table 7.21 $\sim$ 7.24, and Figure 7.24 $\sim$ 7.27 present comparisons of zone cooling energy rates with numerical information in Table 7.25 $\sim$ 7.28.

Tests Having Dynamic Characteristics of the Building

The dynamic tests used the same HVAC systems as the non-dynamic tests; however, the dynamic tests utilized schedules for room thermostat set points and baseboard heaters as described in Chapter 4. In addition an air-side economizer was used except for 4PFCU test, which did not use any outside air.

Comparison of CAVRH(2) System

The test was conducted during late February, 1999. During the test, cooling equipment was available, but it never was used. This was the same as in the programs, so system cooling energy rates were not compared with the simulation programs' results. Since the system used the air-side economizer, most of cooling load was met utilizing outside air.

Table 7.19 Statistical summary of system cooling energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	4825	1176	3488	4083±841
MEAN(DT)	-742	2907	594	-
MEAN ERROR(%)	-18.2	71.2	14.6	±20.6
STDE(DT)	410	373	345	-
RMSE	3532	4279	2969	-
MIN(DT)	-6953	-1469	-4686	-
MAX(DT)	11967	13078	13078	-
MIN	0	0	0	149±221
MAX	16138	5416	12960	13078±1484

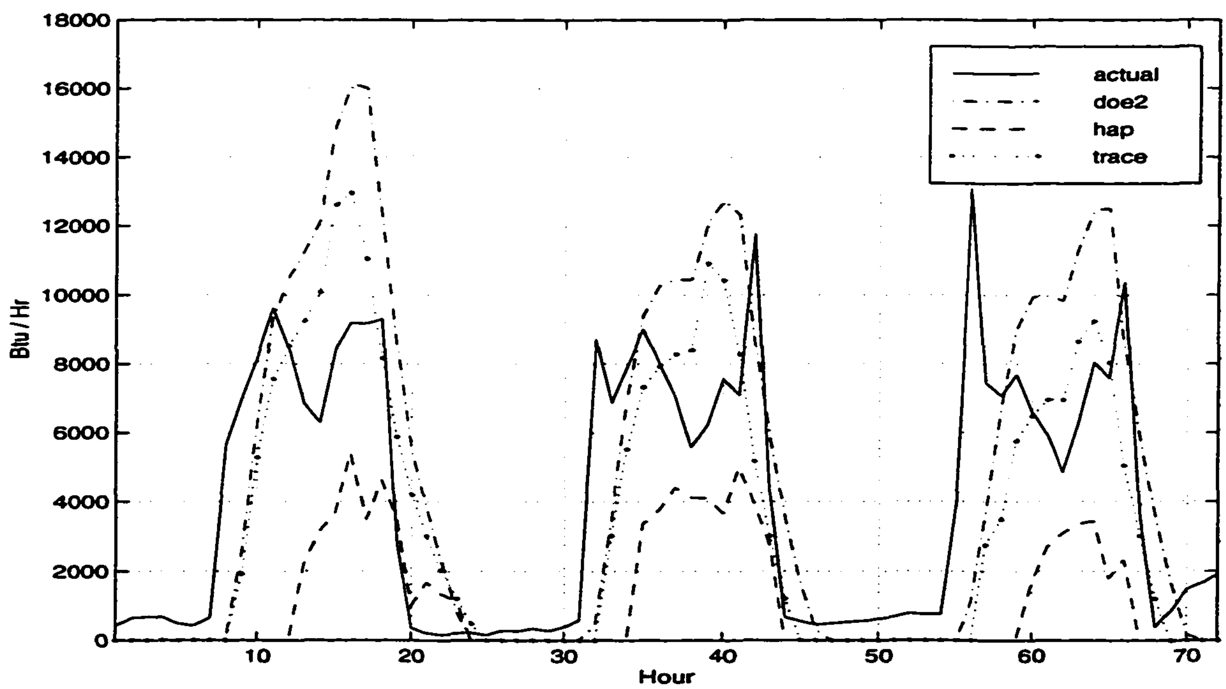


Figure 7.18 System cooling energy rate for 4PFCU(1) from 990316 through 990318

Table 7.20 Statistical summary of system heating energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	2140	1159	2690	2690±942
MEAN(DT)	550	1531	1	-
MEAN ERROR(%)	20.4	56.9	0.0	±35.0
STDE(DT)	162	240	217	-
RMSE	1472	2538	1827	-
MIN(DT)	-2956	-2130	-5265	-
MAX(DT)	4229	5984	4645	-
MIN	0	0	20	233±303
MAX	6401	6639	10070	8062±1554

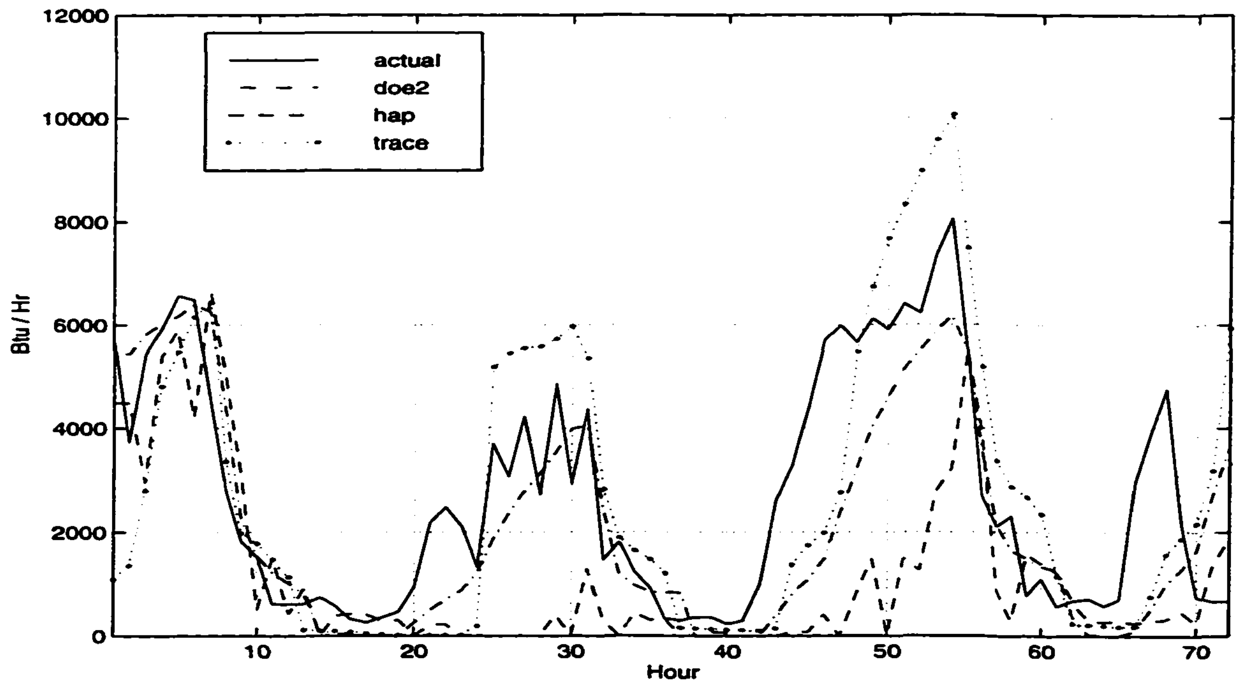


Figure 7.19 Total reheat energy rate for 4PFCU(1) from 990316 through 990318

Table 7.21 Statistical summary of east room reheat energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	725	382	799±183
MEAN(DT)	73	417	-
MEAN ERROR(%)	9.2	52.2	±22.9
STDE(DT)	65	100	-
RMSE	555	938	-
MIN(DT)	-1677	-1262	-
MAX(DT)	1692	2194	-
MIN	0	0	0
MAX	2133	2351	2759±445

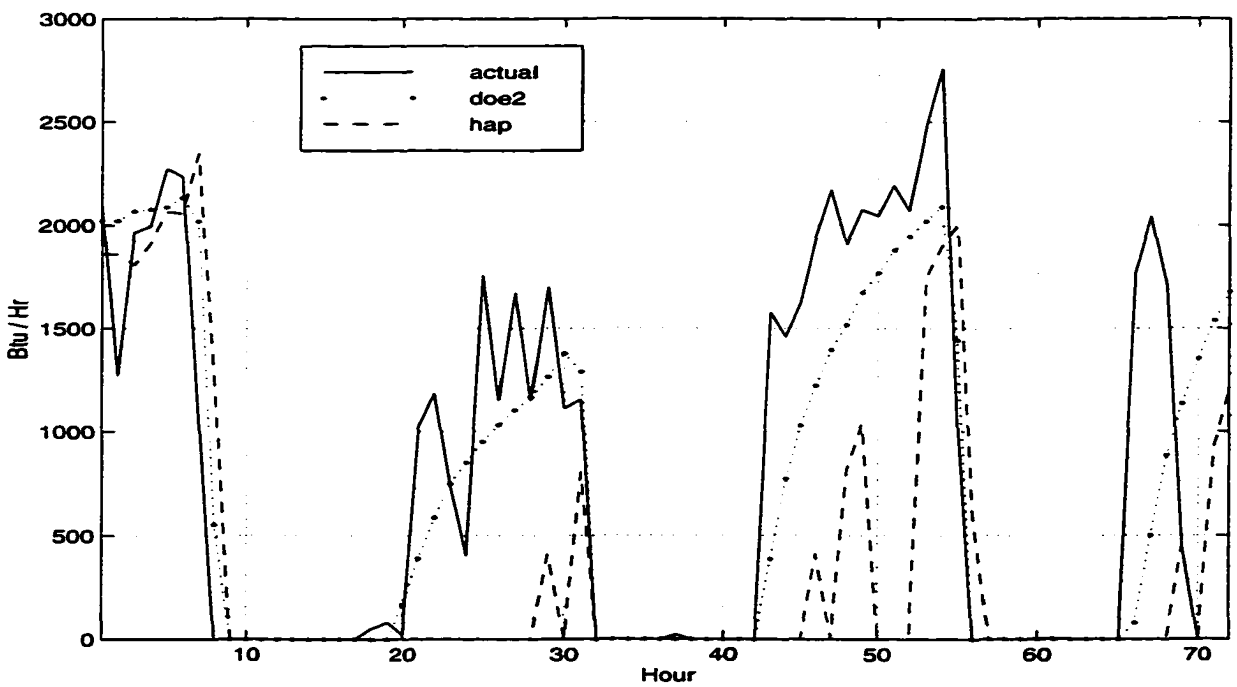


Figure 7.20 East room reheat energy rate for 4PFCU(1) from 990316 through 990318

Table 7.22 Statistical summary of south room reheat energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	498	224	605±229
MEAN(DT)	107	381	-
MEAN ERROR(%)	17.7	63.0	±37.8
STDE(DT)	51	65	-
RMSE	439	667	-
MIN(DT)	-838	-471	-
MAX(DT)	1460	1780	-
MIN	0	0	0
MAX	1943	1728	2324±444

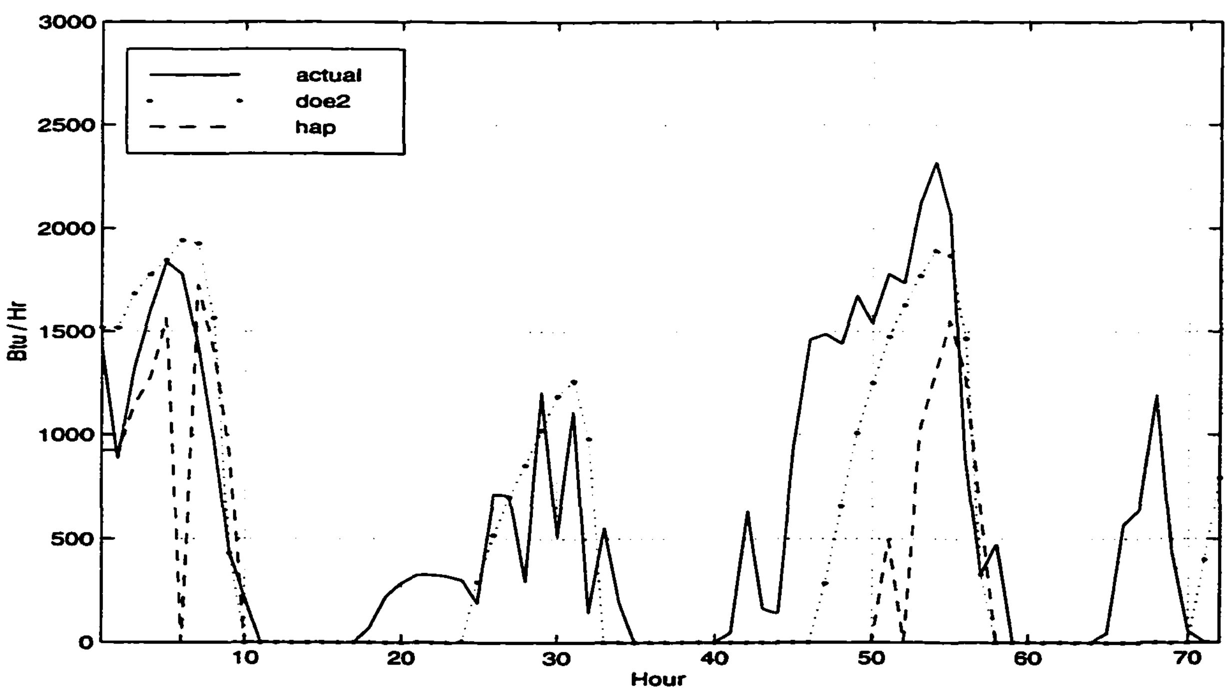


Figure 7.21 South room reheat energy rate for 4PFCU(1) from 990316 through 990318

Table 7.23 Statistical summary of west room reheat energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	793	379	724±108
MEAN(DT)	-68	345	-
MEAN ERROR(%)	-9.4	47.7	±14.9
STDE(DT)	69	88	-
RMSE	587	820	-
MIN(DT)	-1247	-1085	-
MAX(DT)	1468	2268	-
MIN	0	0	0
MAX	1976	2090	2268±281

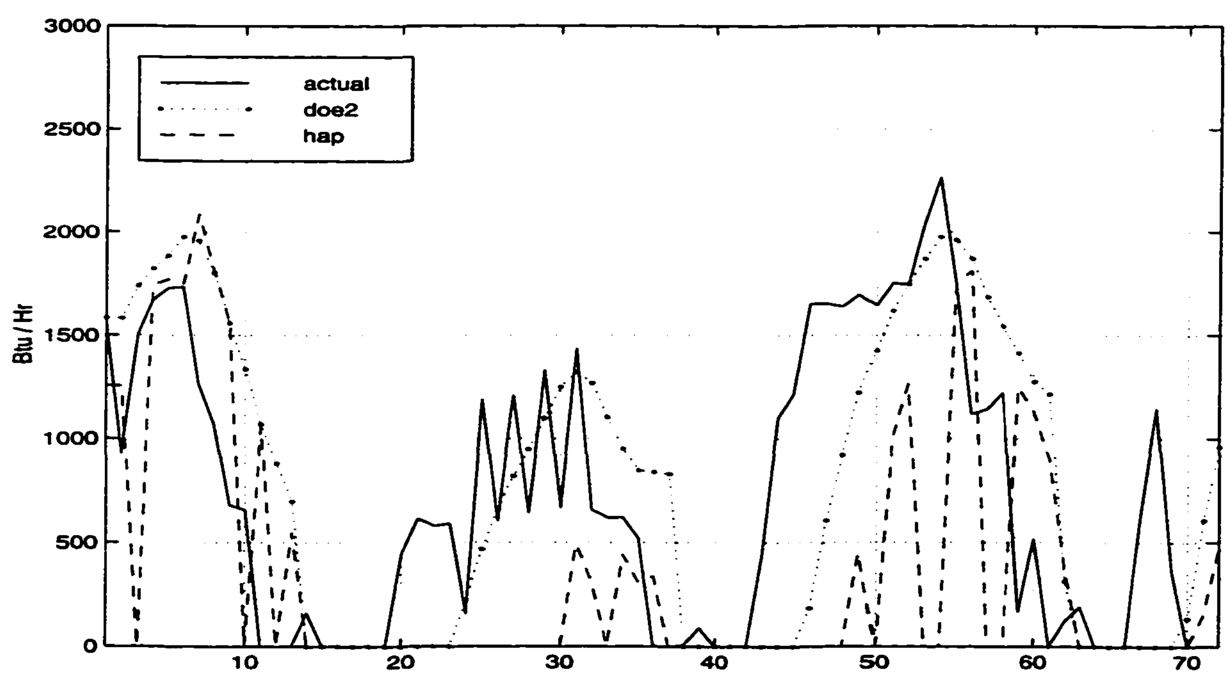


Figure 7.22 West room reheat energy rate for 4PFCU(1) from 990316 through 990318

Table 7.24 Statistical summary of interior room reheat energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	124	174	562±423
MEAN(DT)	438	388	-
MEAN ERROR(%)	77.9	69.0	±75.2
STDE(DT)	15	27	-
RMSE	455	448	-
MIN(DT)	108	-150	-
MAX(DT)	774	909	-
MIN	0	0	164±236
MAX	353	574	909±444

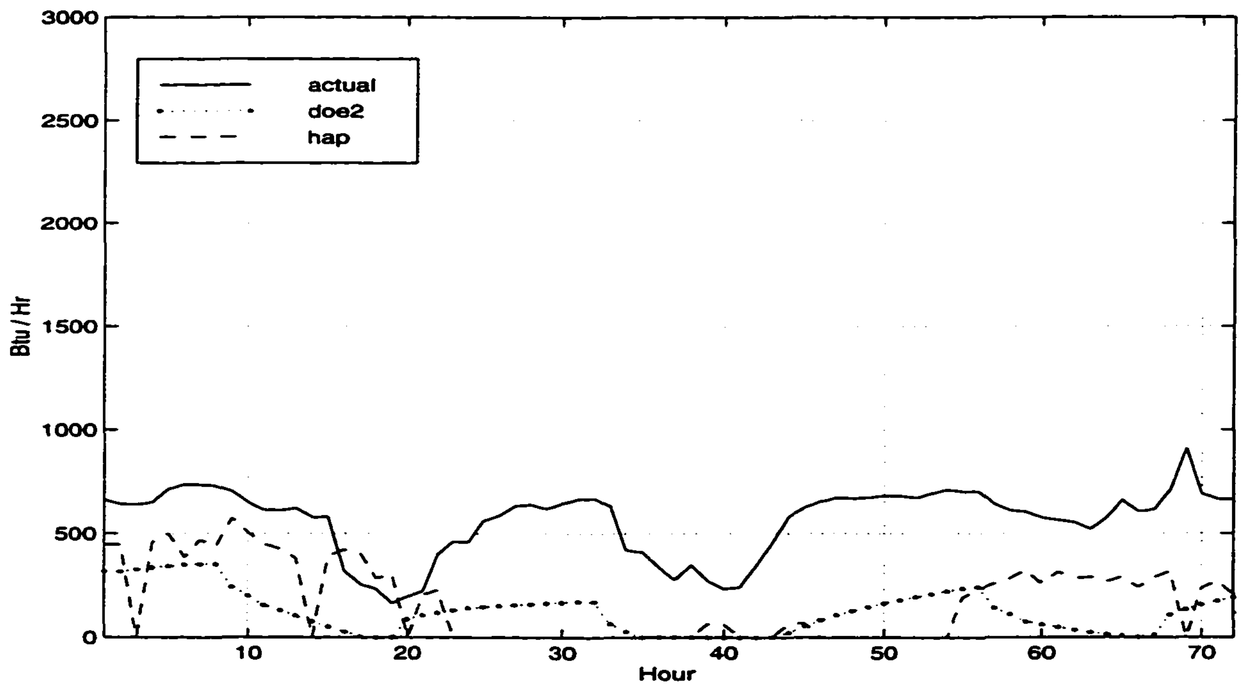


Figure 7.23 Interior room reheat energy rate for 4PFCU(1) from 990316 through 990318

Table 7.25 Statistical summary of east room cooling energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	1233	58	1267±264
MEAN(DT)	34	1210	-
MEAN ERROR(%)	2.7	95.5	±20.3
STDE(DT)	249	274	-
RMSE	2095	2609	-
MIN(DT)	-3159	-270	-
MAX(DT)	10884	11995	-
MIN	0	0	0
MAX	5507	1692	11995±491

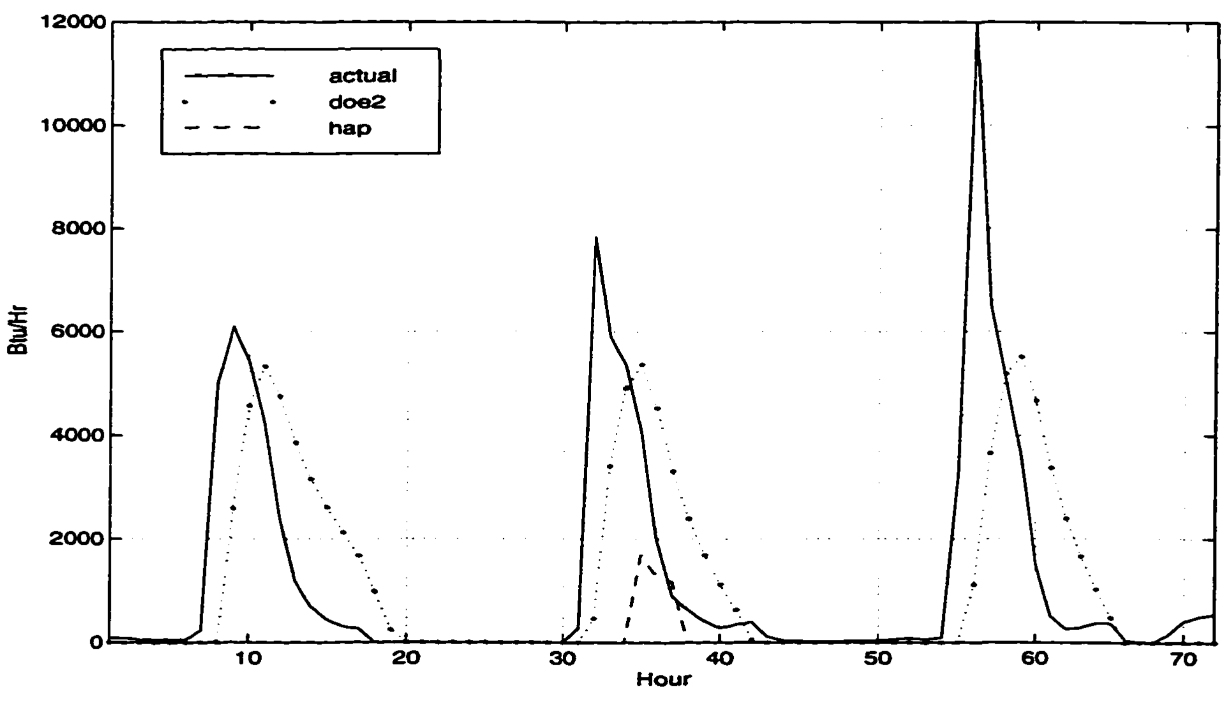


Figure 7.24 East room cooling energy rate for 4PFCU(1) from 990316 through 990318

Table 7.26 Statistical summary of south room cooling energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	2615	962	1272±217
MEAN(DT)	-1343	310	-
MEAN ERROR(%)	-105.5	24.4	±17.1
STDE(DT)	210	158	-
RMSE	2222	1364	-
MIN(DT)	-5052	-2576	-
MAX(DT)	284	5077	-
MIN	0	0	0
MAX	9120	4116	5125±452

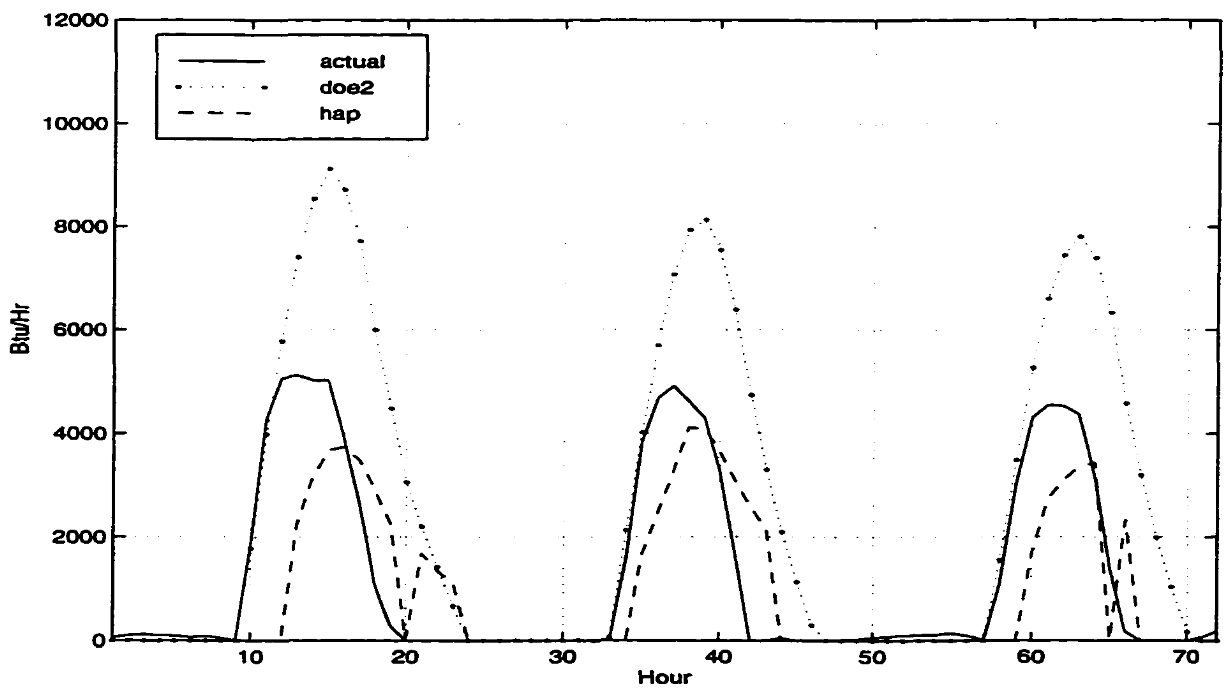


Figure 7.25 South room cooling energy rate for 4PFCU(1) from 990316 through 990318

Table 7.27 Statistical summary of west room cooling energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	963	156	1523±339
MEAN(DT)	560	1367	-
MEAN ERROR(%)	36.7	89.8	±22.2
STDE(DT)	155	235	-
RMSE	1424	2407	-
MIN(DT)	-2218	-782	-
MAX(DT)	7597	10157	-
MIN	0	0	66±163
MAX	6624	1910	1134 ±486

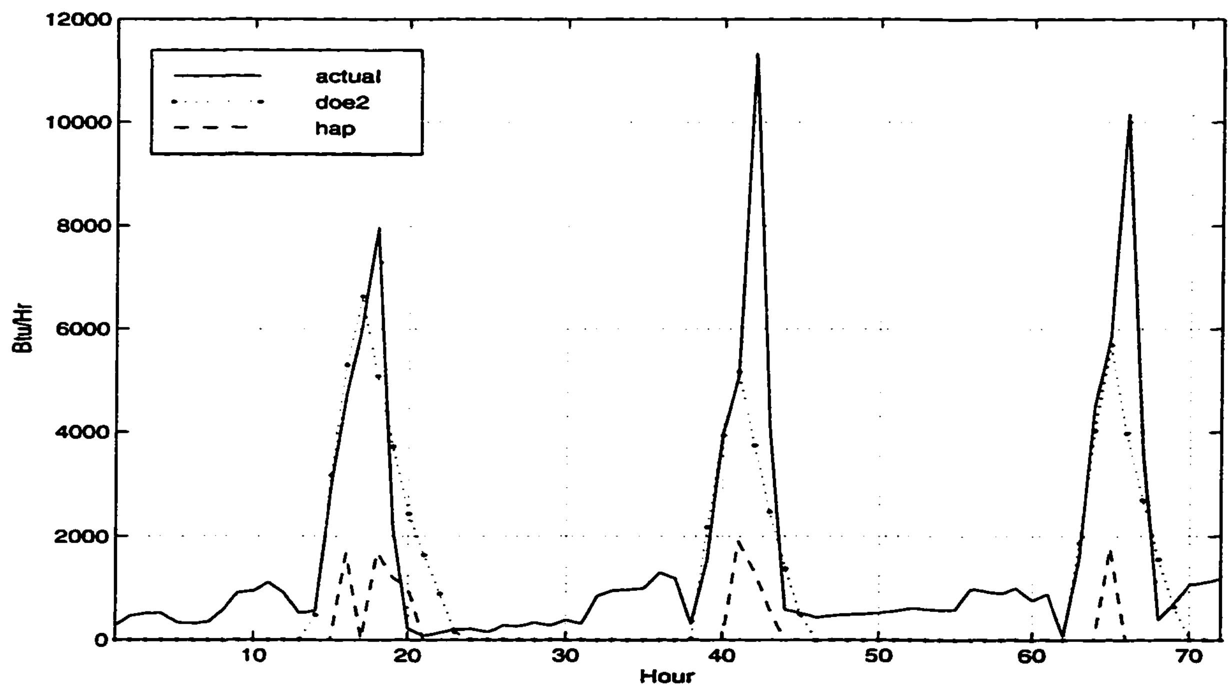


Figure 7.26 West room cooling energy rate for 4PFCU(1) from 990316 through 990318

Table 7.28 Statistical summary of interior room cooling energy rate prediction in 4PFCU(1)

Statistics	DOE2	HAP	ACTUAL
MEAN	13	0	21±20
MEAN(DT)	7	21	-
MEAN ERROR(%)	35.2	100.0	±95.0
STDE(DT)	8	7	-
RMSE	70	66	-
MIN(DT)	-131	0	-
MAX(DT)	348	377	-
MIN	0	0	0
MAX	140	0	377±207

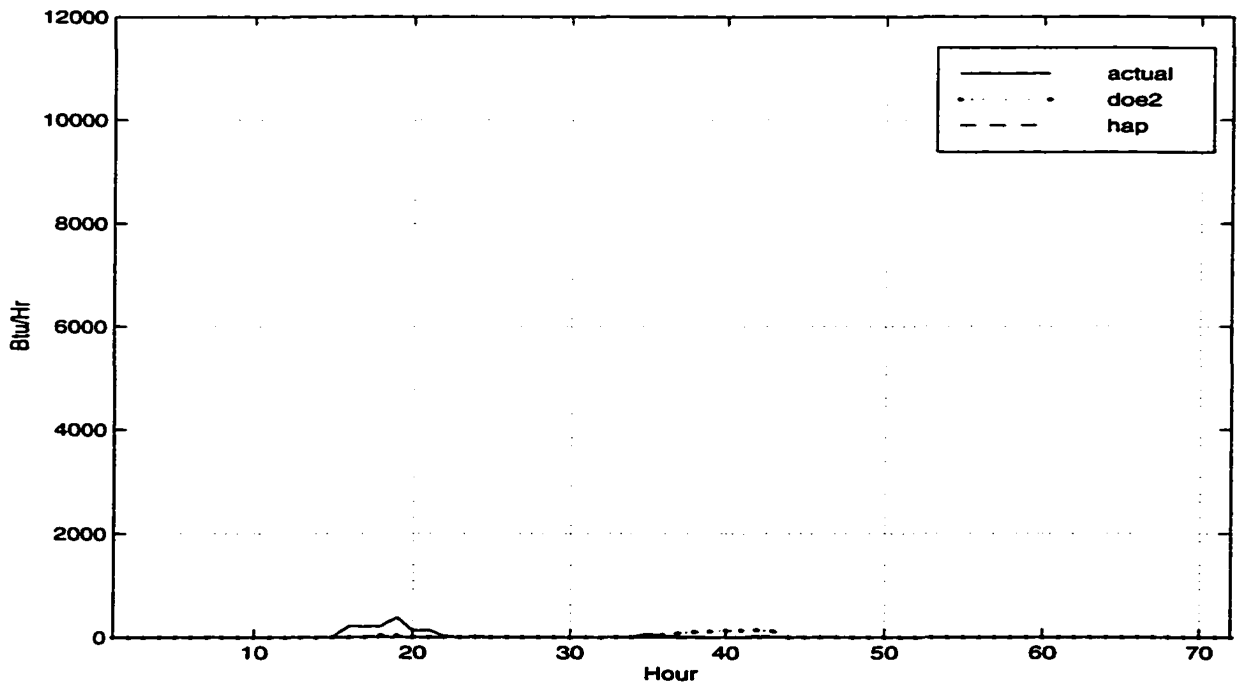


Figure 7.27 Interior room cooling energy rate for 4PFCU(1) from 990316 through 990318

The comparison of system heating energy rates are illustrated in Figure 7.28 and Table 7.29. General predictions by the programs were good when internal loads were added, but there were differences when the internal loads were turned off during the night time.

Comparisons of zone reheat energy rate were made for each zone. These results are shown from Figure 7.29 and Table 7.30 through Figure 7.32 and Table 7.33. The HAP program was better than DOE2 in the reheat energy predictions for all zones.

Outside air predictions by the economizer control were compared with actual ventilation air used by the system in Figure 7.33 and Table 7.34. HAP and TRACE showed almost same trend in their predictions and slightly under predicted. Considering uncertainty of the CFM sensor, the programs' predictions were good.

Comparison of VAVRH(2) System

The test was conducted in mid-March, 1999. During the test, mechanical cooling was not required because the system used the air-side economizer to supply up to 100% of outside air to maintain the discharge air temperature from the AHU. The computer models also did not use any mechanical cooling in their predictions.

For this test, the system fans were scheduled to run continuously during the occupied period. During the unoccupied period the system fans would only run if there was a call for heating or cooling from any of the test rooms. The test results showed that the system did not run the fans during the unoccupied period since the room temperature set points were always satisfied during the unoccupied period. All three computer programs simulated the same fan operation as the test results.

Most of heating to the rooms occurred in the morning and evening because the room thermostat was set up at 7:00 AM and set back at 8:00 PM while the internal loads came on at 9:00 AM and went off at 6:00 PM. Figure 7.34 and Table 7.35 illustrate the comparison of system heating energy rates between the actual data and the programs' predictions. The programs under-predicted the heating energy rates by 11% to 40 %. DOE2 showed the lowest error while HAP showed the largest error. These results are much worse than for the VAVRH(1) tests.

Table 7.29 Statistical summary of system heating energy rate prediction in CAVRH(2)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	36702	30020	28061	30747±915
MEAN(DT)	-5955	728	2687	-
MEAN ERROR(%)	-19.4	2.4	8.7	±3.0
STDE(DT)	435	849	742	-
RMSE	6990	7191	6805	-
MIN(DT)	-19499	-15001	-13363	-
MAX(DT)	1214	12051	14193	-
MIN	9201	10962	3850	4463±151
MAX	50218	40790	37890	49023±1305

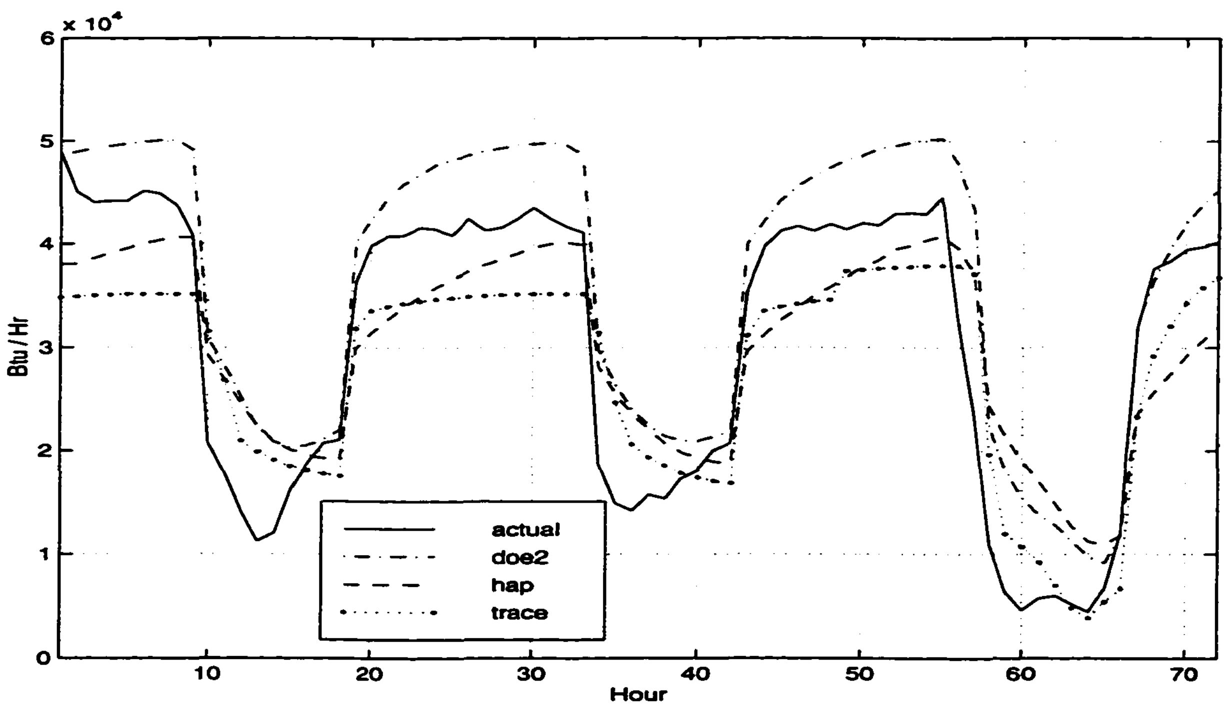


Figure 7.28 Total reheat energy rate for CAVRH(2) from 990223 through 990225

Table 7.30 Statistical summary of east room heating energy rate prediction in CAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	10807	9023	8586±286
MEAN(DT)	-2222	-437	-
MEAN ERROR(%)	-25.9	-5.1	±3.3
STDE(DT)	192	300	-
RMSE	2750	2565	-
MIN(DT)	-10752	-9712	-
MAX(DT)	-361	2797	-
MIN	3268	4723	0
MAX	14339	11950	13585±412

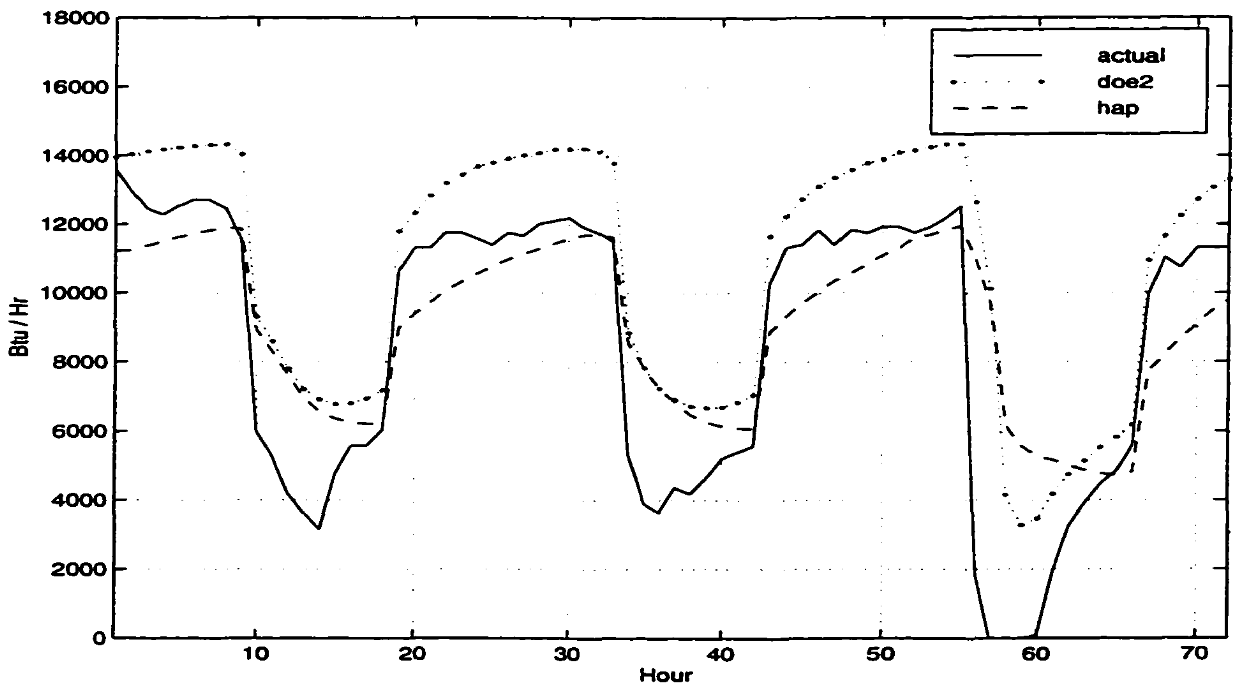


Figure 7.29 East room reheat energy rate for CAVRH(2) from 990223 through 990225

Table 7.31 Statistical summary of south room heating energy rate prediction in CAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	10149	8685	8911±297
MEAN(DT)	-1238	226	-
MEAN ERROR(%)	-13.9	2.5	±3.3
STDE(DT)	164	229	-
RMSE	1858	1941	-
MIN(DT)	-5603	-4889	-
MAX(DT)	3220	3853	-
MIN	0	1616	0
MAX	14359	11948	14345±429

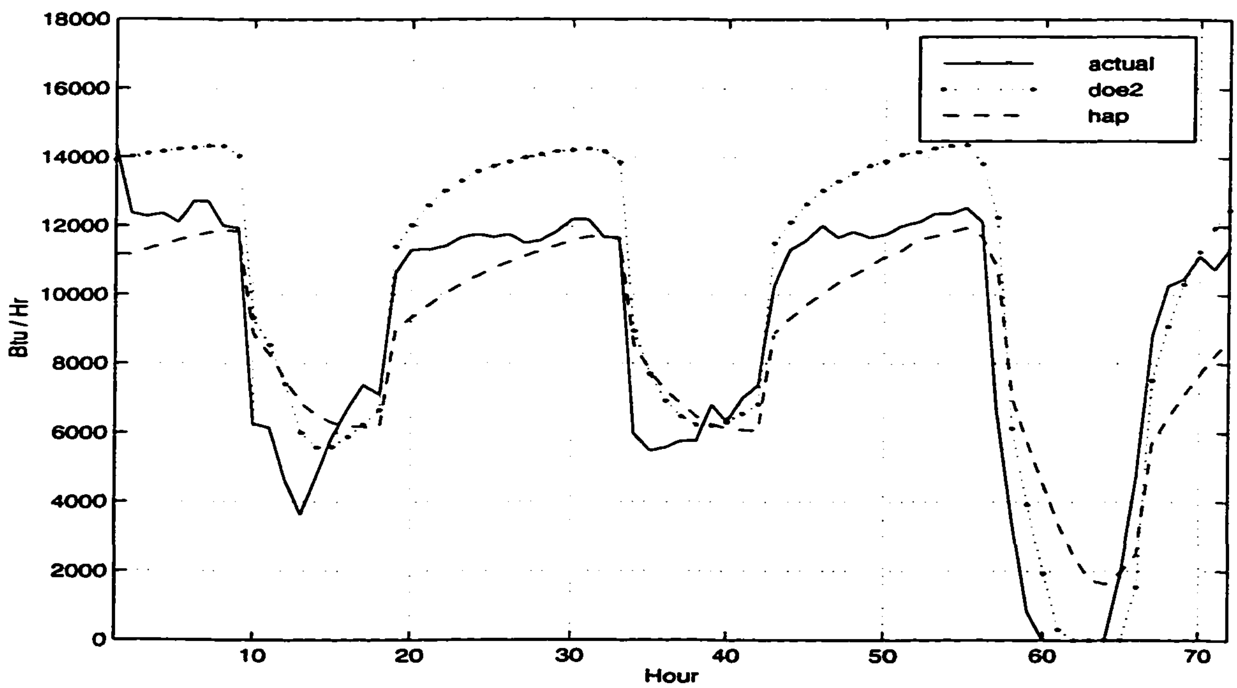


Figure 7.30 South reheat energy rate for CAVRH(2) from 990223 through 990225

Table 7.32 Statistical summary of west room heating energy rate prediction in CAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	10971	9119	9548±313
MEAN(DT)	-1423	430	-
MEAN ERROR(%)	-14.9	4.5	±3.3
STDE(DT)	137	234	-
RMSE	1830	2014	-
MIN(DT)	-3807	-3940	-
MAX(DT)	1332	3849	-
MIN	2355	3624	0
MAX	14331	11951	15057±444

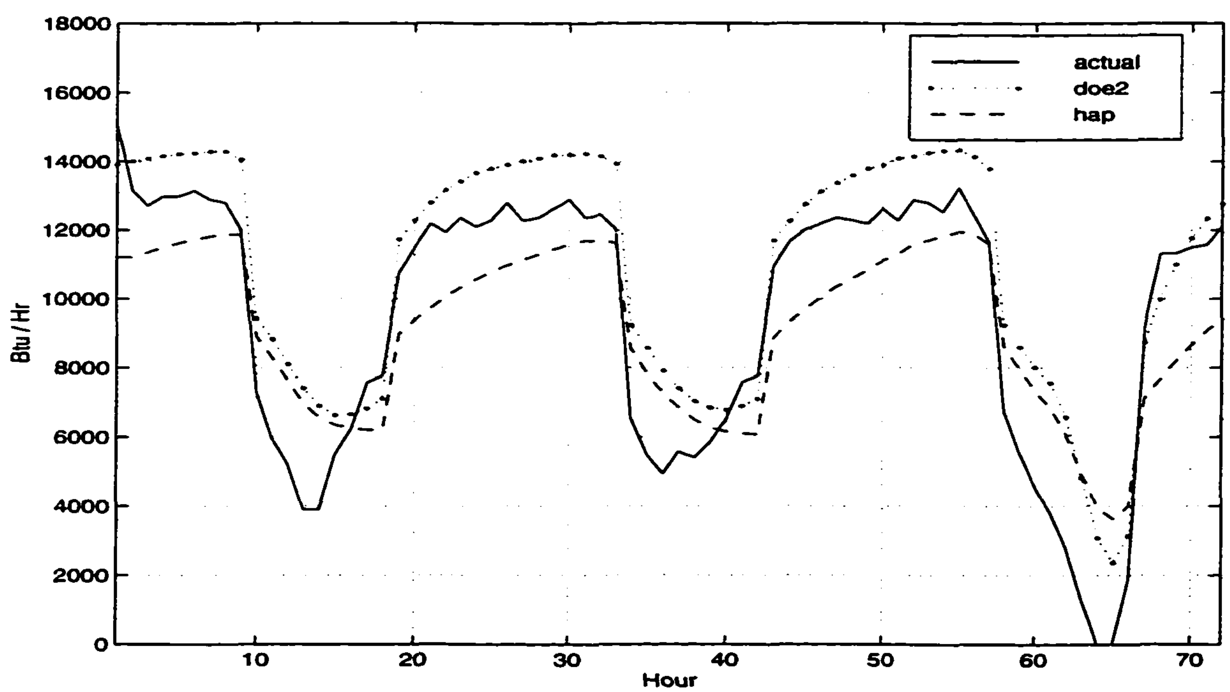


Figure 7.31 West reheat energy rate for CAVRH(2) from 990223 through 990225

Table 7.33 Statistical summary of interior room heating energy rate prediction in CAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	4775	3193	3702±19
MEAN(DT)	-1073	509	-
MEAN ERROR(%)	-29.0	13.8	±0.5
STDE(DT)	62	170	-
RMSE	1193	1521	-
MIN(DT)	-2351	-2157	-
MAX(DT)	206	2742	-
MIN	955	487	0
MAX	7218	5083	6585±33

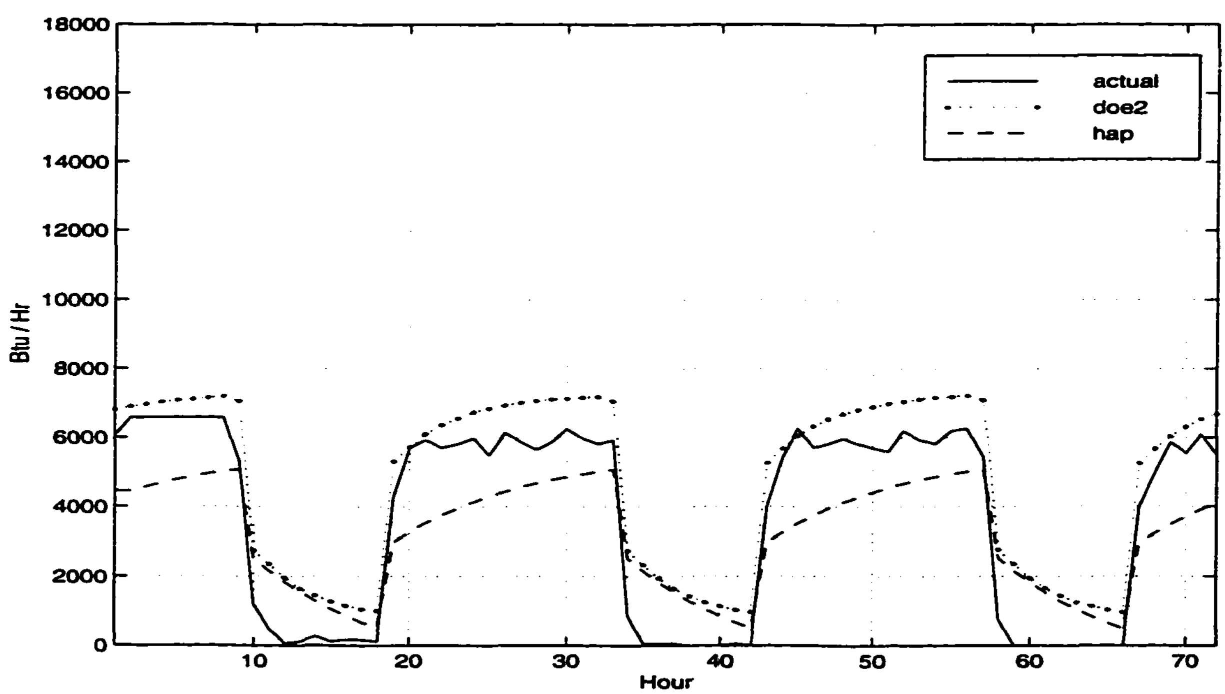


Figure 7.32 Interior reheat energy rate for CAVRH(2) from 990223 through 990225

Table 7.34 Statistical summary of outside air flow rate prediction in CAVRH(2)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	1191	862	832	995±50
MEAN(DT)	-196	133	162	-
MEAN ERROR(%)	-19.8	13.4	16.3	±5.0
STDE(DT)	10	5	10	-
RMSE	213	140	184	-
MIN(DT)	-492	-48	-56	-
MAX(DT)	-86	211	263	-
MIN	913	647	623	753±50
MAX	1770	1331	1475	1495±50

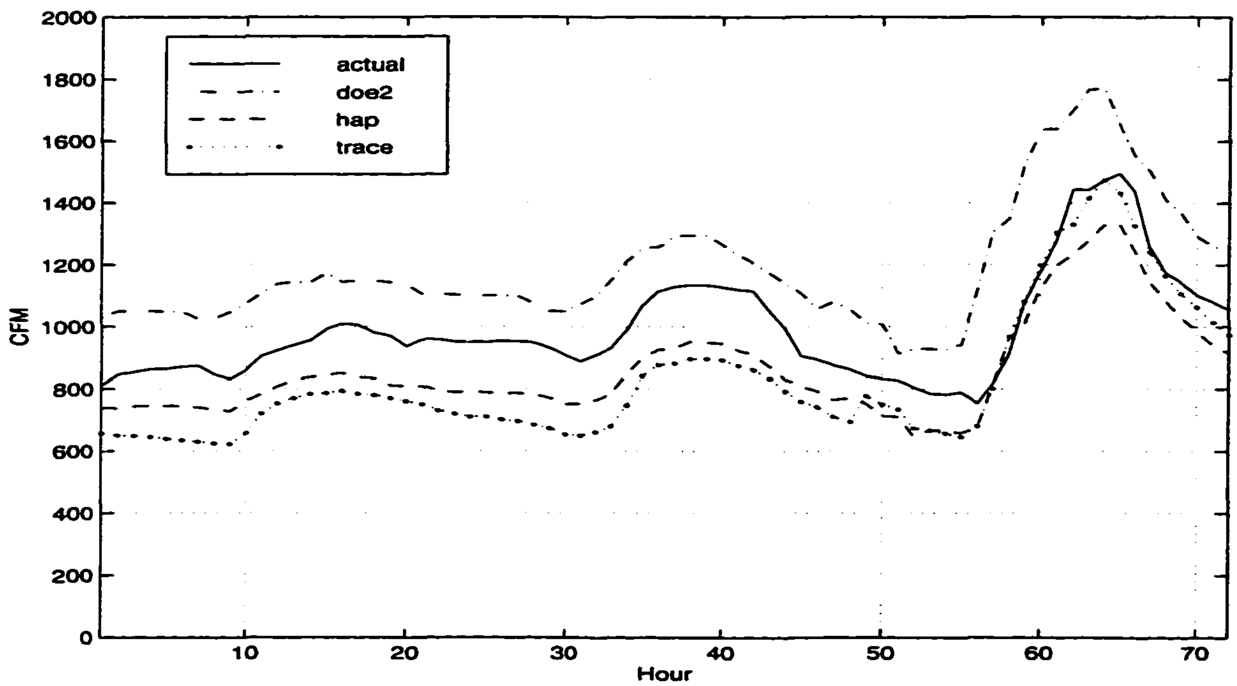


Figure 7.33 Outside air flow rate for CAVRH(2) from 990223 through 990225

Table 7.35 Statistical summary of system heating energy rate prediction in VAVRH(2)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	5597	3831	4763	6323±197
MEAN(DT)	726	2492	1560	-
MEAN ERROR(%)	11.5	39.4	24.7	±3.1
STDE(DT)	419	527	521	-
RMSE	4151	5706	5311	-
MIN(DT)	-9297	-4392	-13765	-
MAX(DT)	16895	16895	14316	-
MIN	0	0	0	0
MAX	34792	22978	25430	38465±1178

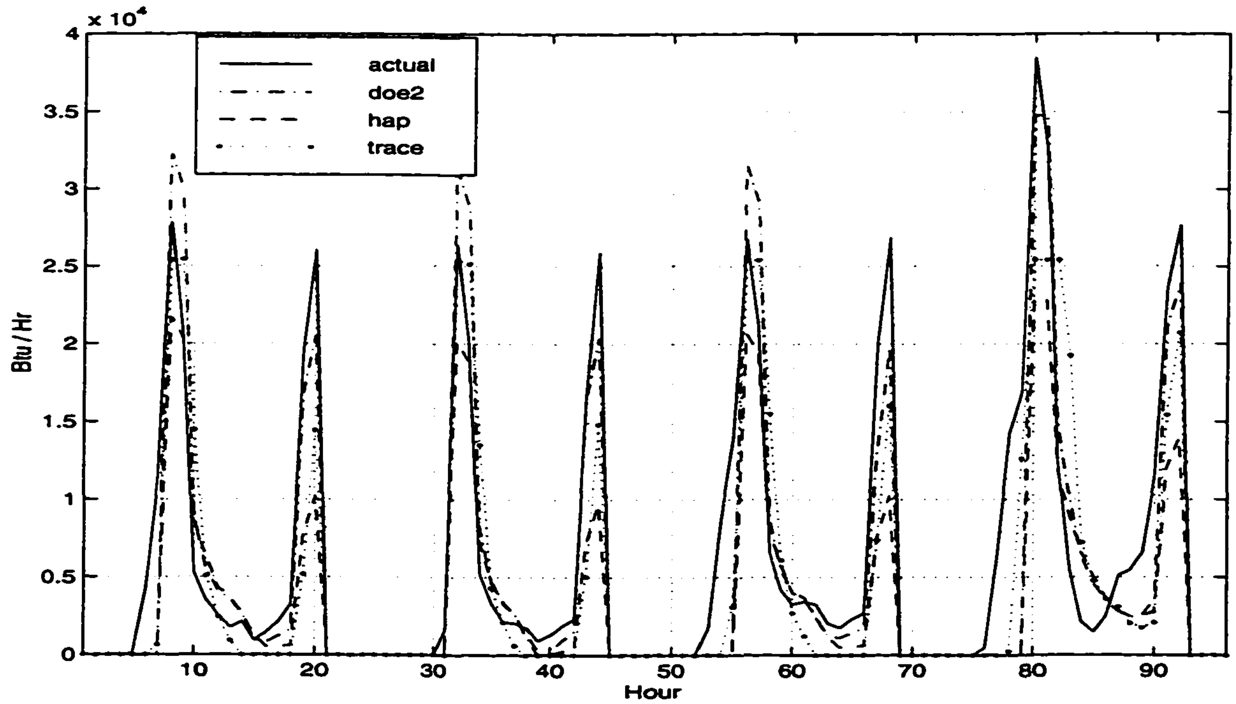


Figure 7.34 Total reheat energy rate for VAVRH(2) from 990319 through 990322

The reason for the under-predicted heating energy rates might be better understood after looking at the room temperatures which are presented below. Comparison results of zone reheat energy predictions are presented in Figure 7.35 ~ Figure 7.38 and Table 7.36 ~ Table 7.39.

For the comparison of air flow rates, the AHU supply and outdoor air flow rates as well as zone supply air flow rates were compared with the measured values. These results are presented in Figure 7.39 ~ Figure 7.44 and Table 7.40 ~ Table 7.45. Predictions by each program for the air flow rates were better than the predictions for the heating energies. Considering the uncertainty in the air-flow sensors in the test building, the predictions for the air flow rates were pretty good.

Of particular interest in this test is the comparison of the predicted room temperatures to the actual room temperatures. This is of interest because of the use of thermostat schedules and internal load schedules. During the night time, the system did not show any heating or cooling action because the room temperature in each room was within the dead band (a range of 65°F to 80°F). During the daytime, (occupied period) the room temperatures predicted by the models were close to the measured temperatures. During the night time (unoccupied period), the room temperatures decreased with similar decay rates in the exterior rooms as shown in Figure 7.45 ~ Figure 7.47. However, the actual temperatures started from around 72°F (the daytime setpoint) and decayed to the night setpoint,65°F while the predicted temperatures from DOE2 and HAP showed a sudden increase (2°F to 5°F) in room temperature in the hour following the scheduled temperature setpoint change. The HAP program showed a big jump in the interior room temperature and decreased with a smaller decay rate as shown in Figure 7.48. Table 7.46 through Table 7.49 display how much difference there was between the actual room temperatures and the computer model predictions.

The sudden rise in room temperatures as calculated by the models only occurs when the system fans are cycled with the heating/cooling demand. If the system fan is modeled to be on during the night set back period, the temperature decay in the space follows the trend of the actual test data. This suggests that the computer programs are not correctly accounting

Table 7.36 Statistical summary of east room reheat energy rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	1543	1268	1432±49
MEAN(DT)	-111	164	-
MEAN ERROR(%)	-7.7	11.5	±3.4
STDE(DT)	206	220	-
RMSE	2013	2155	-
MIN(DT)	-7710	-6104	-
MAX(DT)	5578	5578	-
MIN	0	0	0
MAX	10411	7954	11221±382

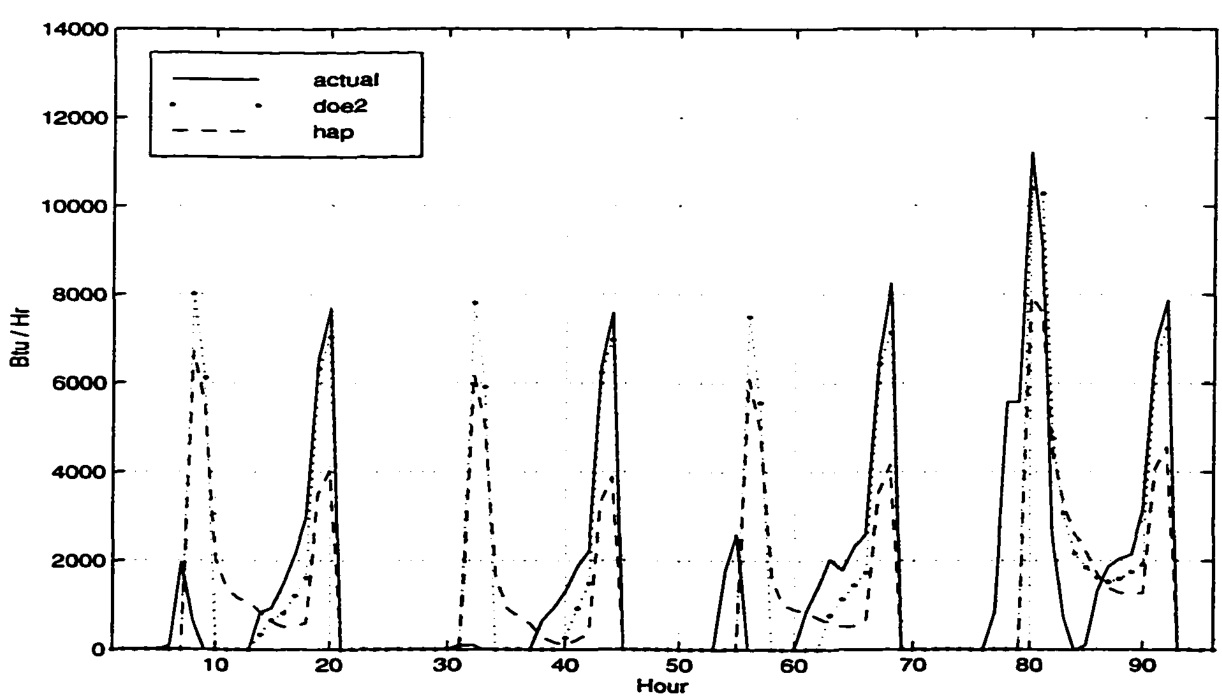


Figure 7.35 East room reheat energy rate for VAVRH(2) from 990319 through 990322

Table 7.37 Statistical summary of south room reheat energy rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	1354	896	1540±52
MEAN(DT)	186	644	-
MEAN ERROR(%)	12.1	41.8	±3.4
STDE(DT)	122	170	-
RMSE	1199	1775	-
MIN(DT)	-3432	-1839	-
MAX(DT)	4897	4911	-
MIN	0	0	0
MAX	9910	6523	11317±385

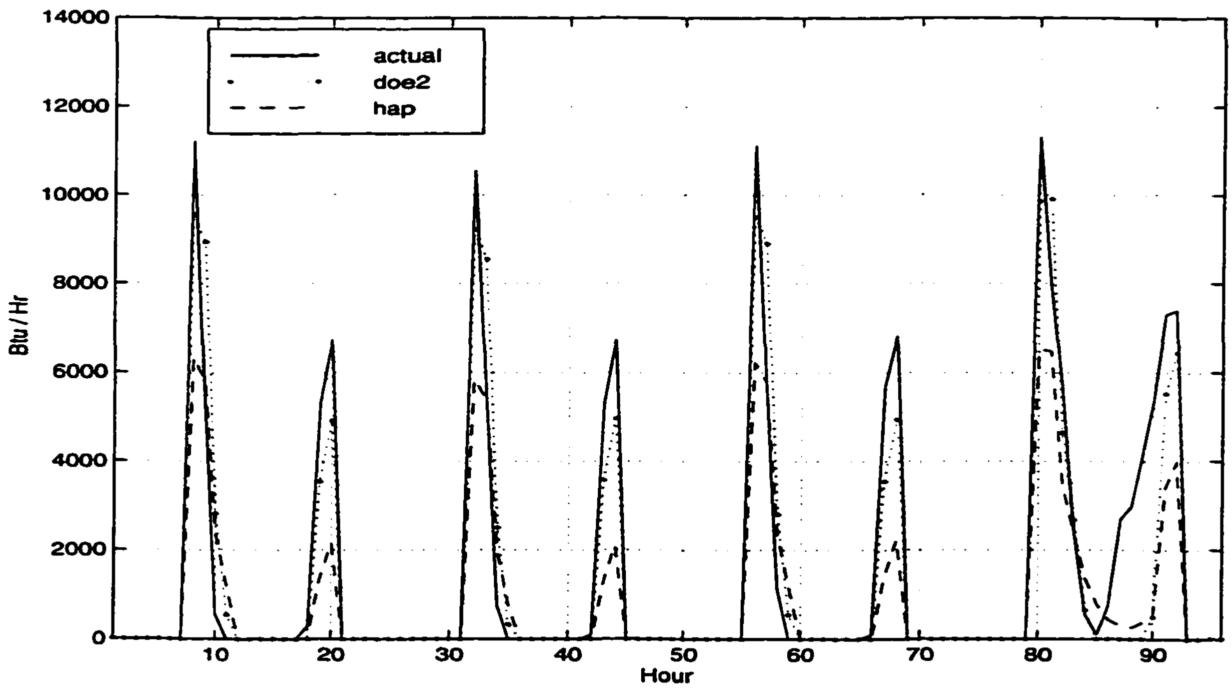


Figure 7.36 South reheat energy rate for VAVRH(2) from 990319 through 990322

Table 7.38 Statistical summary of west room reheat energy rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	2020	1457	2712±92
MEAN(DT)	692	1255	-
MEAN ERROR(%)	25.5	46.3	±3.4
STDE(DT)	254	269	-
RMSE	2569	2907	-
MIN(DT)	-1893	-1046	-
MAX(DT)	11317	11317	-
MIN	0	0	0
MAX	10223	7136	11317±385

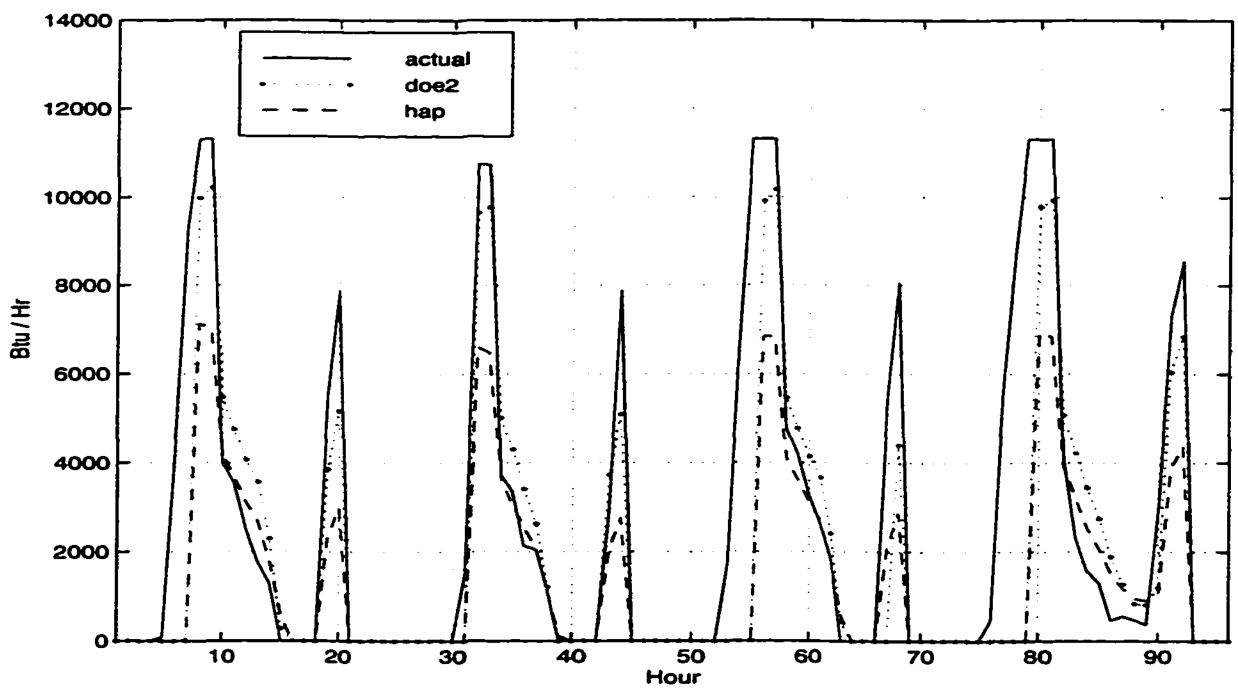


Figure 7.37 West reheat energy rate for VAVRH(2) from 990319 through 990322

Table 7.39 Statistical summary of interior room reheat energy rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	679	210	638±4
MEAN(DT)	-41	429	-
MEAN ERROR(%)	-6.4	67.1	±0.6
STDE(DT)	23	95	-
RMSE	232	1024	-
MIN(DT)	-880	0	-
MAX(DT)	517	3485	-
MIN	0	0	0
MAX	4706	1932	4993±28

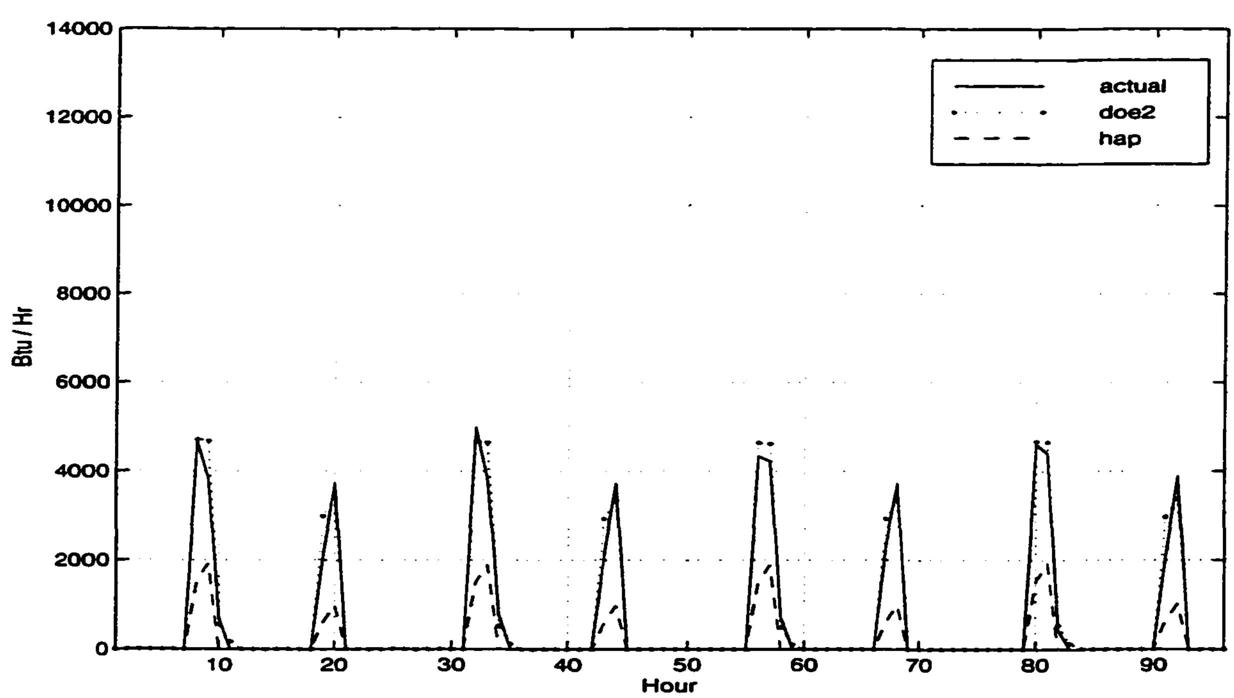


Figure 7.38 Interior reheat energy rate for VAVRH(2) from 990319 through 990322

Table 7.40 Statistical summary of AHU supply air flow rate prediction in VAVRH(2)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	950	905	1046	965±50
MEAN(DT)	15	60	-81	-
MEAN ERROR(%)	1.6	6.2	-8.4	±5.1
STDE(DT)	8	9	35	-
RMSE	78	106	352	-
MIN(DT)	-207	-6	-1620	-
MAX(DT)	264	342	264	-
MIN	0	0	0	0
MAX	2084	1822	2277	2115±50

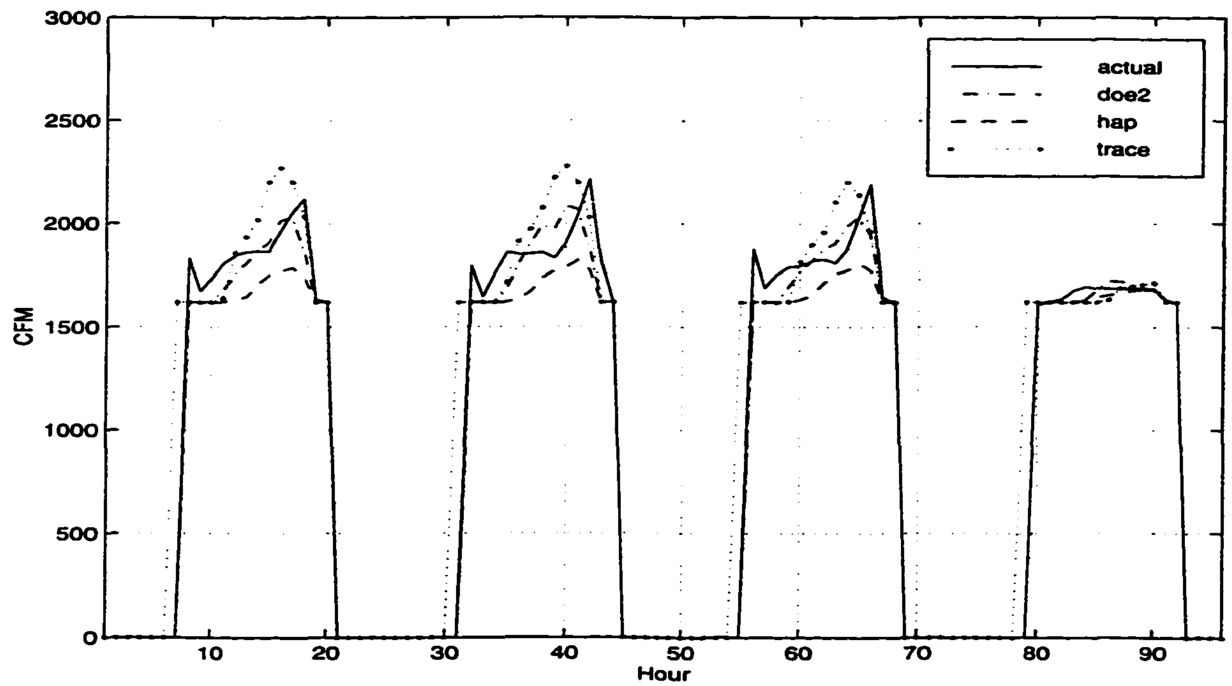


Figure 7.39 AHU supply air flow rate for VAVRH(2) from 990319 through 990322

Table 7.41 Statistical summary of outside air flow rate prediction in VAVRH(2)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	759	546	656	644±50
MEAN(DT)	-115	98	-12	-
MEAN ERROR(%)	-17.8	15.2	-1.9	±7.8
STDE(DT)	16	13	20	-
RMSE	197	161	192	-
MIN(DT)	-483	-166	-617	-
MAX(DT)	241	551	448	-
MIN	0	0	0	0
MAX	2084	1786	2277	1824±50

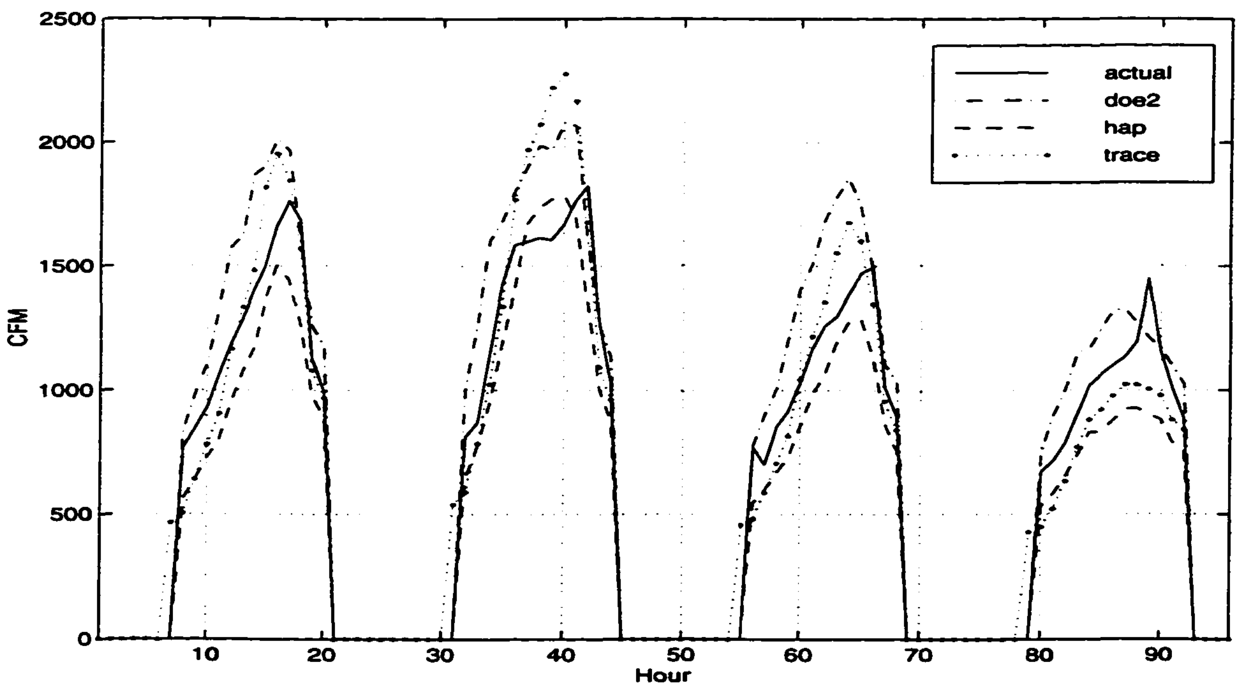


Figure 7.40 Outside air flow rate for VAVRH(2) from 990319 through 990322

Table 7.42 Statistical summary of east room supply air flow rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	248	244	261±50
MEAN(DT)	12	17	-
MEAN ERROR(%)	4.7	6.5	±19.1
STDE(DT)	5	5	-
RMSE	48	51	-
MIN(DT)	-45	-4	-
MAX(DT)	263	263	-
MIN	0	0	0
MAX	523	450	713±50

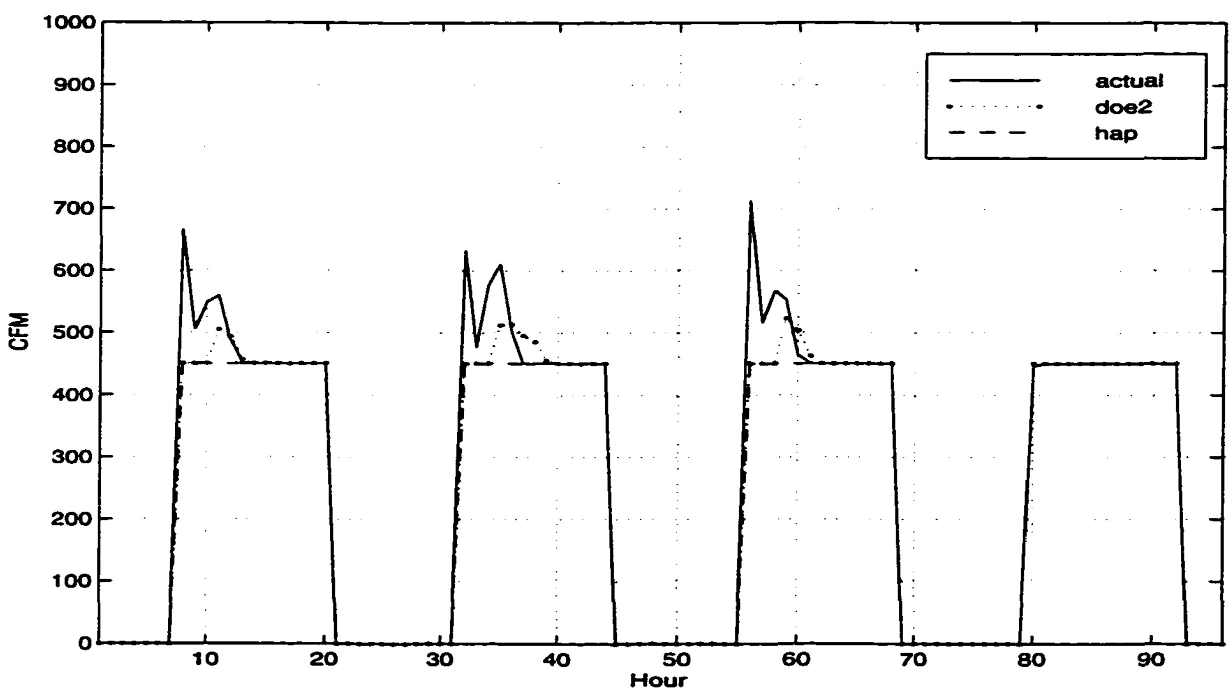


Figure 7.41 East room supply air flow rate for VAVRH(2) from 990319 through 990322

Table 7.43 Statistical summary of south room supply air flow rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	286	257	266±50
MEAN(DT)	-20	9	-
MEAN ERROR(%)	-7.4	3.5	±18.7
STDE(DT)	5	4	-
RMSE	48	38	-
MIN(DT)	-164	-59	-
MAX(DT)	30	155	-
MIN	0	0	0
MAX	729	560	623±50

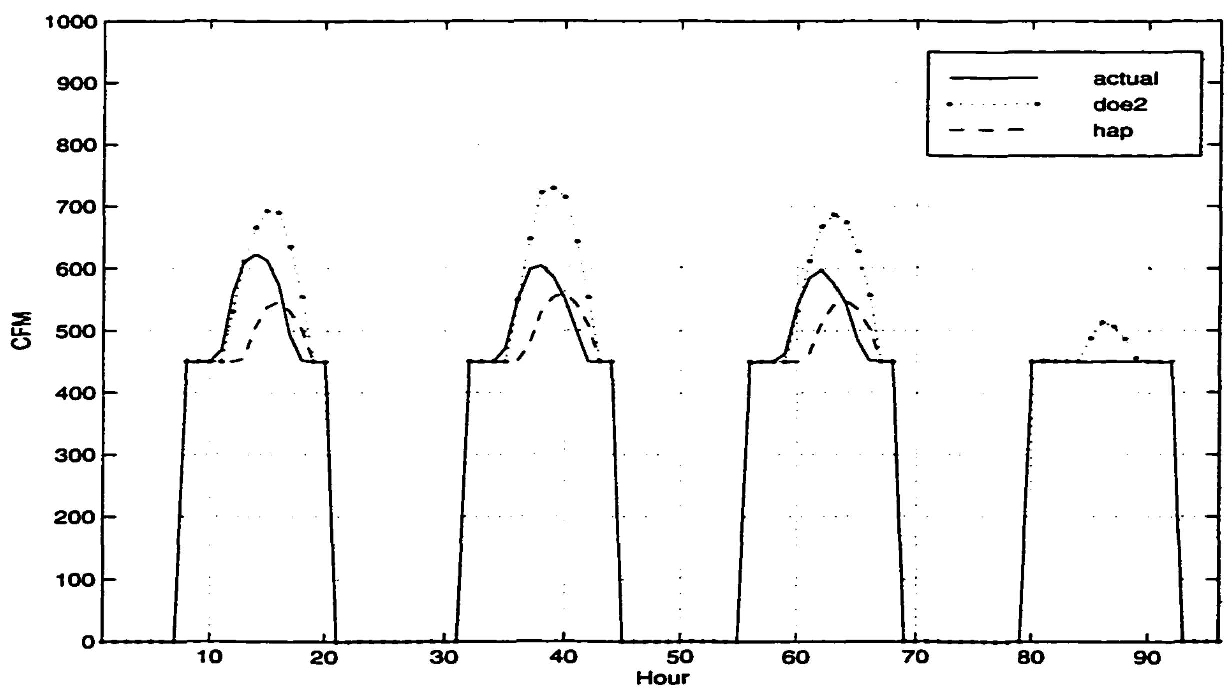


Figure 7.42 South room supply air flow rate for VAVRH(2) from 990319 through 990322

Table 7.44 Statistical summary of west room supply air flow rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	256	245	274±50
MEAN(DT)	18	29	-
MEAN ERROR(%)	6.6	10.5	±18.2
STDE(DT)	7	10	-
RMSE	74	101	-
MIN(DT)	-19	-7	-
MAX(DT)	431	501	-
MIN	0	0	0
MAX	639	496	974±50

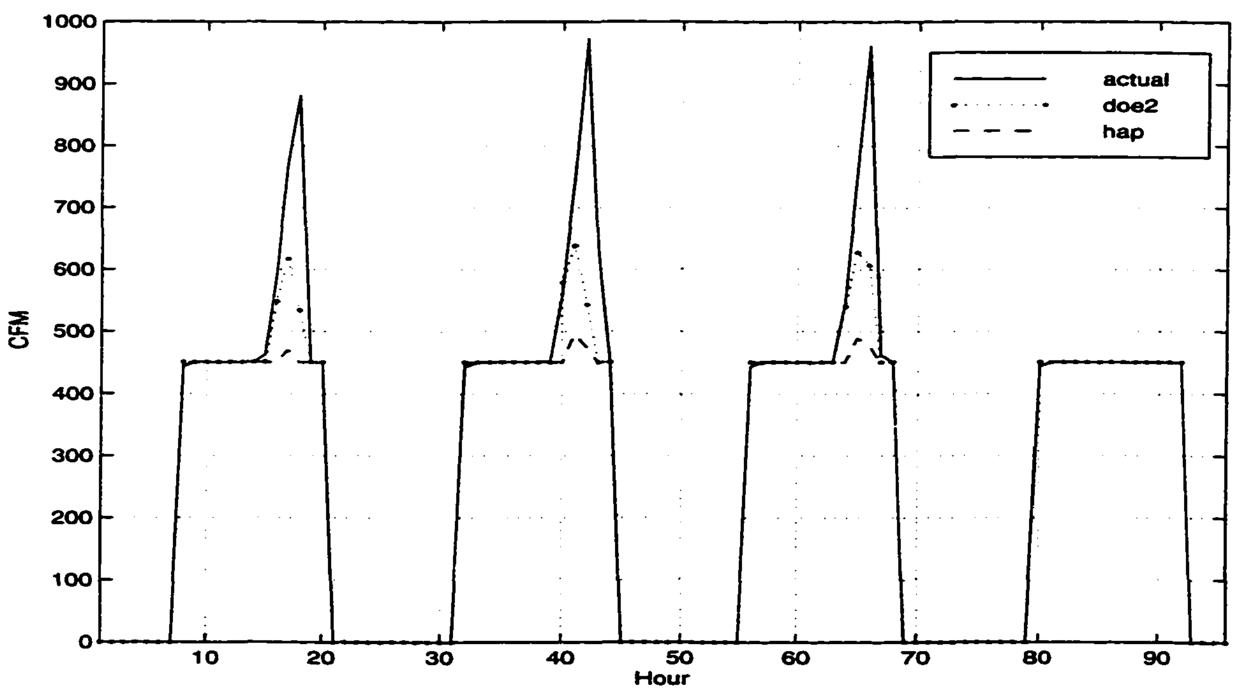


Figure 7.43 West room supply air flow rate for VAVRH(2) from 990319 through 990322

Table 7.45 Statistical summary of interior room supply air flow rate prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	159	159	170±50
MEAN(DT)	10	11	-
MEAN ERROR(%)	6.2	6.4	±29.4
STDE(DT)	2	2	-
RMSE	21	22	-
MIN(DT)	-3	-13	-
MAX(DT)	65	65	-
MIN	0	0	0
MAX	341	342	353±50

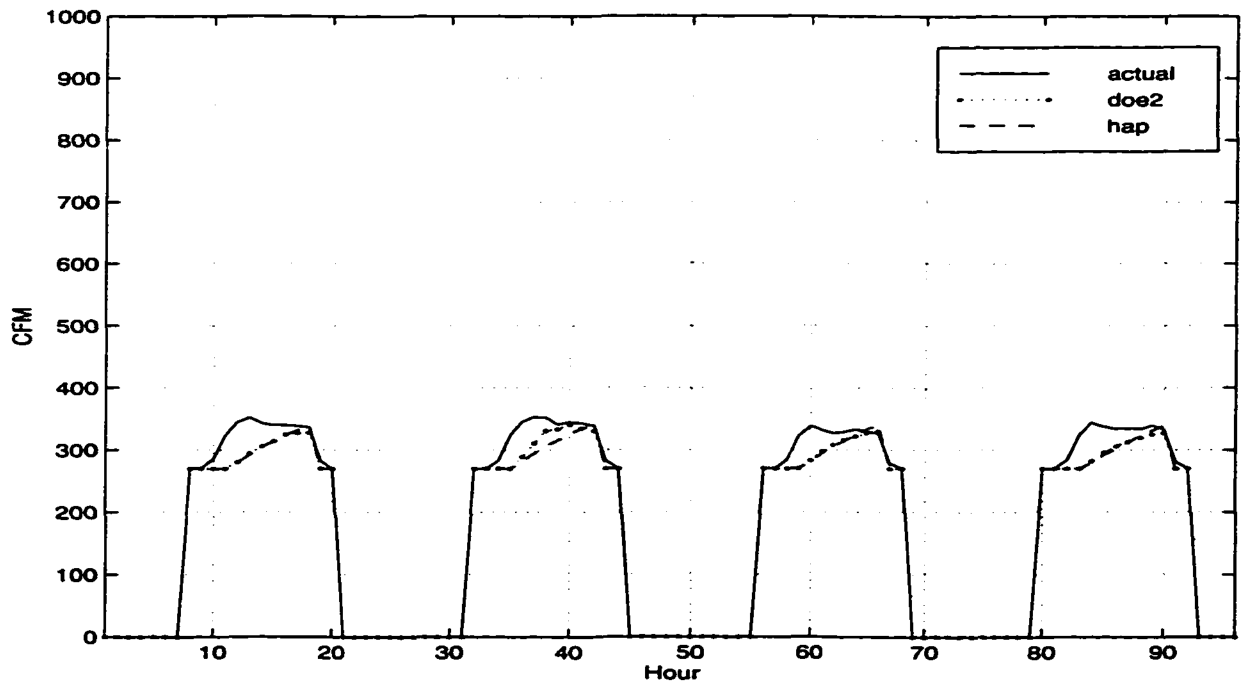


Figure 7.44 Interior room supply air flow rate for VAVRH(2) from 990319 through 990322

Table 7.46 Statistical summary of east room temperature prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	70	72	70±0.5
MEAN(DT)	0	-2	-
MEAN ERROR(%)	-0.7	-2.2	±0.7
STDE(DT)	0	0	-
RMSE	1	3	-
MIN(DT)	-4	-5	-
MAX(DT)	3	4	-
MIN	65	68	65±0.5
MAX	73	74	75±0.5

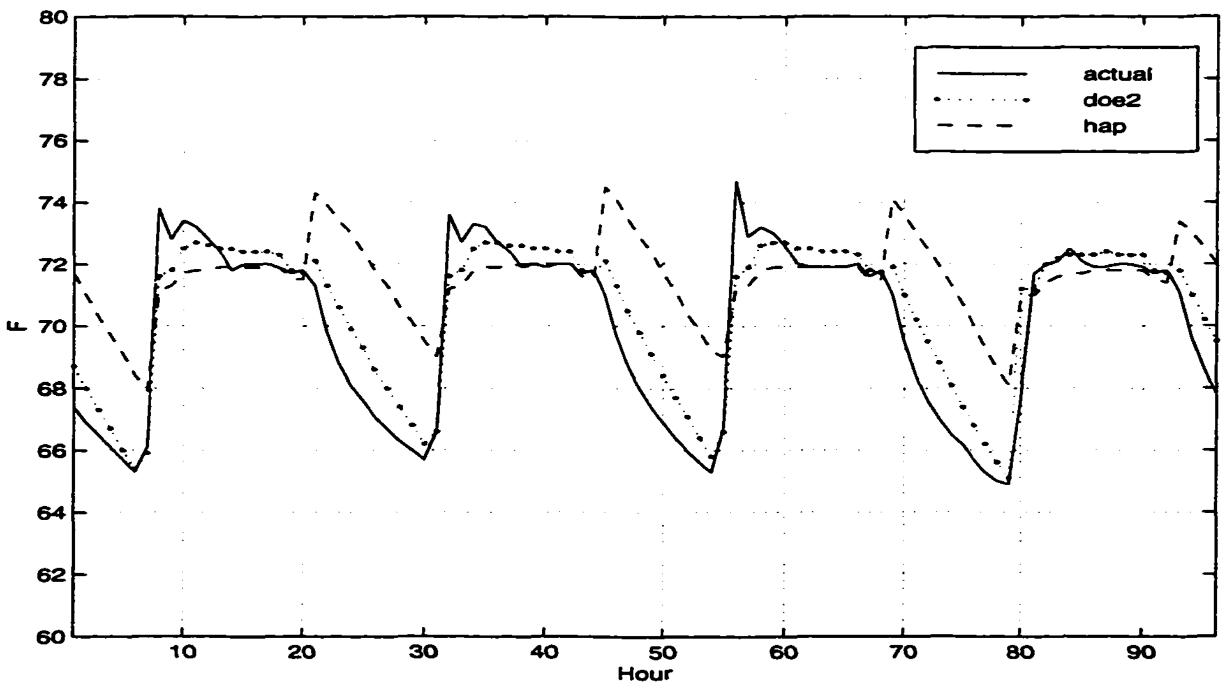


Figure 7.45 East room temperature for VAVRH(2) from 990319 through 990322

Table 7.47 Statistical summary of south room temperature prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	72	73	70±0.5
MEAN(DT)	-1	-3	-
MEAN ERROR(%)	-1.5	-3.7	±0.7
STDE(DT)	0	0	-
RMSE	2	4	-
MIN(DT)	-4	-7	-
MAX(DT)	1	1	-
MIN	67	71	66±0.5
MAX	75	77	73±0.5

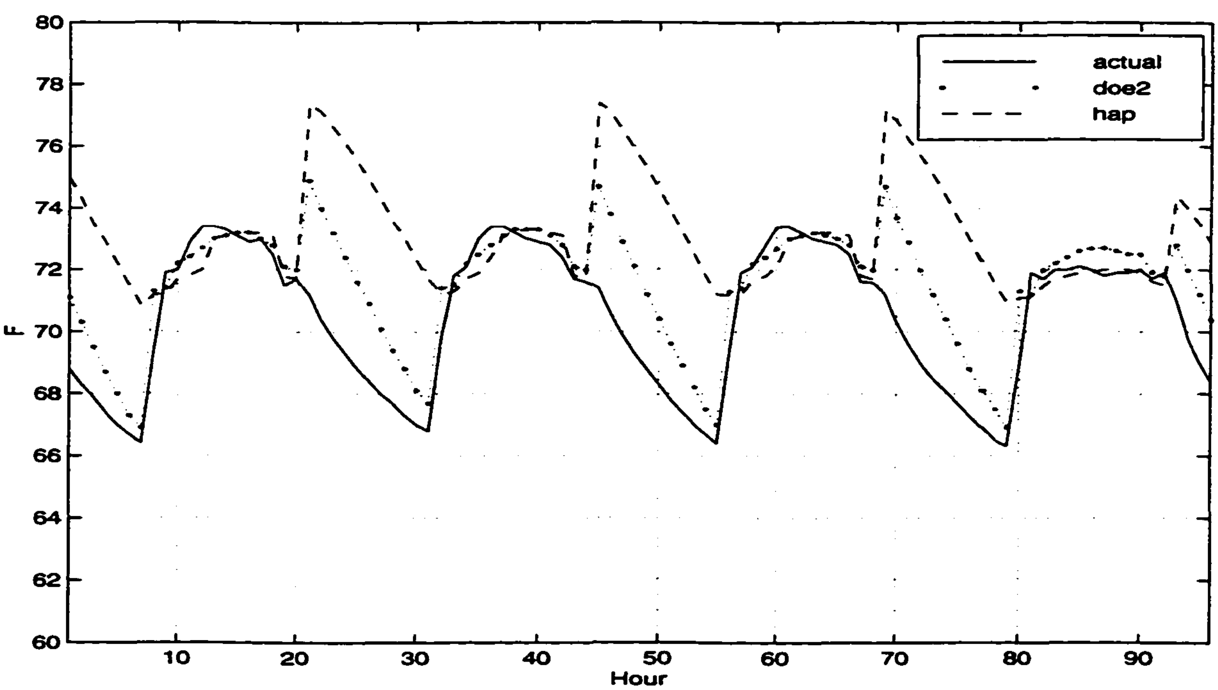


Figure 7.46 South room temperature for VAVRH(2) from 990319 through 990322

Table 7.48 Statistical summary of west room temperature prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	71	72	70±0.5
MEAN(DT)	-2	-3	-
MEAN ERROR(%)	-2.4	-3.9	±0.7
STDE(DT)	0	0	-
RMSE	3	4	-
MIN(DT)	-5	-7	-
MAX(DT)	4	4	-
MIN	67	70	64±0.5
MAX	75	76	77±0.5

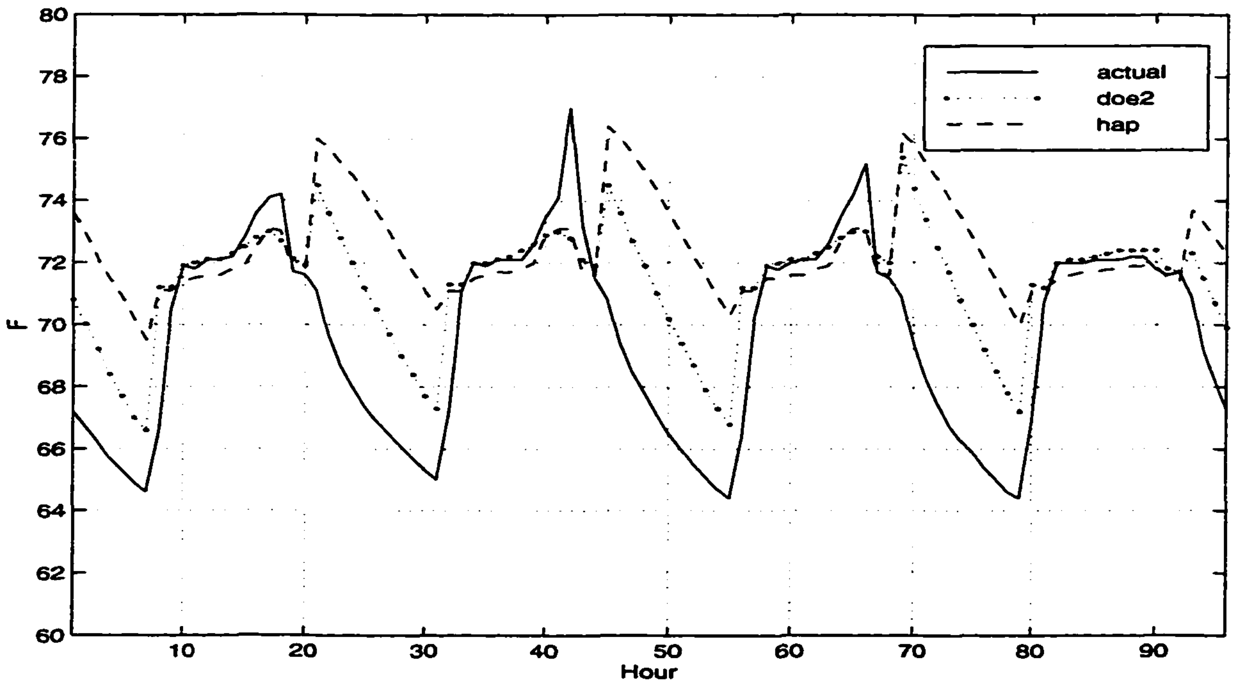


Figure 7.47 West room temperature for VAVRH(2) from 990319 through 990322

Table 7.49 Statistical summary of interior room temperature prediction in VAVRH(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	72	74	72±0.5
MEAN(DT)	-1	-2	-
MEAN ERROR(%)	-0.7	-3.3	±0.7
STDE(DT)	0	0	-
RMSE	1	4	-
MIN(DT)	-2	-6	-
MAX(DT)	1	0	-
MIN	72	72	71±0.5
MAX	73	76	73±0.5

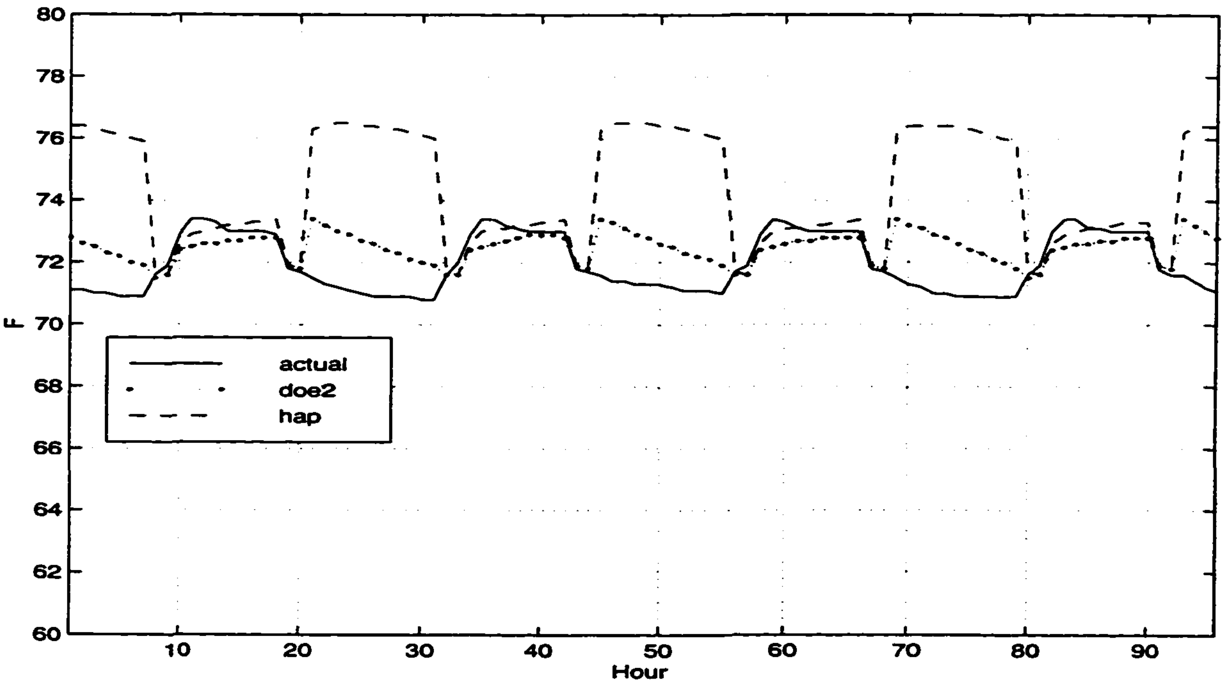


Figure 7.48 Interior room temperature for VAVRH(2) from 990319 through 990322

for stored energy.

Because the computer models predict the room temperatures to be warmer than they actually are when the schedule calls for morning set up, there is less heating energy required to bring the space to the occupied thermostat set point. Thus all of the models under-predict the heating energy during the occupied times of the day.

Comparison of 4PFCU(2) System

The test was conducted during late March, 1999. This test used thermostat and internal load schedules, but ventilation air was not allowed throughout the test. During the day time (occupied period), 1 KW of internal sensible load was applied to each test room. During the night time (unoccupied period) the internal loads were removed and the room thermostat was changed to 65 °F and 80 °F for heating and cooling setpoints, respectively. During the occupied period, the FCU fan was scheduled to run continuously. During the unoccupied period the FCU fan only ran whenever the room needed heating or cooling. The results from this test showed the same type of fan operation as in the VAVRH(2) system: the FCU fans did not run during the unoccupied period throughout the test period. All three programs showed the same fan operation as the actual system.

Figure 7.49 $\sim$ 7.50 present comparisons of the cooling and heating energy rates at the system level with numerical information presented in Table 7.50 $\sim$ 7.51. Trace predicted both cooling and heating well. HAP showed differences much in heating energy prediction and DOE2 showed difference in cooling energy prediction. Uncertainty for the measured data was so big because energy calculations were made by taking the air-side energy balance. Mean predicted values in system cooling and heating energies were close to the actual considering the uncertainty, but their RMSE values are pretty big for all programs.

Figure 7.51 $\sim$ 7.54 present comparisons of zone heating energy rates with numerical information in Table 7.52 $\sim$ 7.55, and Figure 7.55 $\sim$ 7.58 present comparisons of zone cooling energy rates with numerical information in Table 7.56 $\sim$ 7.59.

Table 7.50 Statistical summary of system cooling energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	6327	3685	5840	4695±780
MEAN(DT)	-1632	1010	-1145	-
MEAN ERROR(%)	-34.8	21.5	-24.4	±16.6
STDE(DT)	537	399	595	-
RMSE	4813	3510	5144	-
MIN(DT)	-12435	-5555	-13855	-
MAX(DT)	10676	10676	10076	-
MIN	0	0	0	0
MAX	22655	15390	24360	13515±1794

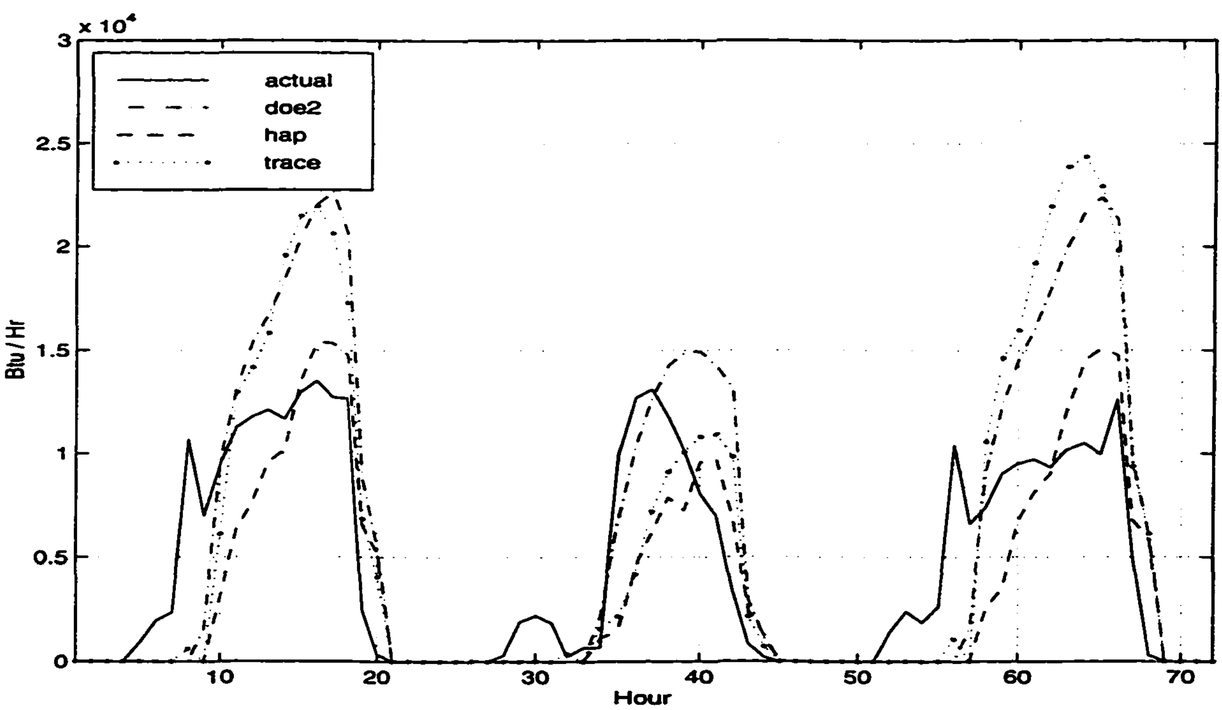


Figure 7.49 System cooling energy rate for 4PFCU(2) from 990321 through 990323

Table 7.51 Statistical summary of system heating energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	789	451	1653	1344±285
MEAN(DT)	555	892	-310	-
MEAN ERROR(%)	41.3	66.4	-23.0	±21.2
STDE(DT)	203	263	316	-
RMSE	1795	2388	2684	-
MIN(DT)	-3119	-1145	-9565	-
MAX(DT)	7724	12641	6745	-
MIN	0	0	0	0
MAX	12611	8911	14570	20335±1722

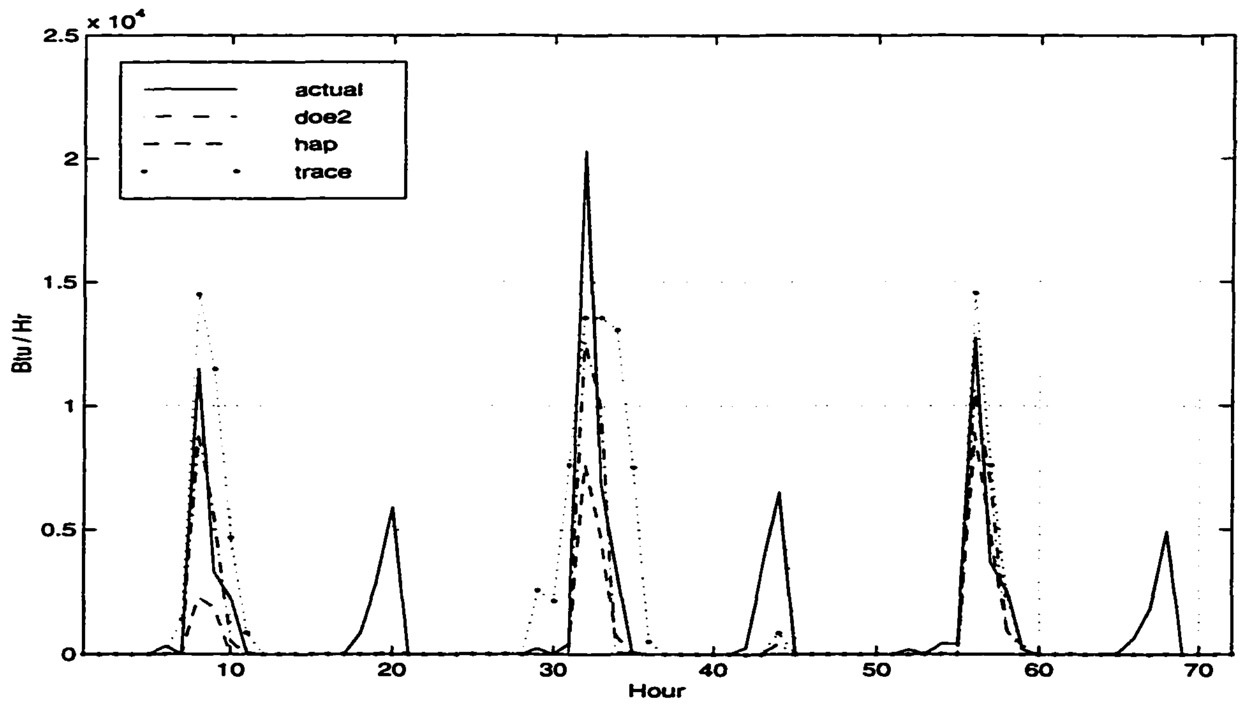


Figure 7.50 Total heating energy rate for 4PFCU(2) from 990321 through 990323

Table 7.52 Statistical summary of east room heating energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	160	120	267±48
MEAN(DT)	107	147	-
MEAN ERROR(%)	40.3	55.2	±17.9
STDE(DT)	73	81	-
RMSE	624	701	-
MIN(DT)	-2204	-2038	-
MAX(DT)	2097	3468	-
MIN	0	0	0
MAX	4737	3252	6720±446

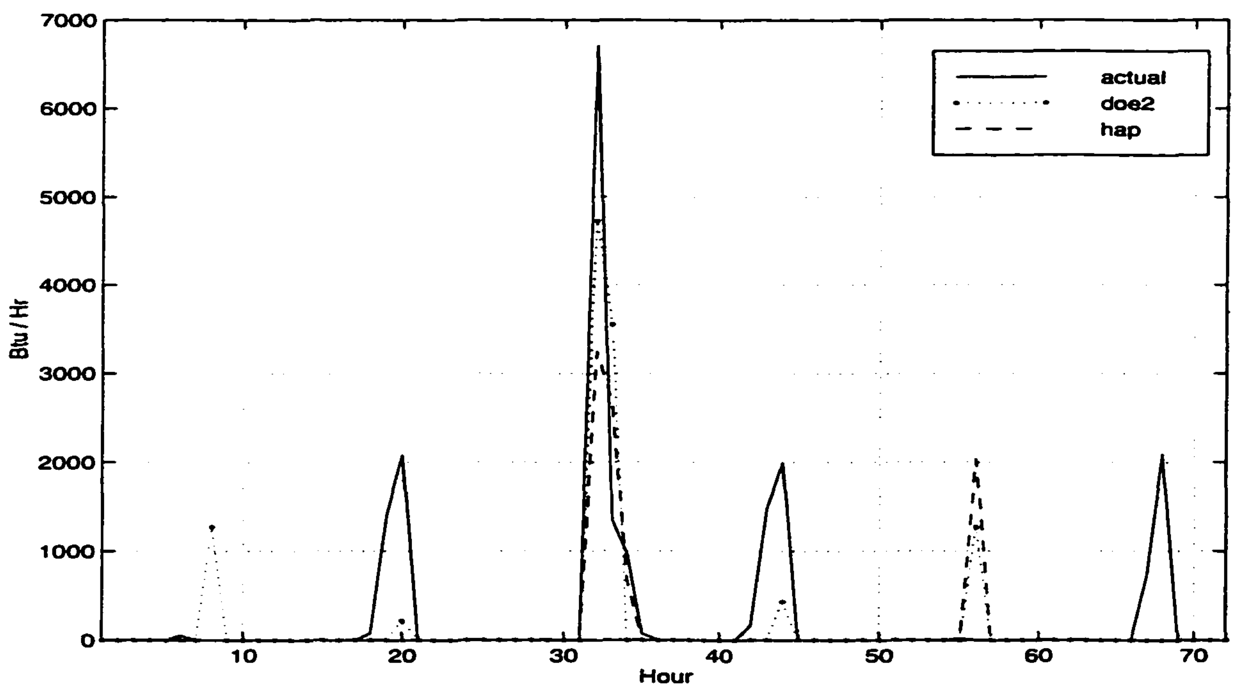


Figure 7.51 East room heating energy rate for 4PFCU(2) from 990321 through 990323

Table 7.53 Statistical summary of south room heating energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	255	97	405±94
MEAN(DT)	151	309	-
MEAN ERROR(%)	37.2	76.2	±23.2
STDE(DT)	68	98	-
RMSE	592	884	-
MIN(DT)	-1579	-928	-
MAX(DT)	1979	4706	-
MIN	0	0	0
MAX	4076	3129	5727±446

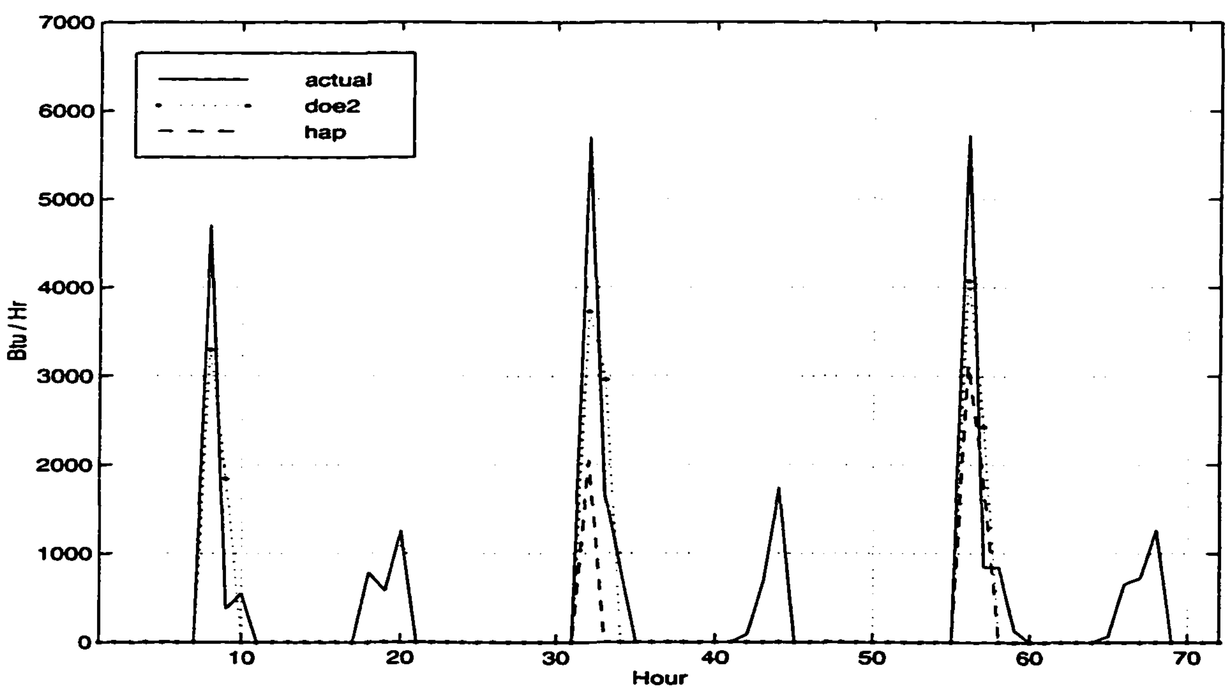


Figure 7.52 South room heating energy rate for 4PFCU(2) from 990321 through 990323

Table 7.54 Statistical summary of west room heating energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	335	235	413±57
MEAN(DT)	78	178	-
MEAN ERROR(%)	18.8	43.1	±13.8
STDE(DT)	62	69	-
RMSE	528	606	-
MIN(DT)	-2210	-1392	-
MAX(DT)	1589	2813	-
MIN	0	0	0
MAX	4666	3744	5202±400

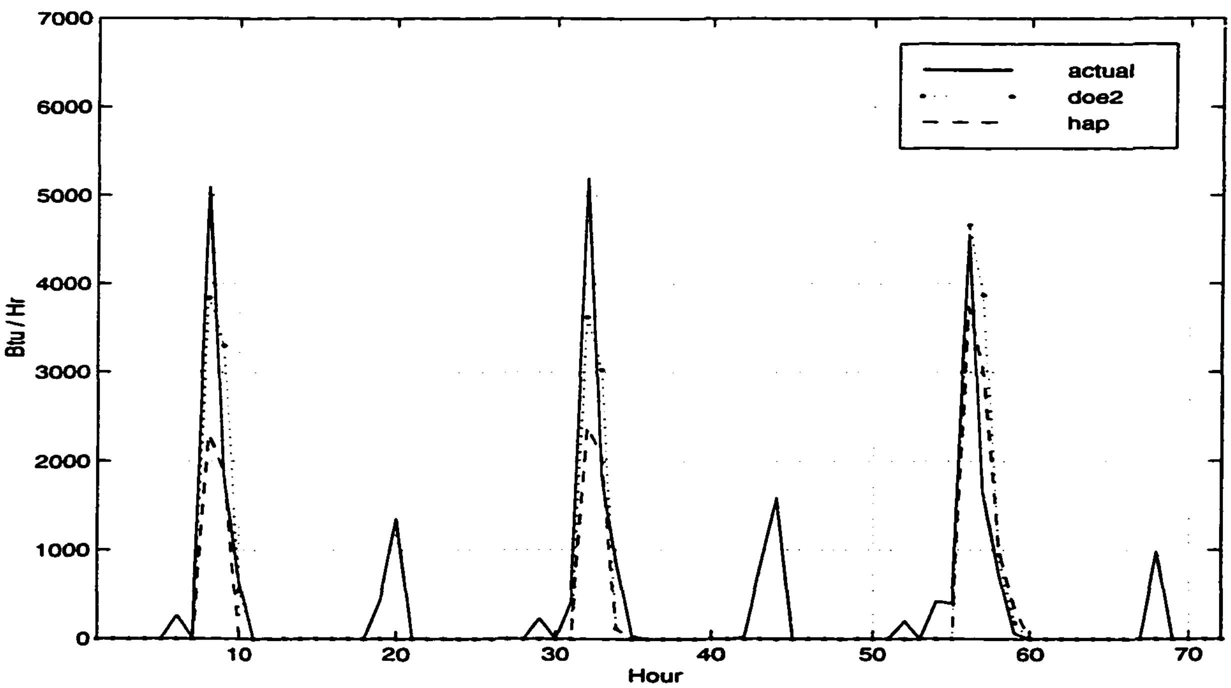


Figure 7.53 West room heating energy rate for 4PFCU(2) from 990321 through 990323

Table 7.55 Statistical summary of interior room heating energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	40	0	259±86
MEAN(DT)	219	259	-
MEAN ERROR(%)	84.6	100.0	±33.2
STDE(DT)	58	70	-
RMSE	532	647	-
MIN(DT)	0	0	-
MAX(DT)	2187	2705	-
MIN	0	0	0
MAX	643	0	2705±456

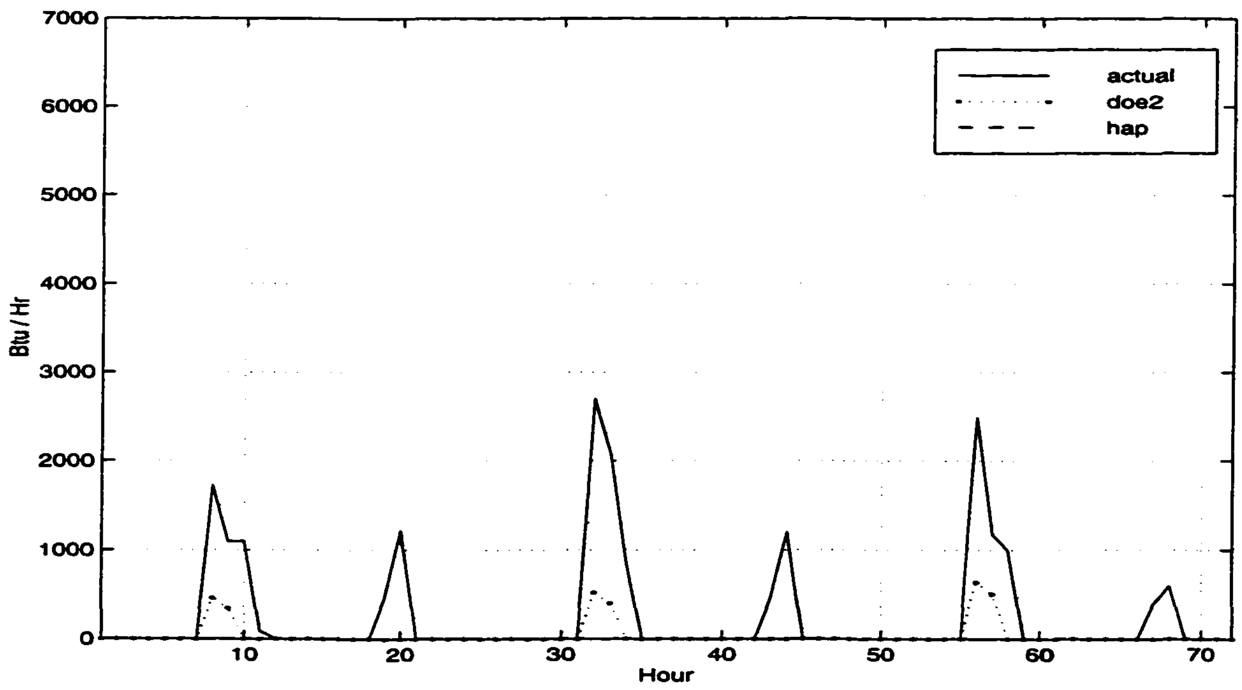


Figure 7.54 Interior room heating energy rate for 4PFCU(2) from 990321 through 990323

Table 7.56 Statistical summary of east room cooling energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	1515	831	1460±232
MEAN(DT)	-54	629	-
MEAN ERROR(%)	-3.7	43.1	±15.9
STDE(DT)	268	278	-
RMSE	2261	2429	-
MIN(DT)	-2995	-2330	-
MAX(DT)	10422	10422	-
MIN	0	0	0
MAX	6461	3108	10422±481

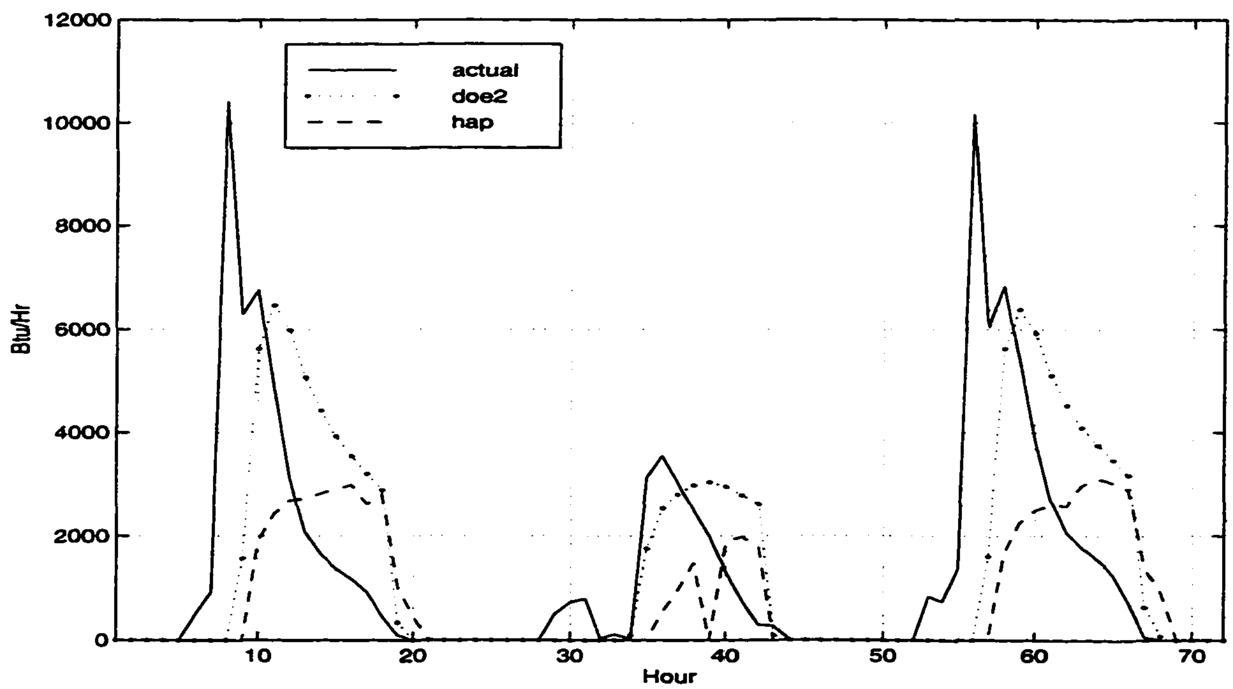


Figure 7.55 East room cooling energy rate for 4PFCU(2) from 990321 through 990323

Table 7.57 Statistical summary of south room cooling energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	2468	1417	1233±149
MEAN(DT)	-1235	-183	-
MEAN ERROR(%)	-100.1	-14.9	±12.1
STDE(DT)	244	187	-
RMSE	2399	1589	-
MIN(DT)	-7379	-4729	-
MAX(DT)	1337	3603	-
MIN	0	0	0
MAX	9608	5945	6698±458

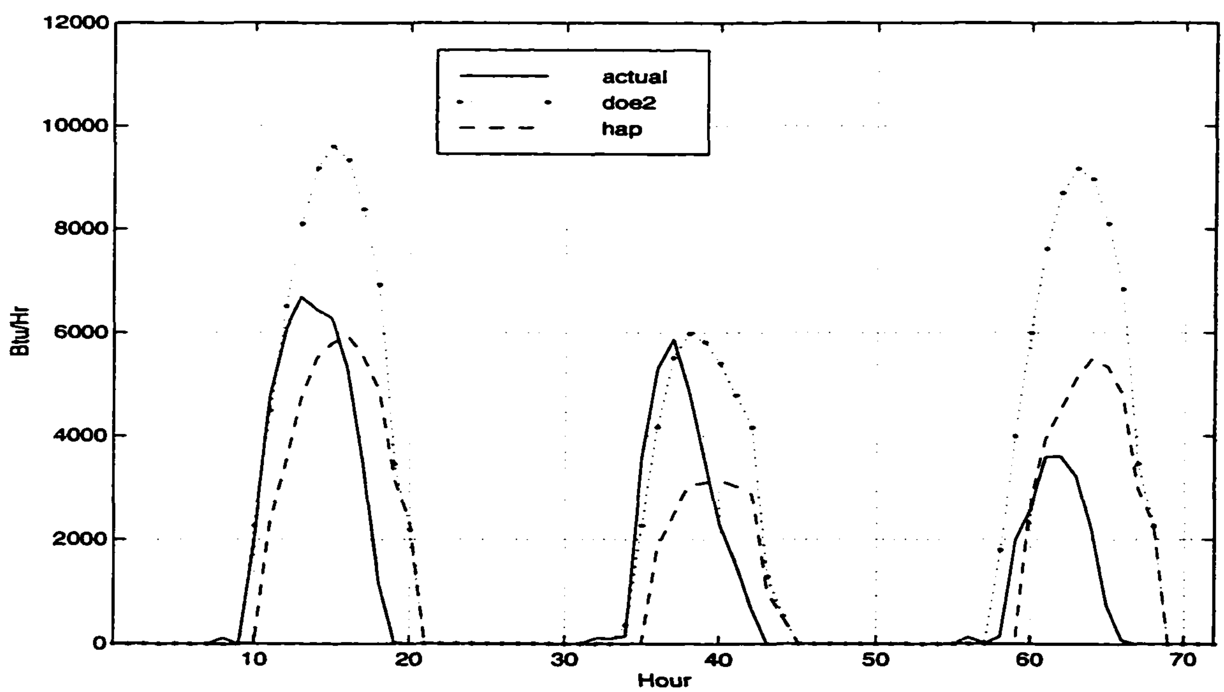


Figure 7.56 South room cooling energy rate for 4PFCU(2) from 990321 through 990323

Table 7.58 Statistical summary of west room cooling energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	1339	715	1493±244
MEAN(DT)	153	778	-
MEAN ERROR(%)	10.3	52.1	±16.3
STDE(DT)	109	131	-
RMSE	932	1354	-
MIN(DT)	-2864	-1627	-
MAX(DT)	1845	5543	-
MIN	0	0	0
MAX	8345	4978	10190±478

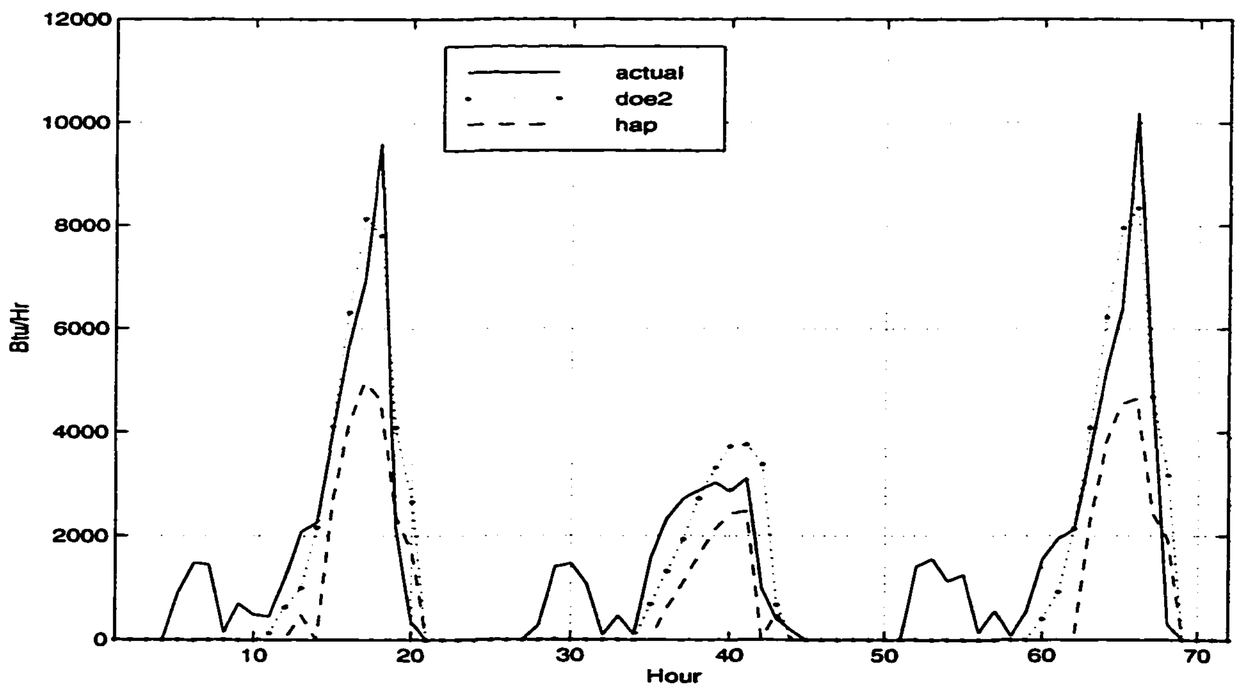


Figure 7.57 West room cooling energy rate for 4PFCU(2) from 990321 through 990323

Table 7.59 Statistical summary of interior room cooling energy rate prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	1004	722	508±155
MEAN(DT)	-496	-214	-
MEAN ERROR(%)	-97.6	-42.1	±30.5
STDE(DT)	69	40	-
RMSE	766	397	-
MIN(DT)	-1587	-1051	-
MAX(DT)	0	202	-
MIN	0	0	0
MAX	2989	2455	1662±445

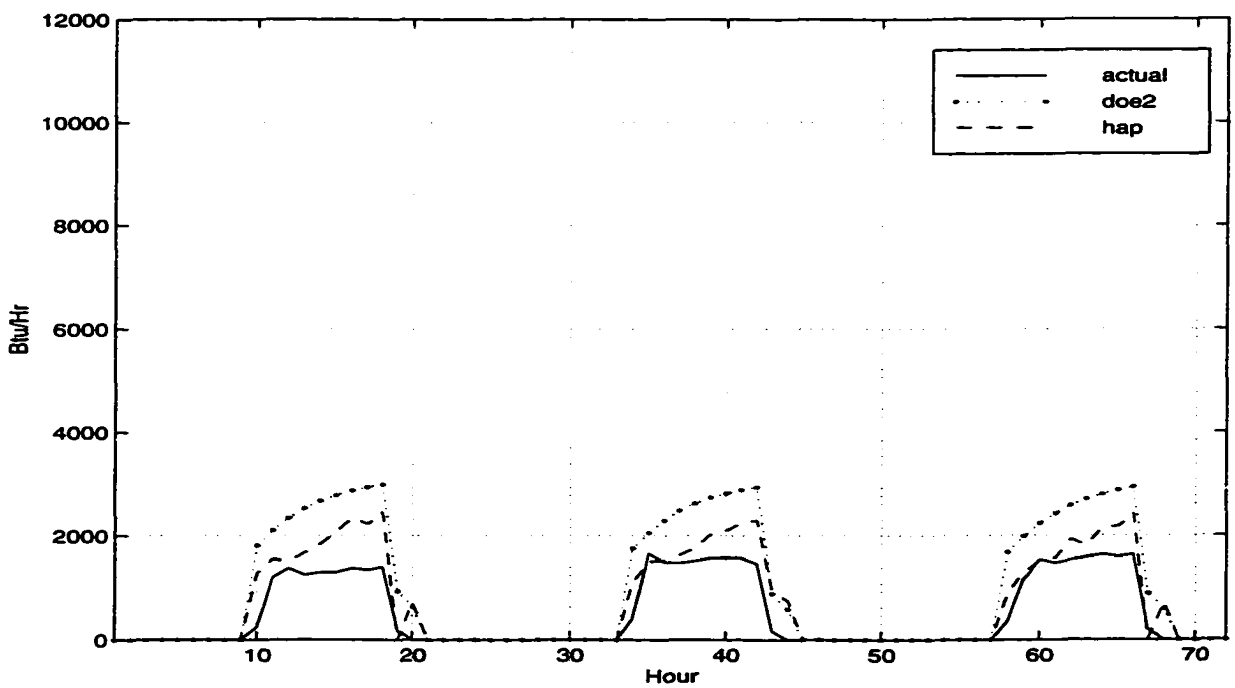


Figure 7.58 Interior room cooling energy rate for 4PFCU(2) from 990321 through 990323

Figure 7.59 presents room temperature comparison in east room with statistical summary as shown in Table 7.60. At the hour when the sun rises in the morning for 2 sunny days, actual room temperature went up to 78°F while programs (DOE2 and HAP) did not go up as the actual did. Also evident in the plot is the jump in the predicted room temperature when the thermostat schedule changes to the unoccupied period. This is the same result as was observed in the VAVRH(2) test. Similar jumps in temperature as predicted by the models can be seen in the other rooms as well.

Figure 7.60 and Table 7.61 present room temperature comparison in south room. During the daytime, (occupied period) the room temperatures predicted by the models were close to the measured temperatures. During the night time (unoccupied period), the room temperatures decreased with similar decay rate. However, the actual temperatures started from around 72.5°F (the daytime setpoint) and decayed to around the night setpoint,65°F while the predicted temperatures from DOE2 and HAP showed a sudden increase (2°F to 4°F) in room temperature in the hour following the scheduled temperature setpoint change. Specifically, HAP program showed a big jump. Of particular interest in the south room is temperature predictions for a cloudy day. In the second day of the test, we cannot see the temperature jump in the hour following the scheduled temperature setpoint change. In the VAVRH(2) we found that there was a temperature jump for a cloudy day as shown in Figure 7.46.

Figure 7.61 presents room temperature comparison in west room with statistical summary as shown in Table 7.62. At the hour when the sun sets in the evening for 2 sunny days, actual room temperature went up to 79°F while programs (DOE2 and HAP) predicted their temperatures within the range of setpoints. As we saw in the south room, we can see that temperature jumped in the hour following the scheduled temperature setpoint change and decayed. For the cloudy day, the phenomena is similar to the south room.

For the comparison of interior room temperature, Figure 7.62 and Table 7.63 display their results. The predictions were pretty good, but there still was a temperature jump after the thermostat setpoints changed. However, the magnitude of the temperature jump was not as big as the exterior rooms were.

Table 7.60 Statistical summary of east room temperature prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	71	71	70±0.5
MEAN(DT)	0	-1	-
MEAN ERROR(%)	-0.1	-1.2	±0.7
STDE(DT)	0	0	-
RMSE	1	2	-
MIN(DT)	-2	-4	-
MAX(DT)	6	6	-
MIN	65	66	65±0.5
MAX	73	74	78±0.5

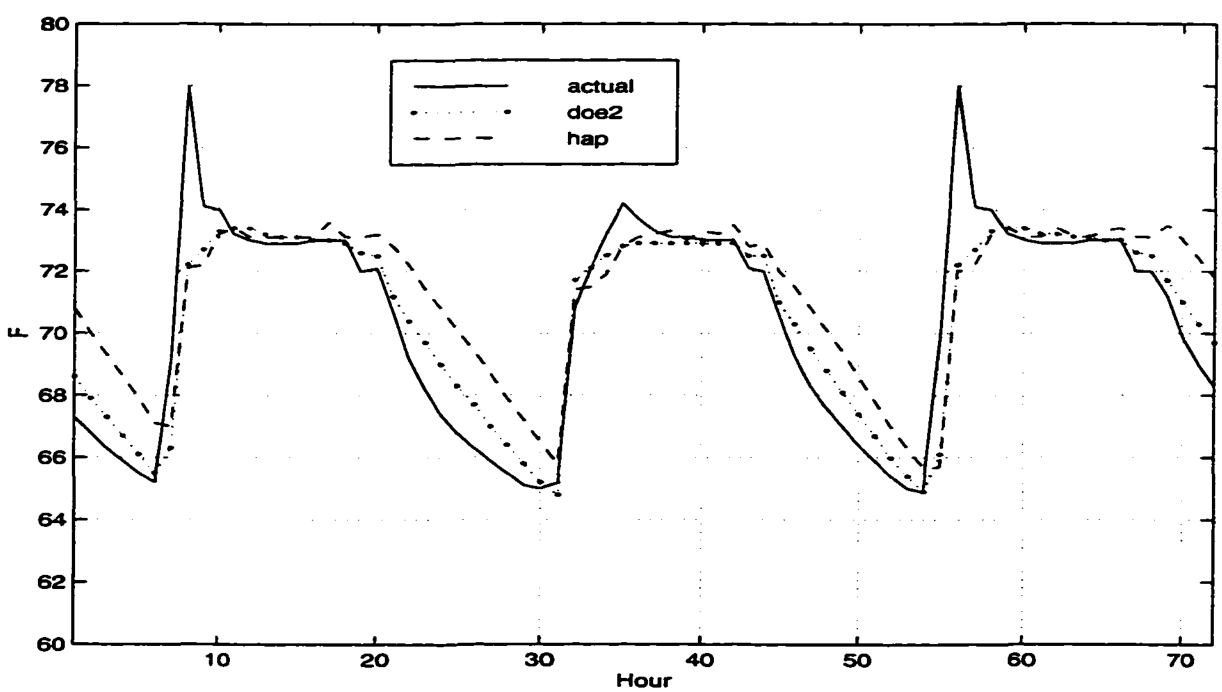


Figure 7.59 East room room temperature for 4PFCU(2) from 990321 through 990323

Table 7.61 Statistical summary of south room temperature prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	72	72	71±0.5
MEAN(DT)	-1	-2	-
MEAN ERROR(%)	-1.1	-2.2	±0.7
STDE(DT)	0	0	-
RMSE	1	2	-
MIN(DT)	-3	-5	-
MAX(DT)	1	1	-
MIN	65	66	66±0.5
MAX	74	76	74±0.5

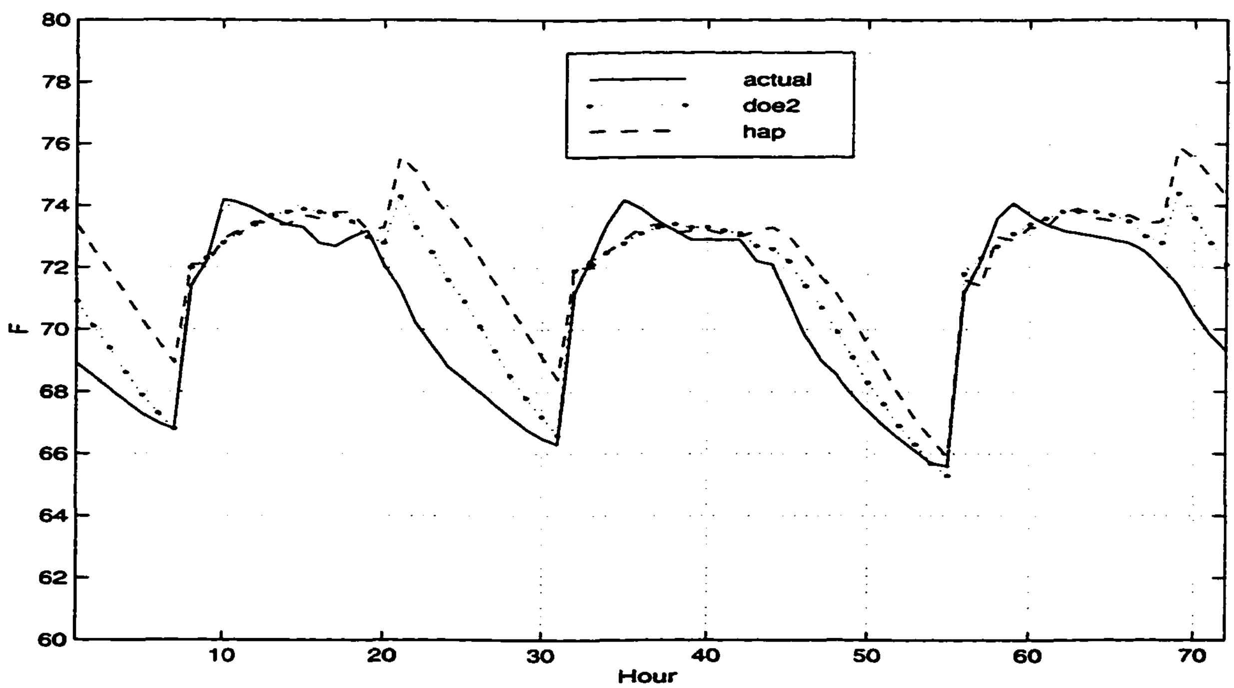


Figure 7.60 South room temperature for 4PFCU(2) from 990321 through 990323

Table 7.62 Statistical summary of west room temperature prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	71	72	70±0.5
MEAN(DT)	-1	-1	-
MEAN ERROR(%)	-1.4	-2.1	±0.7
STDE(DT)	0	0	-
RMSE	2	3	-
MIN(DT)	-5	-6	-
MAX(DT)	6	6	-
MIN	65	65	65±0.5
MAX	76	75	79±0.5

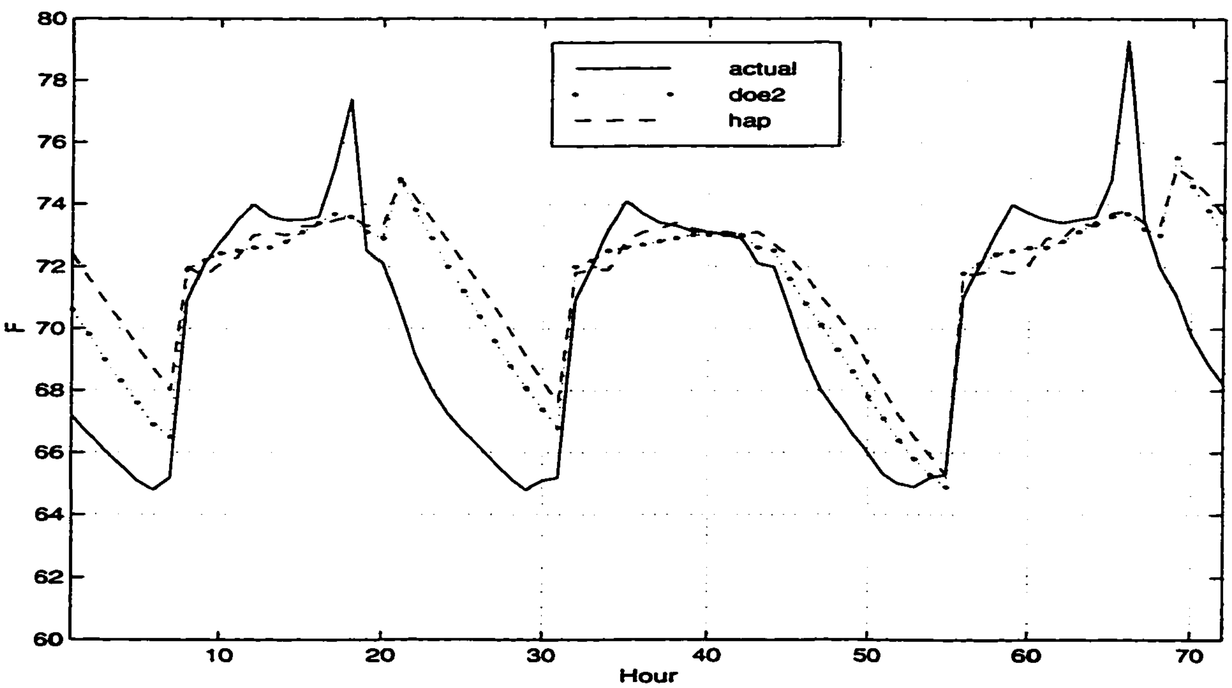


Figure 7.61 West room temperature for 4PFCU(2) from 990321 through 990323

Table 7.63 Statistical summary of interior room temperature prediction in 4PFCU(2)

Statistics	DOE2	HAP	ACTUAL
MEAN	73	73	72±0.5
MEAN(DT)	-1	-1	-
MEAN ERROR(%)	-0.7	-1.8	±0.7
STDE(DT)	0	0	-
RMSE	1	2	-
MIN(DT)	-2	-3	-
MAX(DT)	1	1	-
MIN	72	72	70±0.5
MAX	73	74	74±0.5

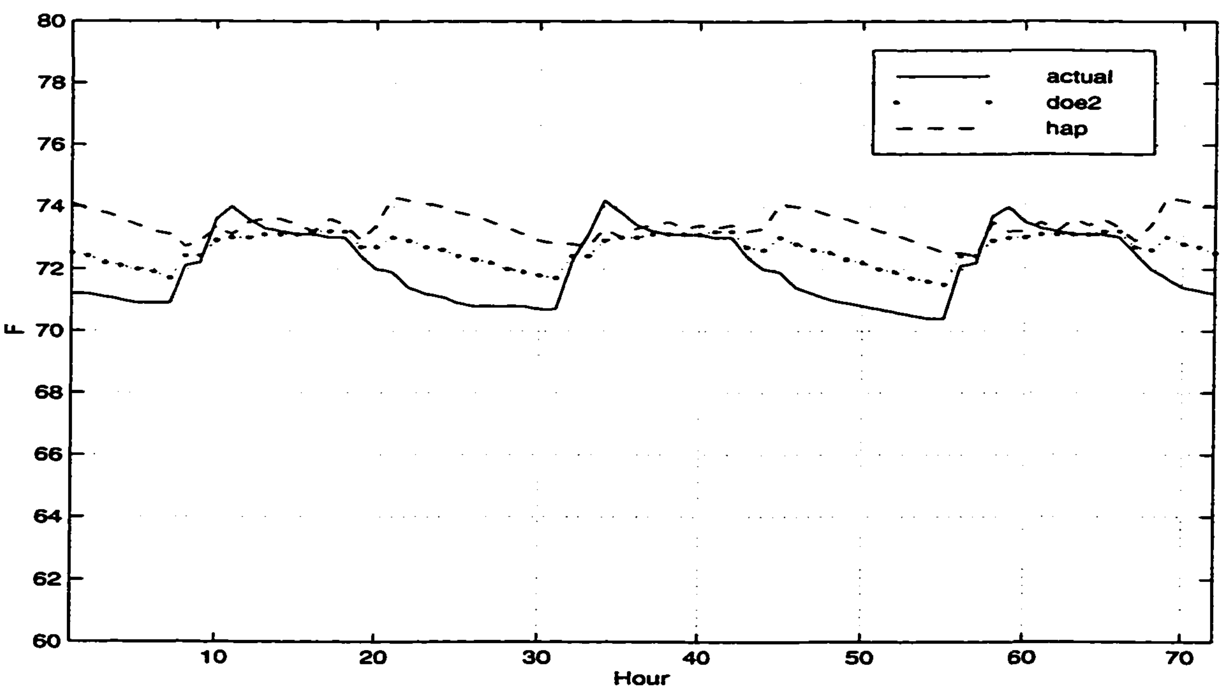


Figure 7.62 Interior room temperature for 4PFCU(2) from 990321 through 990323

Tests Having Daylight Control Strategy in the Building

The test was conducted during late March, 1999. Three of the four test days were sunny and the last day was mostly cloudy. Lights in the rooms were scheduled so that they are turned on at 6:00 AM, about one hour before sunrise, and turned off at 8:00 PM, about one hour after sunset. The three exterior rooms had daylighting controllers in them. The interior room did not use daylighting control because there was no exterior windows in the interior room. The VAVRH system was utilized with constant thermostat settings or 72 °F and 73 °F for heating and cooling setpoints, respectively. The outside air flow rate was set up to be constant at 30 CFM throughout the test. There were no blinds in the windows of the test rooms. This resulted in very high values of room illuminance during the times when direct sunlight entered the space.

For this test comparisons were only made between the actual building data and the DOE2 program. Three types of comparisons were made for the test: cooling and heating energy rates, lighting power usage, and room illuminance.

Comparison results for system cooling and heating energies are presented in Figure 7.63 $\sim$ Figure 7.64 and Table 7.64 $\sim$ Table 7.65. DOE predicted very well both system cooling energy and heating energy. RMSE values for both cooling and heating energy predictions are small enough considering uncertainty values, ± 5473 and ± 582 for cooling and heating energies.

Comparisons of zone heating energies were made as shown in Figure 7.65 through Figure 7.68 and Table 7.66 through Table 7.69. In all zones DOE2 predicted reheat energy rates very well.

Comparison results for total lighting power is illustrated in Figure 7.69 and Table 7.70. Comparisons of lighting power for all zones were made as shown in Figure 7.70 through Figure 7.73 and Table 7.71 through Table 7.74. In all zones DOE2 predicted lighting power very well. Considering the uncertainty in the experimental data, the predictions were almost exactly the same as the actual values.

Comparisons of zone illuminance were made as shown in Figure 7.74 through Figure 7.76 and Table 7.75 through Table 7.77. Interior room was excluded for this comparison since it

Table 7.64 Statistical summary of system cooling energy rate prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	27256	26774±5473
MEAN(DT)	-482	-
MEAN ERROR(%)	-1.8	±20.4
STDE(DT)	153	-
RMSE	1567	-
MIN(DT)	-4364	-
MAX(DT)	6852	-
MIN	25916	24591±5421
MAX	29894	35276±5491

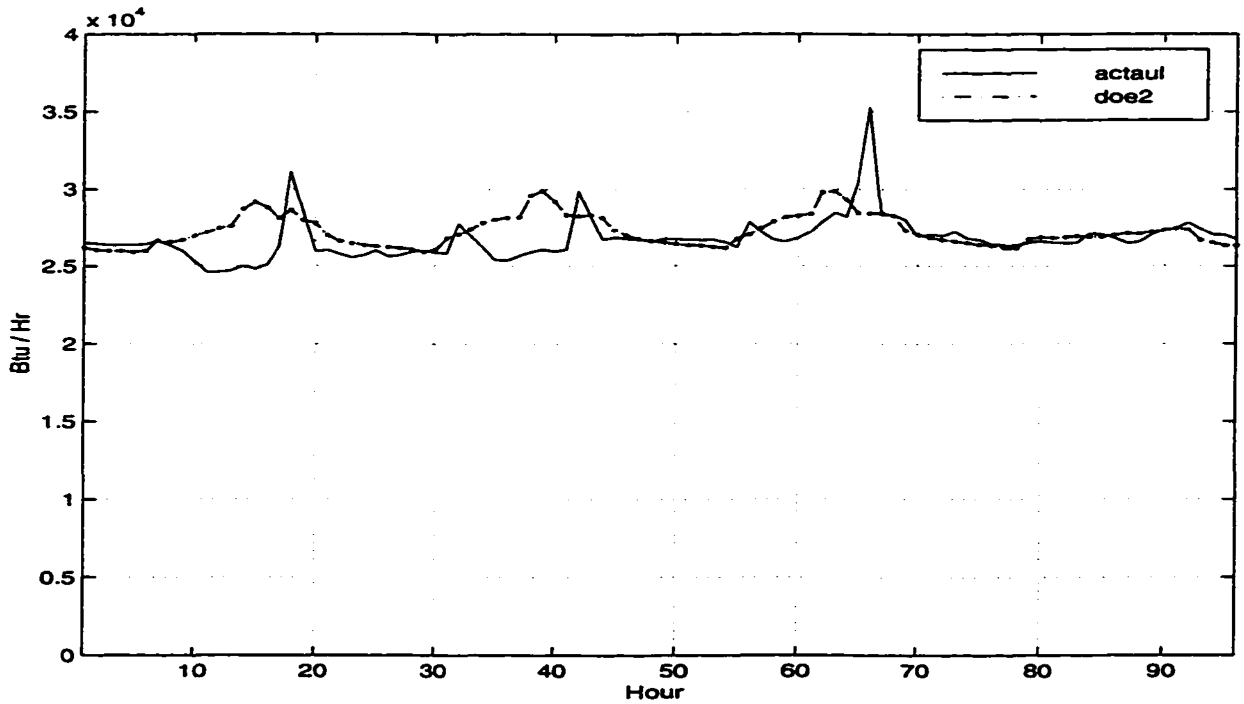


Figure 7.63 System cooling energy rate for daylighting test from 990328 through 990331

Table 7.65 Statistical summary of system heating energy rate prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	19641	20133±582
MEAN(DT)	492	-
MEAN ERROR(%)	2.4	±2.9
STDE(DT)	278	-
RMSE	2753	-
MIN(DT)	-4908	-
MAX(DT)	8401	-
MIN	7283	6648±152
MAX	27884	30321±904

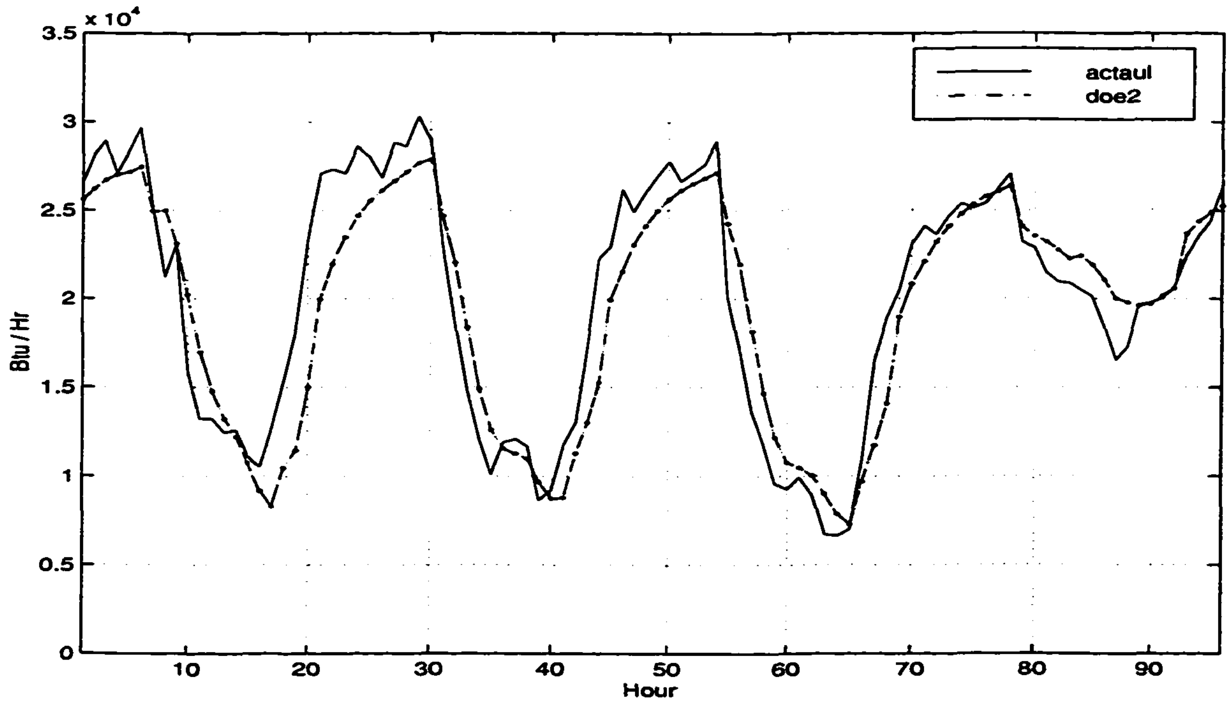


Figure 7.64 Total reheat energy rate for daylighting test from 990328 through 990331

Table 7.66 Statistical summary of east room heating energy rate prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	5638	5524±187
MEAN(DT)	-114	-
MEAN ERROR(%)	-2.1	±3.4
STDE(DT)	122	-
RMSE	1194	-
MIN(DT)	-4666	-
MAX(DT)	1855	-
MIN	283	0
MAX	8062	8639±293

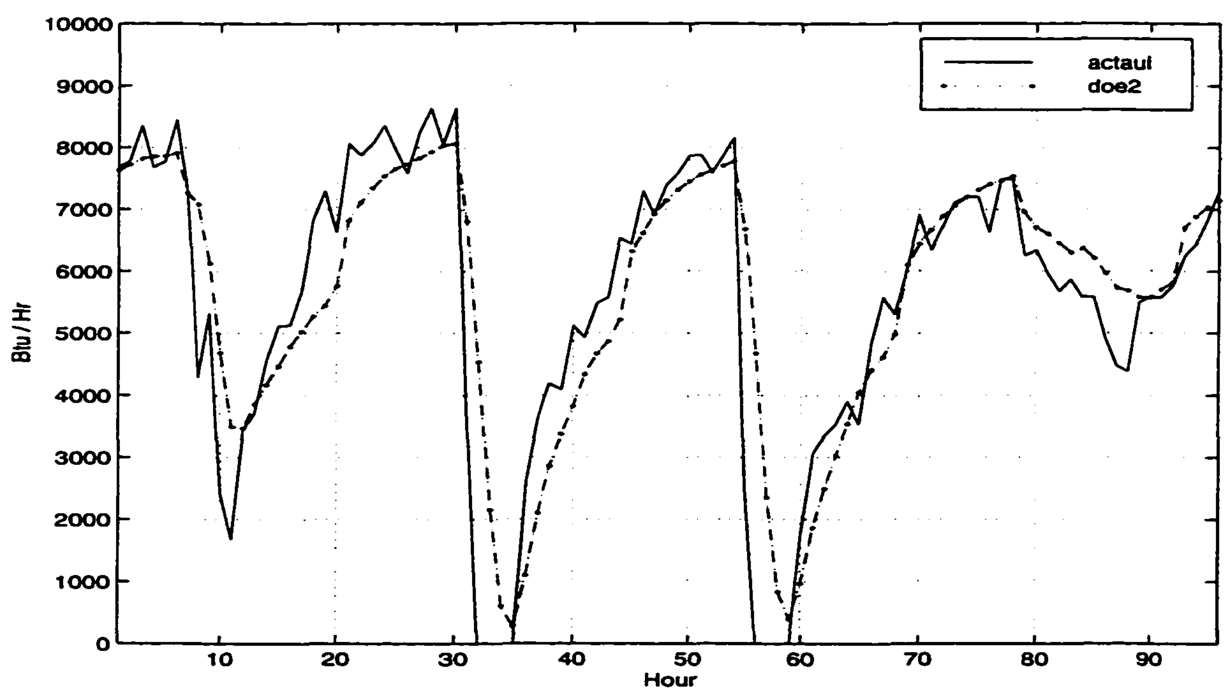


Figure 7.65 East room reheat energy rate for daylighting test from 990328 through 990331

Table 7.67 Statistical summary of south room heating energy rate prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	4907	5284±179
MEAN(DT)	377	-
MEAN ERROR(%)	7.1	±3.4
STDE(DT)	115	-
RMSE	1179	-
MIN(DT)	-2319	-
MAX(DT)	3347	-
MIN	0	0
MAX	7919	8639±293

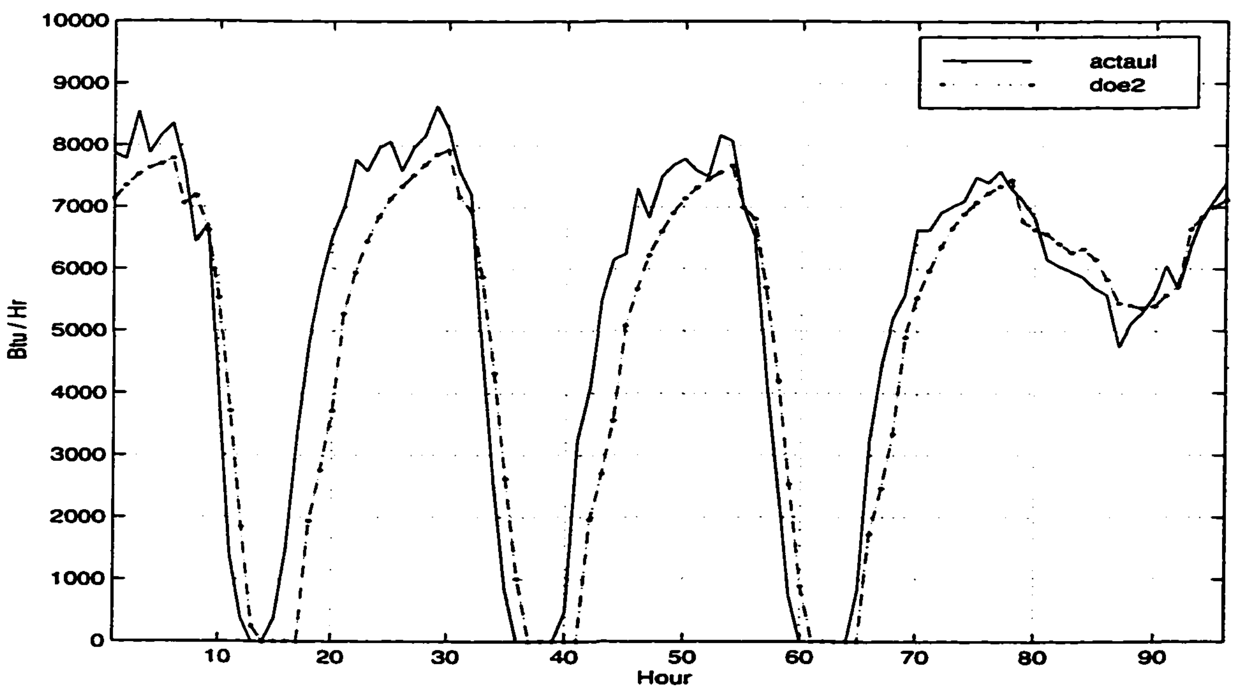


Figure 7.66 South room reheat energy rate for daylighting test from 990328 through 990331

Table 7.68 Statistical summary of west room heating energy rate prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	5512	5640±191
MEAN(DT)	129	-
MEAN ERROR(%)	2.3	±3.4
STDE(DT)	119	-
RMSE	1164	-
MIN(DT)	-2341	-
MAX(DT)	4179	-
MIN	0	0
MAX	7817	9117±310

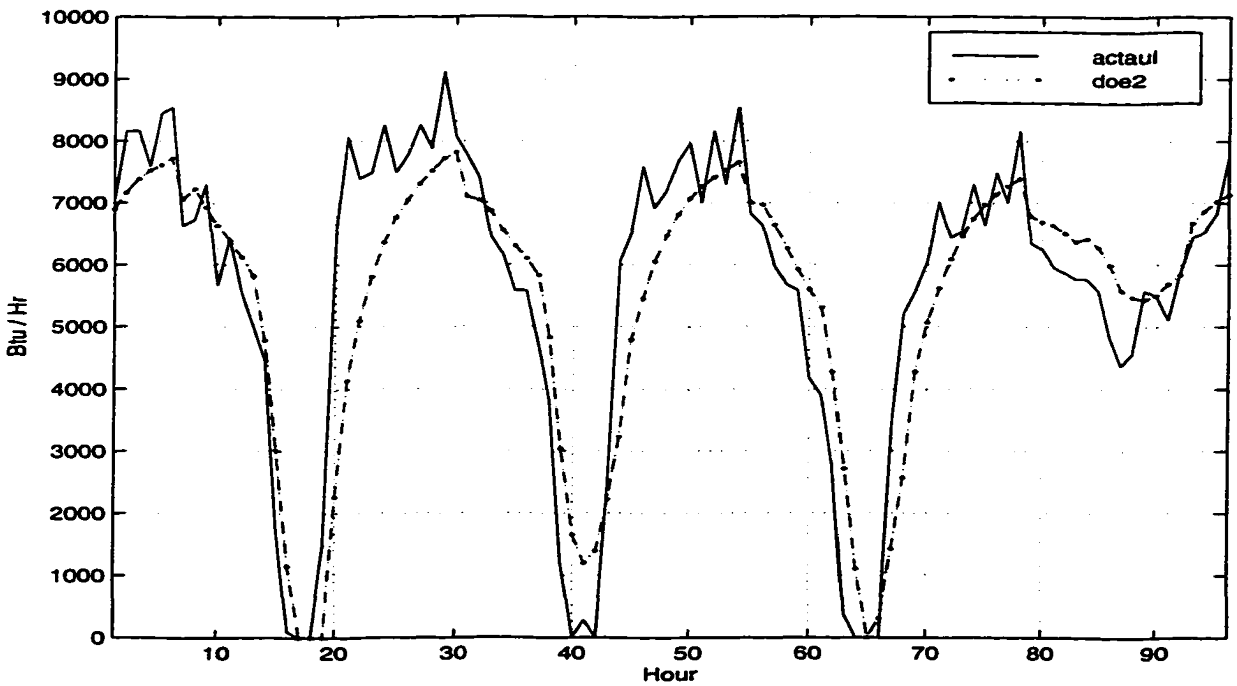


Figure 7.67 West room reheat energy rate for daylighting test from 990328 through 990331

Table 7.69 Statistical summary of interior room heating energy rate prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	3584	3684±24
MEAN(DT)	101	-
MEAN ERROR(%)	2.7	±0.6
STDE(DT)	28	-
RMSE	287	-
MIN(DT)	-598	-
MAX(DT)	633	-
MIN	3211	2634±18
MAX	4085	4500±27

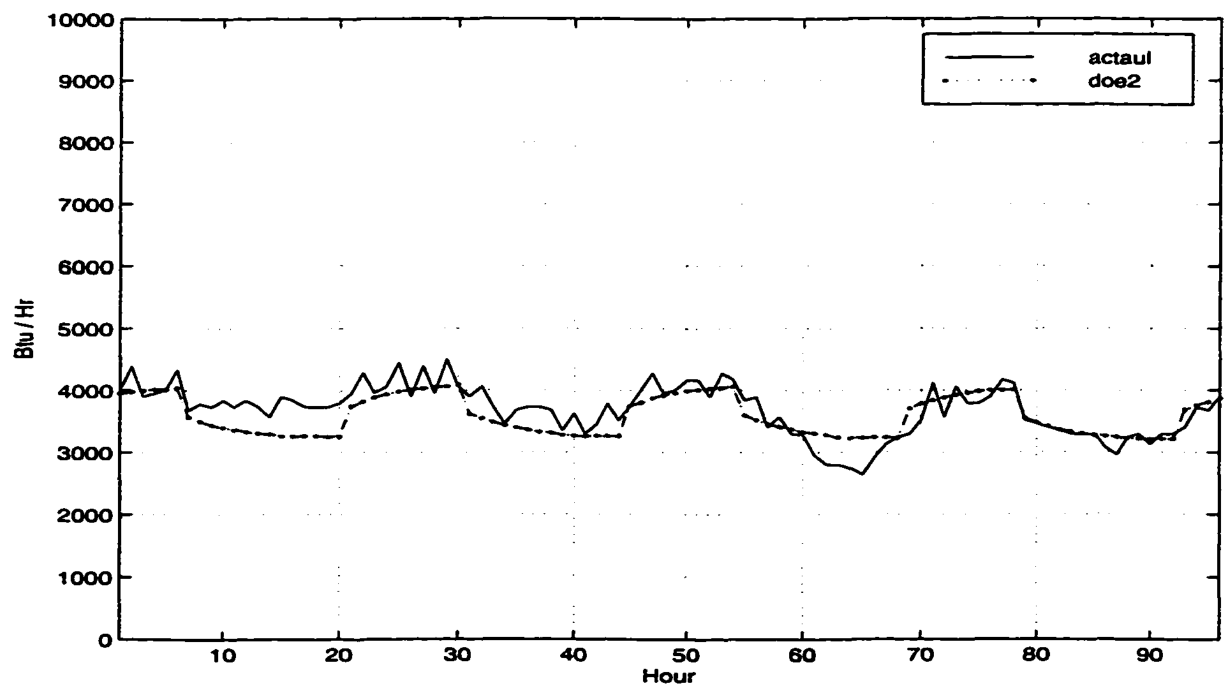


Figure 7.68 Interior room reheat energy rate for daylighting test from 990328 through 990331

Table 7.70 Statistical summary of total electric lighting power prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	573	569±40
MEAN(DT)	-4	-
MEAN ERROR(%)	-0.7	±7.0
STDE(DT)	5	-
RMSE	47	-
MIN(DT)	-195	-
MAX(DT)	161	-
MIN	0	0
MAX	1741	1741±40

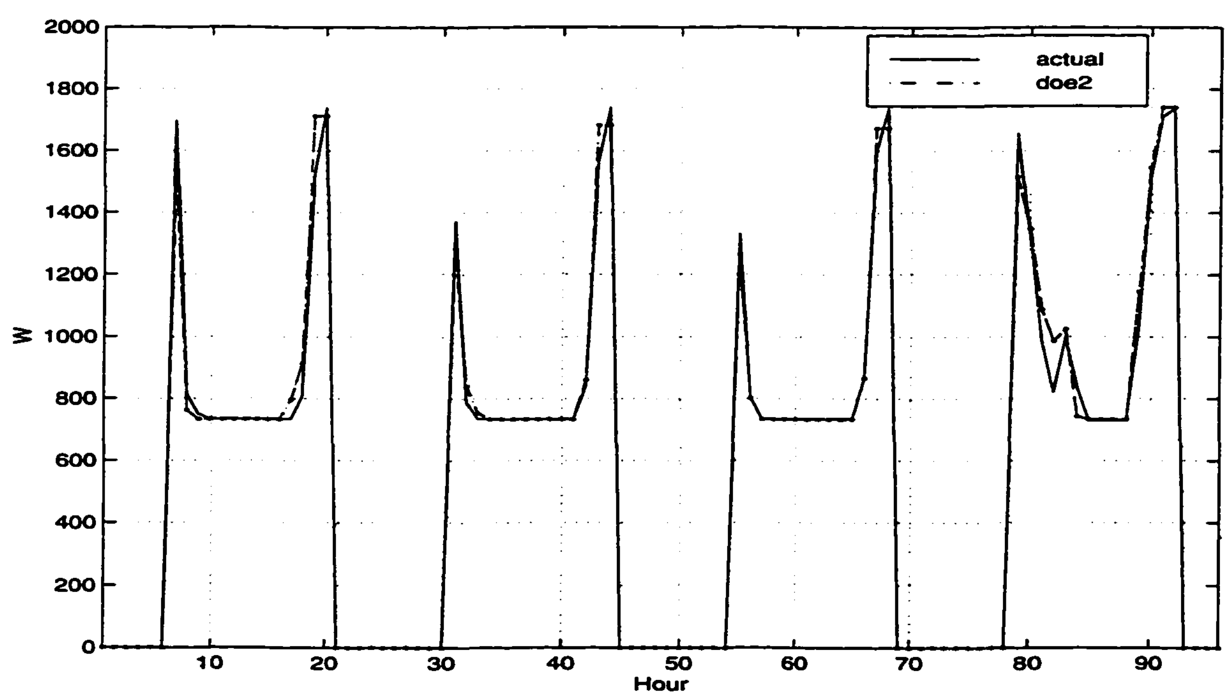


Figure 7.69 Total electric lighting power for daylighting test from 990328 through 990331

Table 7.71 Statistical summary of east room electric lighting power prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	133	130±10
MEAN(DT)	-3	-
MEAN ERROR(%)	-2.5	±7.7
STDE(DT)	3	-
RMSE	28	-
MIN(DT)	-131	-
MAX(DT)	97	-
MIN	0	0
MAX	482	489±10

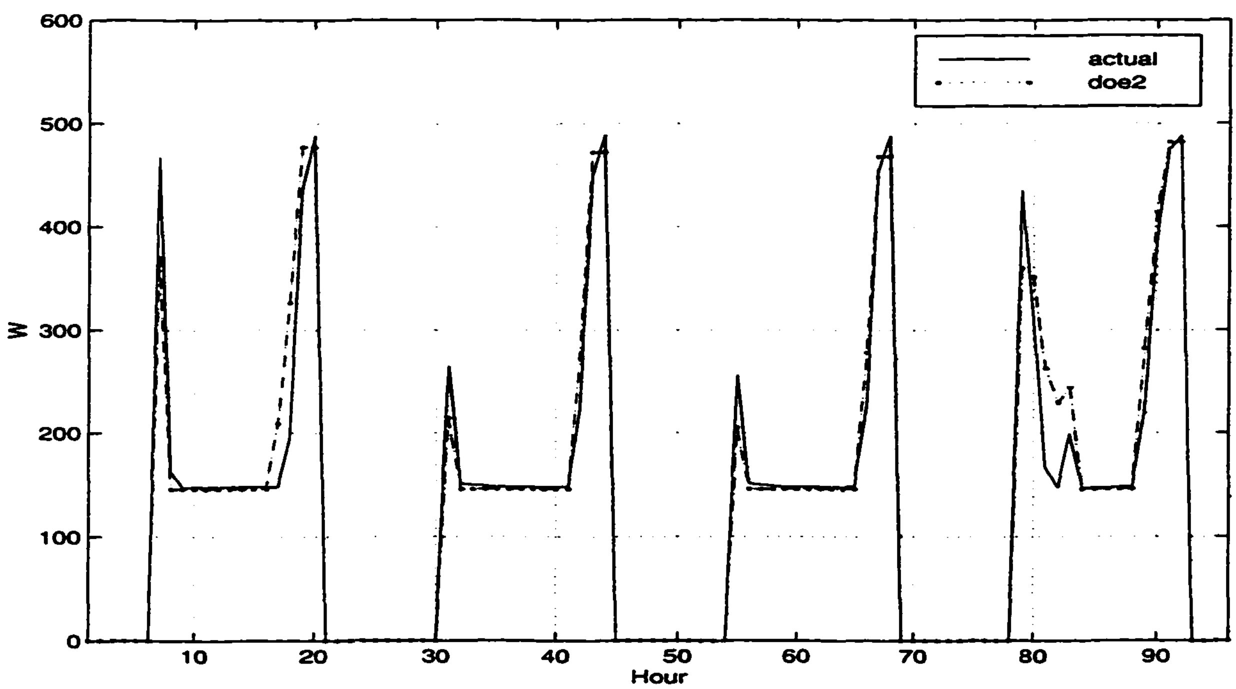


Figure 7.70 East room electric lighting power for daylighting test from 990328 through 990331

Table 7.72 Statistical summary of south room electric lighting power prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	136	140±10
MEAN(DT)	4	-
MEAN ERROR(%)	2.6	±7.1
STDE(DT)	1	-
RMSE	14	-
MIN(DT)	-43	-
MAX(DT)	53	-
MIN	0	0
MAX	482	498±10

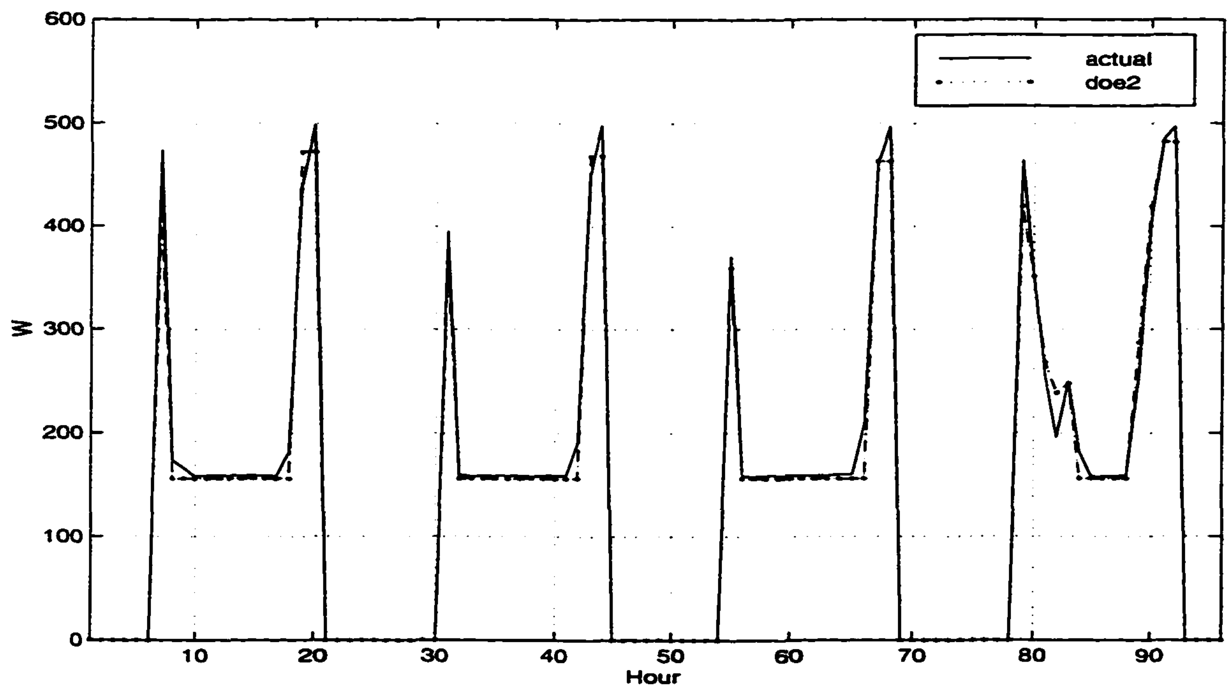


Figure 7.71 South room electric lighting power for daylighting test from 990328 through 990331

Table 7.73 Statistical summary of west room electric lighting power prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	126	121±10
MEAN(DT)	-4	-
MEAN ERROR(%)	-3.7	±8.2
STDE(DT)	2	-
RMSE	20	-
MIN(DT)	-123	-
MAX(DT)	66	-
MIN	0	0
MAX	472	450±10

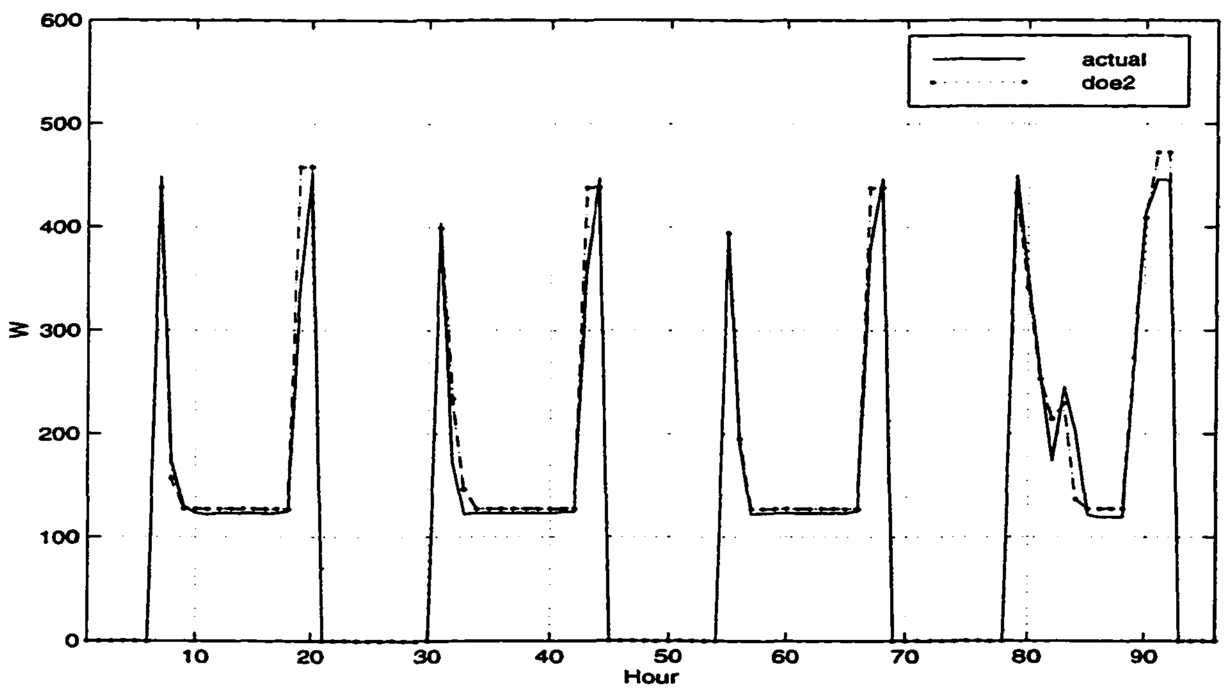


Figure 7.72 West room electric lighting power for daylighting test from 990328 through 990331

Table 7.74 Statistical summary of interior room electric lighting power prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	178	178±10
MEAN(DT)	0	-
MEAN ERROR(%)	0.2	±5.6
STDE(DT)	0	-
RMSE	1	-
MIN(DT)	0	-
MAX(DT)	4	-
MIN	0	0
MAX	305	309±10

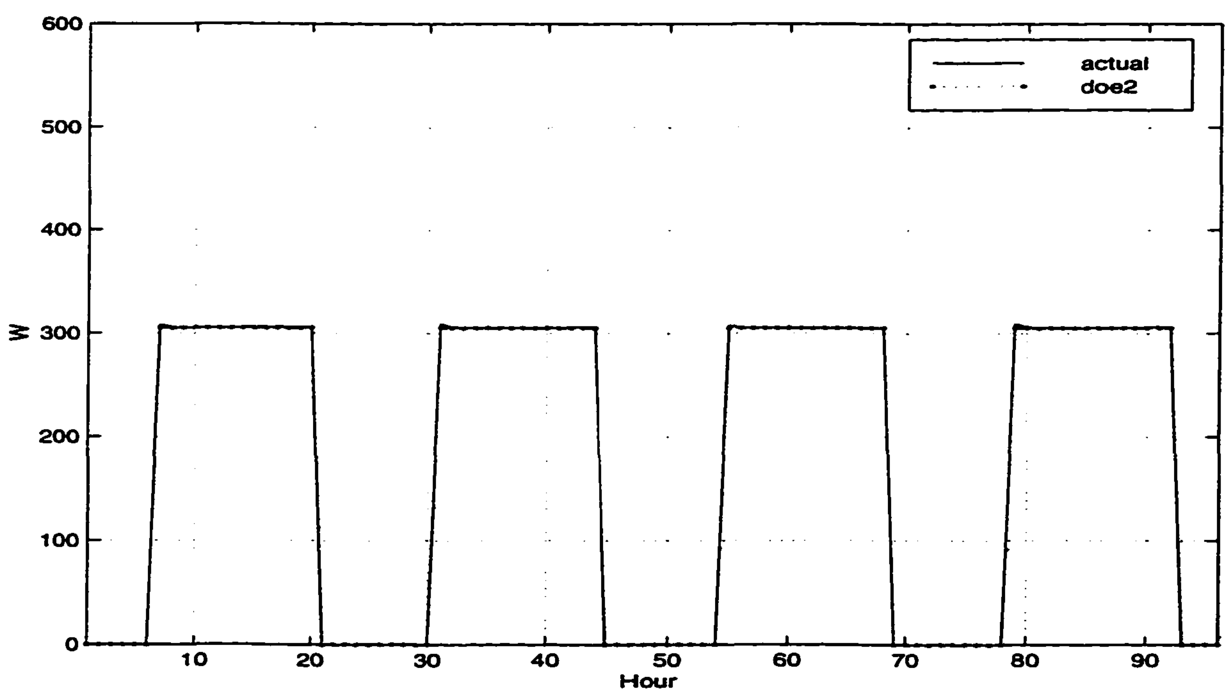


Figure 7.73 Interior room electric lighting power for daylighting test from 990328 through 990331

Table 7.75 Statistical summary of east room illuminance prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	103	98±4
MEAN(DT)	-5	-
MEAN ERROR(%)	-5.0	±4.1
STDE(DT)	7	-
RMSE	66	-
MIN(DT)	-145	-
MAX(DT)	361	-
MIN	0	0
MAX	585	752±4

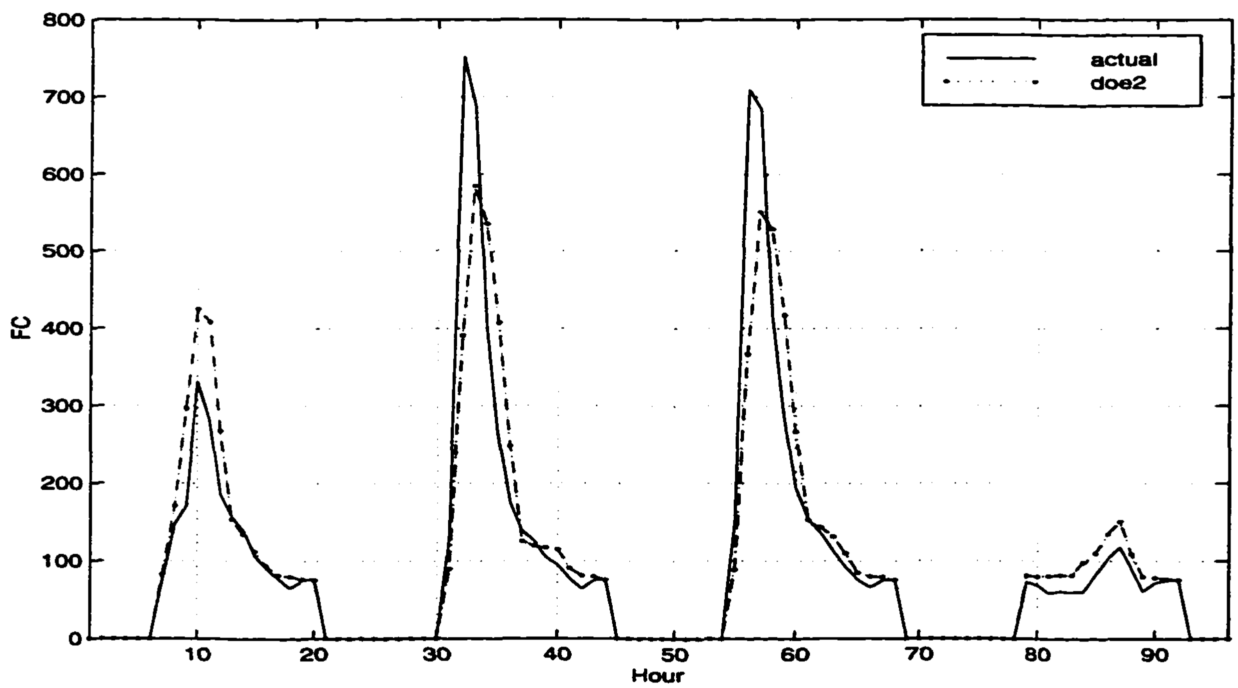


Figure 7.74 East room illuminance for daylighting test from 990328 through 990331

Table 7.76 Statistical summary of south room illuminance prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	146	96±4
MEAN(DT)	-50	-
MEAN ERROR(%)	-51.8	±4.2
STDE(DT)	7	-
RMSE	84	-
MIN(DT)	-241	-
MAX(DT)	2	-
MIN	0	0
MAX	569	336±4

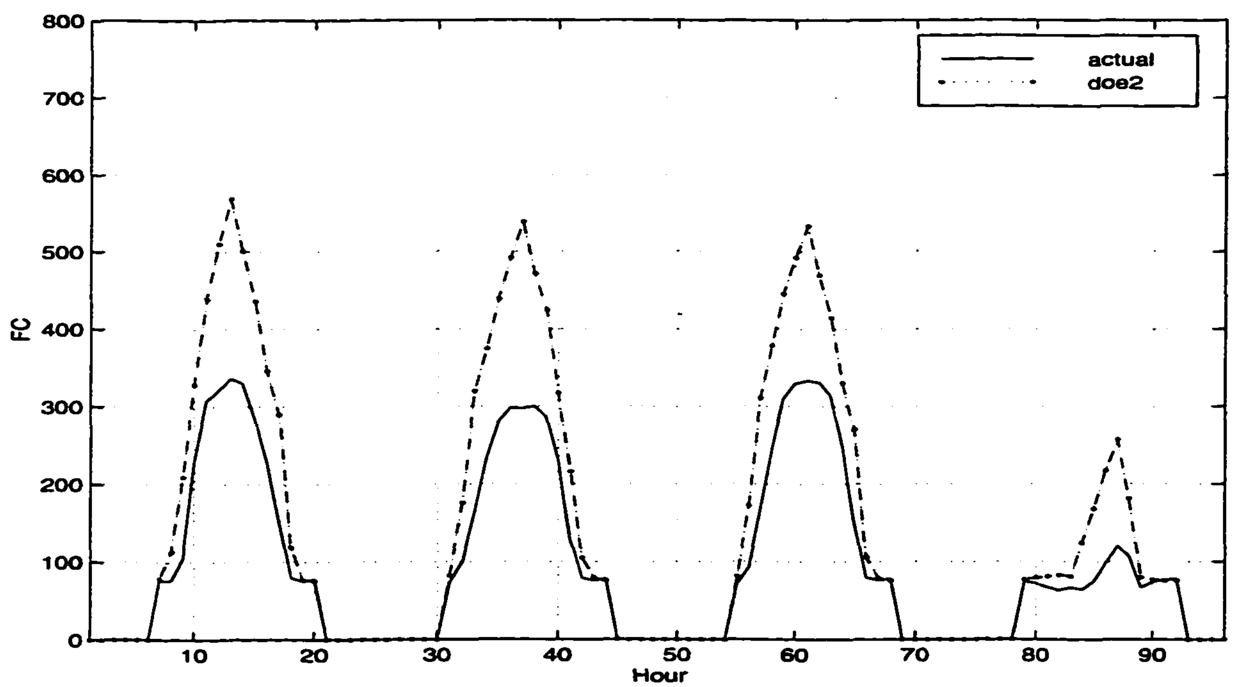


Figure 7.75 South room illuminance for daylighting test from 990328 through 990331

Table 7.77 Statistical summary of west room illuminance prediction in daylighting test

Statistics	DOE2	ACTUAL
MEAN	110	104±4
MEAN(DT)	-6	-
MEAN ERROR(%)	-5.8	±3.8
STDE(DT)	8	-
RMSE	81	-
MIN(DT)	-201	-
MAX(DT)	392	-
MIN	0	0
MAX	580	762±4

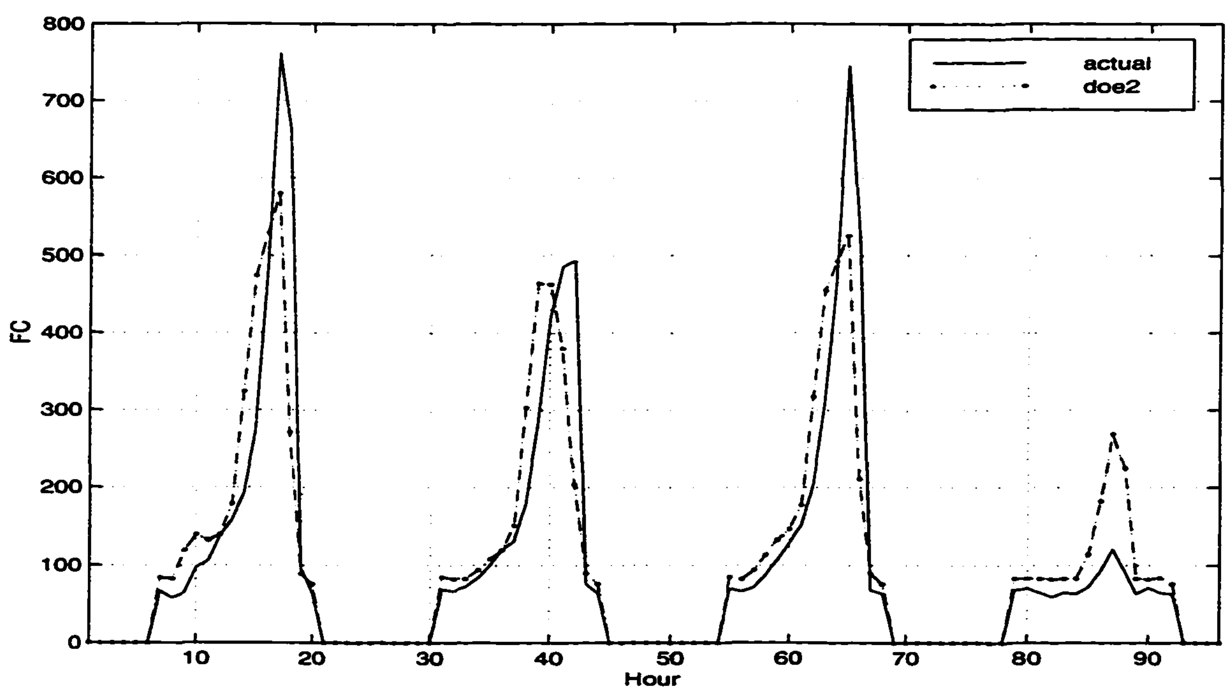


Figure 7.76 West room illuminance for daylighting test from 990328 through 990331

did not use daylighting throughout the test. A direct comparison of actual versus computed room lighting levels is difficult because of the location of the light sensors in the room and orientation of the reference point used by the DOE2 program. DOE2 computes the illuminance on a reference surface (such as the top of a table) located at a specific point in the space. Measurements of the illuminance of this surface were made with a sensor mounted in the ceiling. The sensor "looked" down at the reference table; therefore, the sensor was measuring the reflected light from the table, rather than the incident light on the table. Another issue that must be addressed in the comparison is that DOE2's calculation of illuminance on the reference point is from daylighting only. The ceiling mounted sensor would "see" the additional illuminance from reflected lights in the room. This was accounted for in the comparison by adding a fraction of the room illuminance due to the interior lighting to the DOE2 illuminance values. The fraction was based on the light power measured during the test.

DOE2 under-predicted the illuminance for the hours when the sun's altitude is low such as in the morning in the east room, and evening in the west room. This seems to be the case when directly sunlight enters the space and is probably due to the location of the light sensor. Besides those hours, the predictions were good. In the south room the program over-predicted the illuminance. Differences between the actual and the predictions were good enough in the east and west rooms while the difference in the south room was 50 foot-candles which is 51.8% mean error. For a mostly cloudy day, the program over-predicted the illuminance in all three rooms.

To see the relationship between illuminance and lighting power usage in the actual building and the relationship from the computer model, plots were developed on a room by room basis as shown Figure 7.77 through Figure 7.82.

Summary of Comparison Results

This section discusses how well the programs predicted system cooling and heating energy depending on building's operation characteristics and HVAC system types. In the previous sections, comparisons and discussions were made only for the individual test.

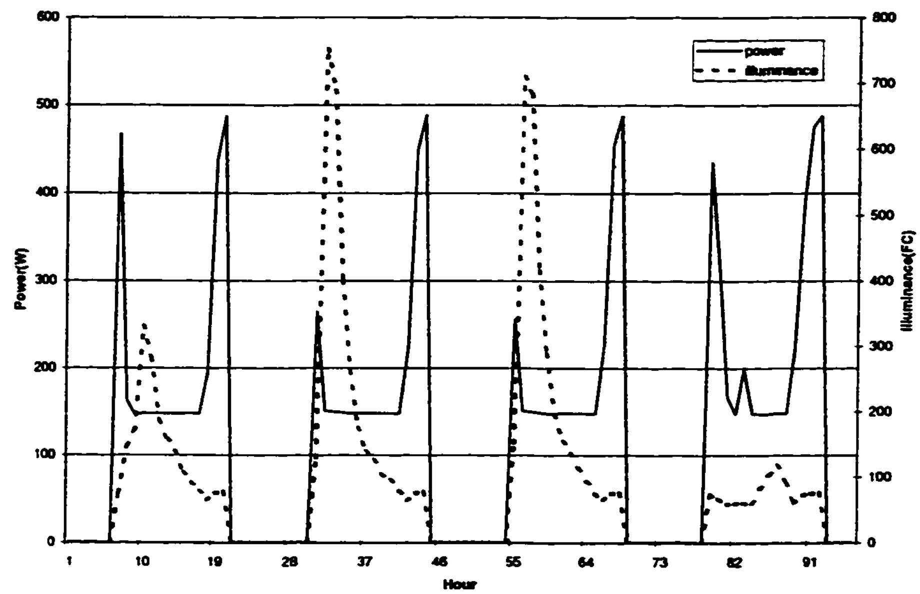


Figure 7.77 Actual lighting power and illuminance in east room from 990328 through 990331

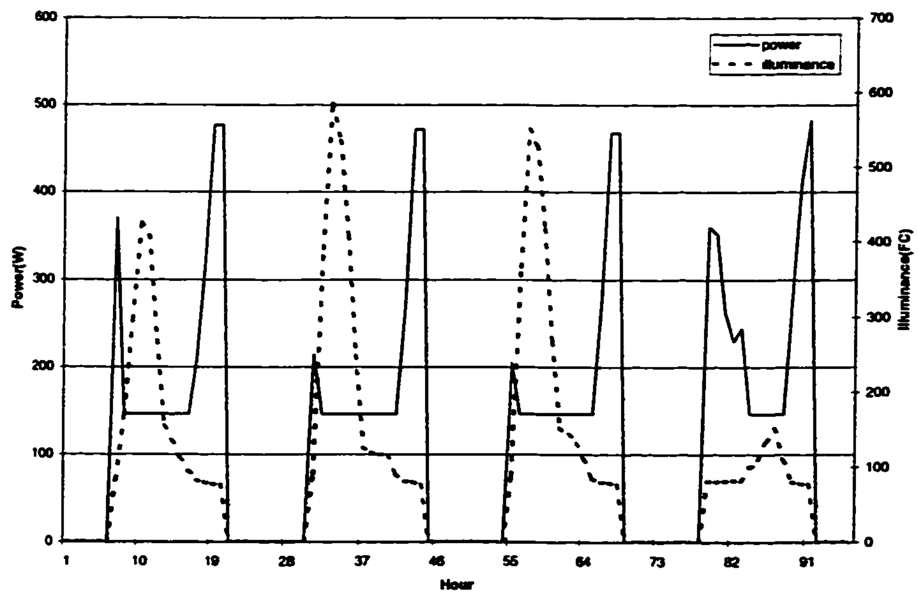


Figure 7.78 Predicted lighting power and illuminance in east room from 990328 through 990331

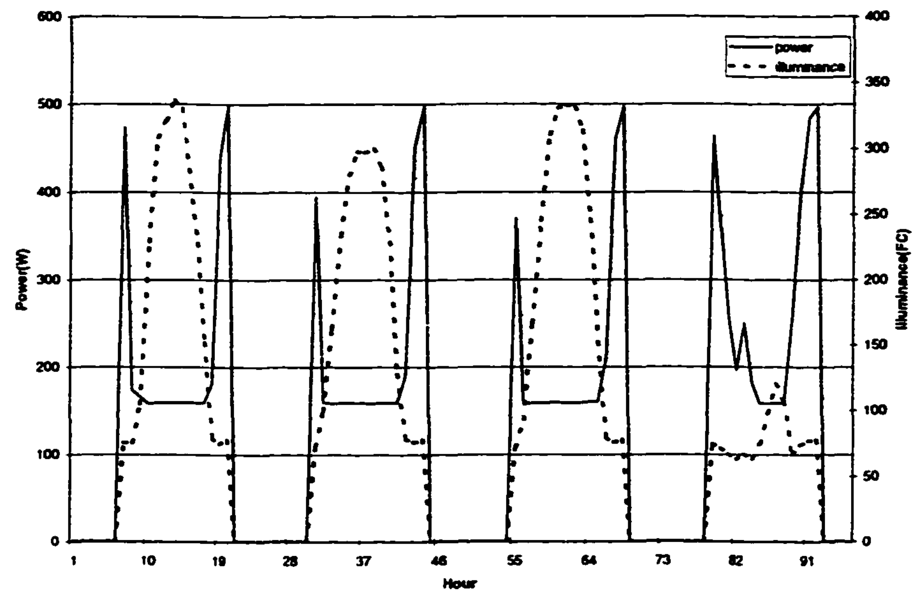


Figure 7.79 Actual lighting power and illuminance in south room from 990328 through 990331

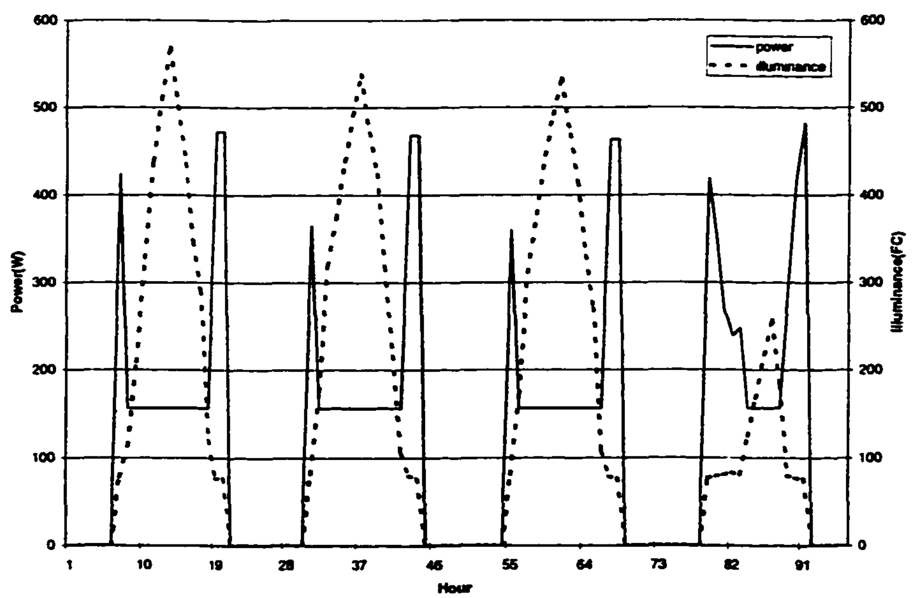


Figure 7.80 Predicted lighting power and illuminance in south room from 990328 through 990331

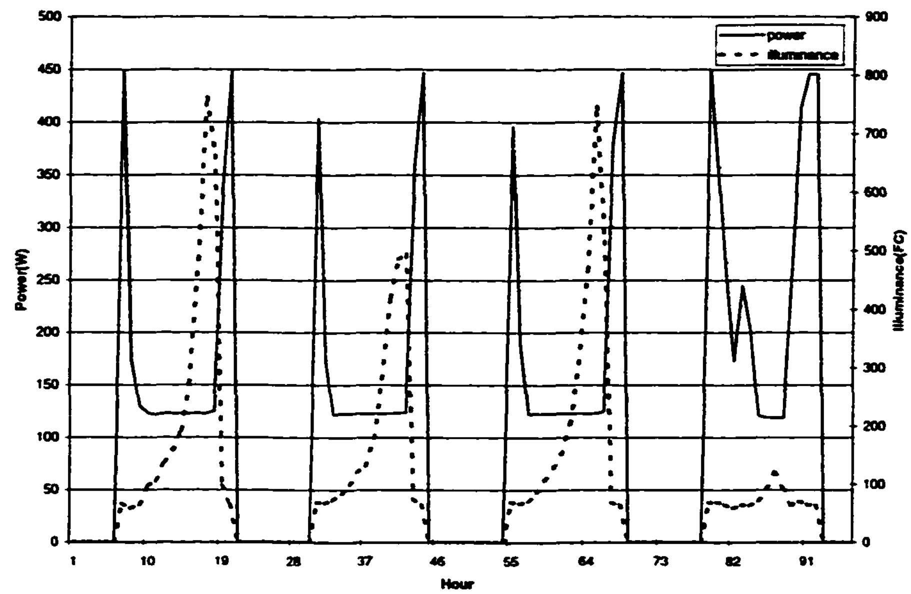


Figure 7.81 Actual lighting power and illuminance in west room from 990328 through 990331

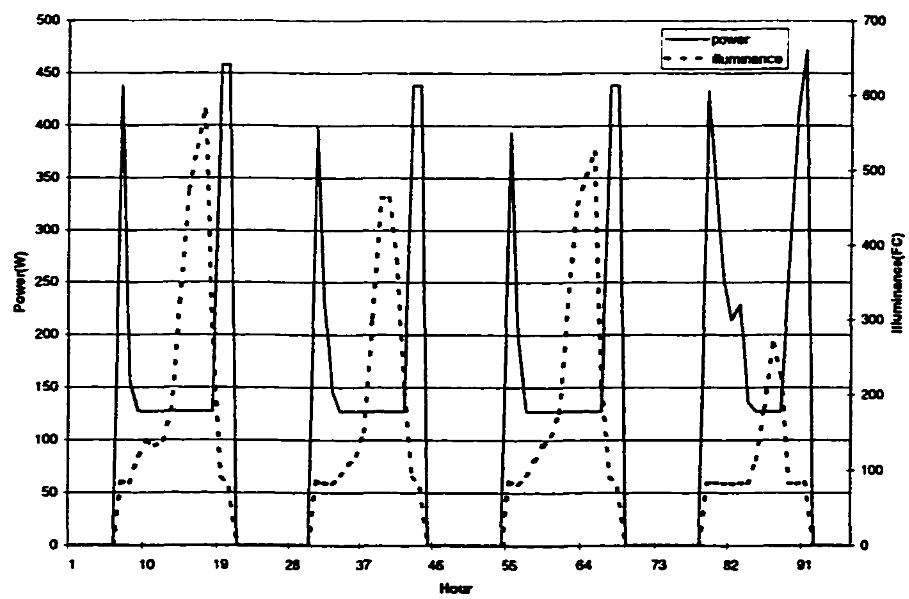


Figure 7.82 Predicted lighting power and illuminance in west room from 990328 through 990331

Even though each test was conducted for more than two days, only two days of test data from each test were used for this comparison in order to provide equal probabilities . One day represents a sunny day from the test period, and the other day represents a cloudy day. For example, the comparison for the non-dynamic test includes six days of test data: two days for CAVRH(1), two days for VAVRH(1) and two days for FCU(1). For the analysis of a HVAC system, four days of test data are used because each HVAC system had two different tests: one for non-dynamic, and one for dynamic. Finally an analysis that includes the whole test series was made to draw general conclusion. This analysis has twelve days of test data.

Non-dynamic Tests

For the analysis of the non-dynamic test series, 3 HVAC systems were used with different weather conditions. The tests were conducted in summer for CAVRH, and spring for VAVRH and 4PFCU, respectively. Comparison results are presented in Figure 7.83 and Figure 7.84 with numerical information as shown in Table 7.78 and Table 7.79. DOE2 had the best prediction of cooling energy of the three programs with a small value of RMSE, 2740. Considering uncertainty of the experimental data, $\pm$14.7% ($\pm$4112), its prediction was pretty good. HAP and TRACE under-predicted their energies by 21.5% and 15.9% considering the uncertainty of the actual data. In heating energy predictions all programs were well matched to the actual.

Dynamic Tests

For the analysis of the dynamic test series, 3 HVAC systems were used with different weather conditions. The tests were conducted with CAVRH, VAVRH and 4PFCU, respectively. Comparison results are presented in Figure 7.85 and Figure 7.86 with numerical information as shown in Table 7.80 and Table 7.81. The TRACE program predicted both cooling and heating energies better than the other two programs. DOE2 over-predicted energies in both cooling and heating while HAP under-predicted energies in both cooling and heating. Generally predictions in heating were better than those in cooling.

Table 7.78 Statistical summary of system cooling energy rate prediction in non-dynamic tests

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	27061	22032	23598	28066±4112
MEAN(DT)	1005	6034	4467	-
MEAN ERROR(%)	3.6	21.5	15.9	±14.7
STDE(DT)	213	289	304	-
RMSE	2740	6956	5760	-
MIN(DT)	-5871	149	-4686	-
MAX(DT)	11967	13078	13078	-
MIN	0	0	0	149±221
MAX	52379	45029	47280	55259±6093

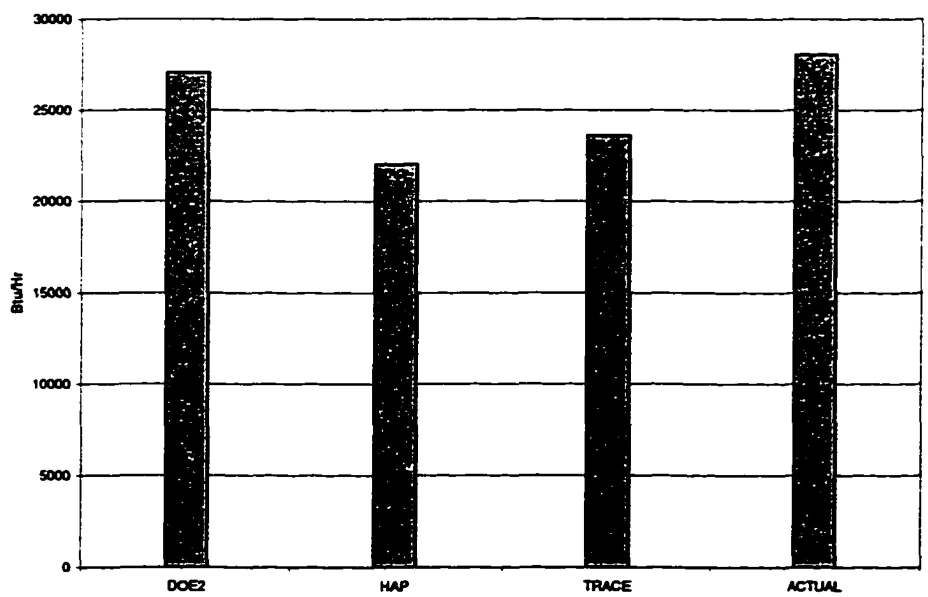


Figure 7.83 Mean of system cooling energy rate for non-dynamic tests

Table 7.79 Statistical summary of system heating energy rate prediction non-dynamic tests

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	17142	16469	17855	16653±781
MEAN(DT)	-489	184	-1202	-
MEAN ERROR(%)	-2.9	1.1	-7.2	±4.7
STDE(DT)	212	298	247	-
RMSE	2587	3572	3191	-
MIN(DT)	-9746	-9408	-7769	-
MAX(DT)	7208	6596	4617	-
MIN	0	0	100	233±127
MAX	34808	33550	35730	31713±1554

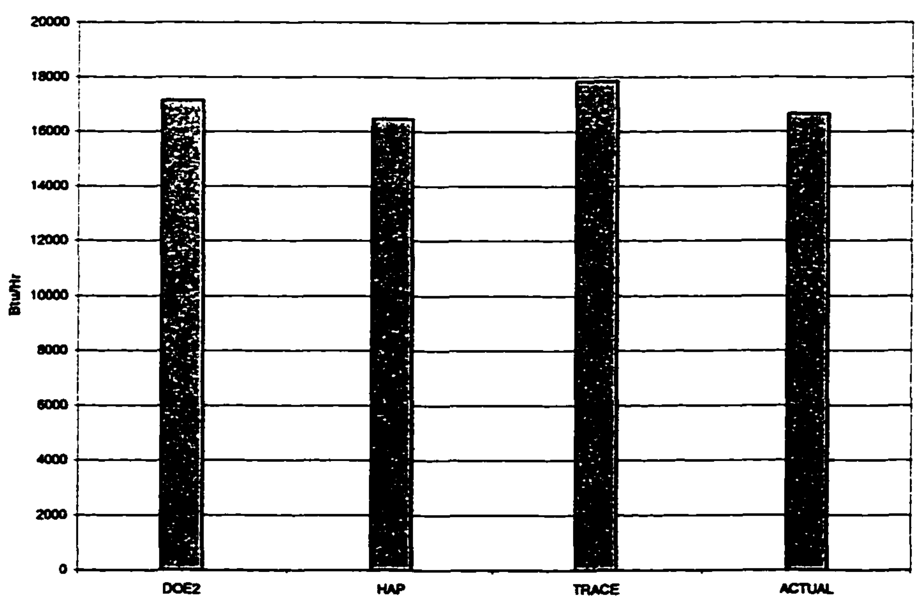


Figure 7.84 Mean of system heating energy rate for non-dynamic tests

Table 7.80 Statistical summary of system cooling energy rate prediction in dynamic tests

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	1963	1154	1602	1525 ±310
MEAN(DT)	-438	371	-77	-
MEAN ERROR(%)	-28.7	24.3	-5.1	±20.3
STDE(DT)	200	163	194	-
RMSE	2435	1985	2317	-
MIN(DT)	-9931	-4875	-8525	-
MAX(DT)	10676	10676	10076	-
MIN	0	0	0	0
MAX	22655	15390	21960	13515 ±1794

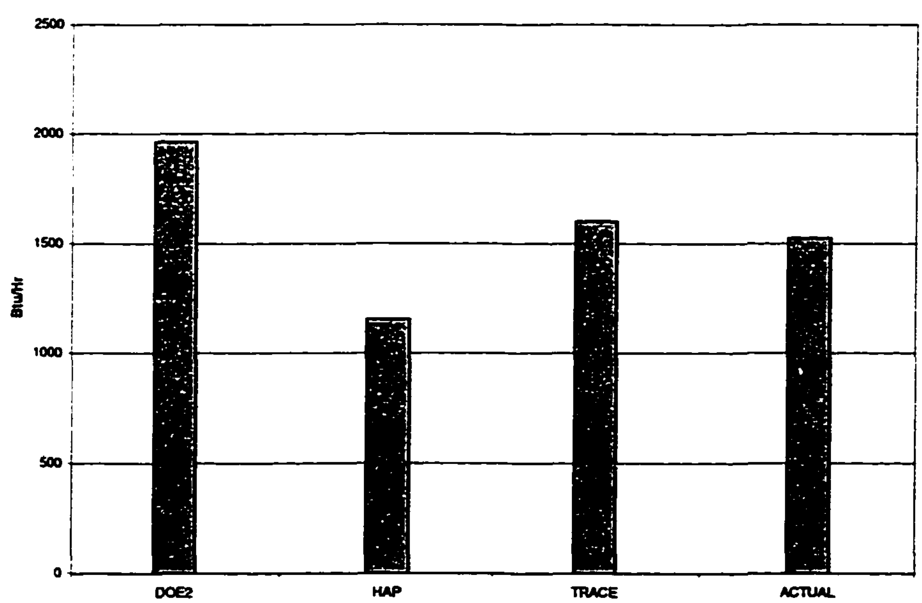


Figure 7.85 Mean of system cooling energy rate for dynamic tests

Table 7.81 Statistical summary of system heating energy rate prediction in dynamic tests

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	14206	11292	11652	12851 ±468
MEAN(DT)	-1355	1559	1199	-
MEAN ERROR(%)	-10.5	12.1	9.3	±3.6
STDE(DT)	423	480	432	-
RMSE	5241	5954	5304	-
MIN(DT)	-19499	-15001	-13765	-
MAX(DT)	16895	16895	14053	-
MIN	0	0	0	0
MAX	50218	40790	37890	44510 ±1722

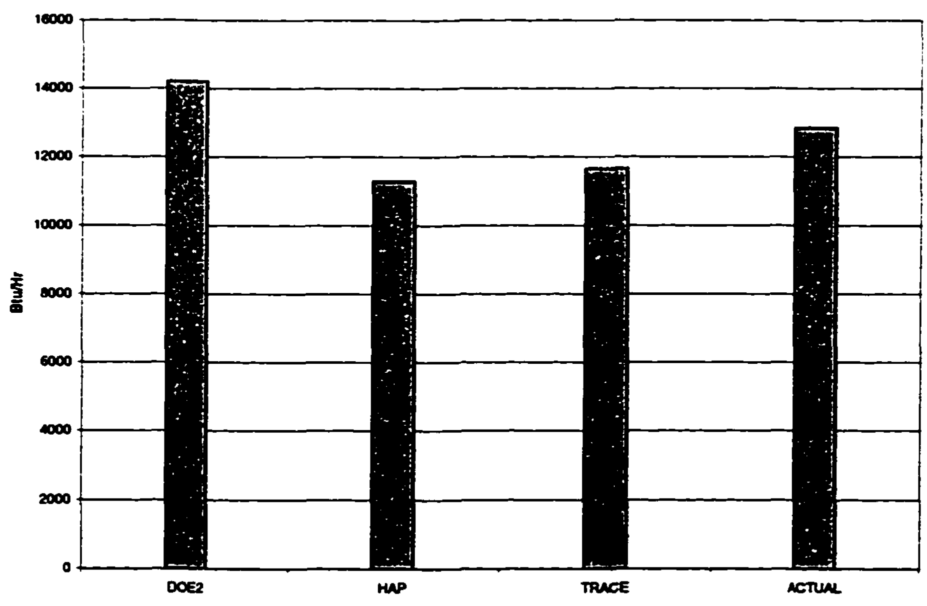


Figure 7.86 Mean of system heating energy rate for dynamic tests

CAVRH System

The tests were conducted in summer for non-dynamic, and in winter for dynamic test. Comparison results are presented in Figure 7.87 and Figure 7.88 with numerical information as shown in Table 7.82 and Table 7.83. In the cooling energy predictions DOE2 predicted best, but HAP and TRACE also matched to the actual considering the uncertainty of the experimental data. RMSE values are 1762, 6873, 5880 for DOE2, HAP and TRACE, respectively. For the heating energy comparison, HAP and TRACE predicted pretty well, and DOE2 over-predicted it by 16.2%.

VAVRH system

In cooling energy predictions DOE2 program predicted the energy closest to the actual while HAP and TRACE under-predicted the cooling energy as shown in Figure 7.89 and Table 7.84 by 19.1% and 14.8%, respectively. However, considering the uncertainty value, ±2850, Their predictions also were pretty good. In heating energy predictions DOE2 and TRACE were close enough to the actual, and HAP under-predicted it by 17.6% as shown in Figure 7.90 and Table 7.85.

4PFCU system

Figure 7.91 and Figure 7.92 show comparison results for system cooling and heating energies between the actual and the programs. TRACE predicted energies better than the other two programs, but its RMSE values are so big for both cooling and heating as shown in Table 7.86 and Table 7.87. HAP predicted the energies worst and under-predicted them significantly.

General Comparison

All test series were included for this comparison. DOE2 predicted cooling energy close to the actual. Its RMSE value also is much smaller than the others' as shown in Figure 7.93 and Table 7.88. As found in the previous comparisons, HAP and TRACE always under-predicted their cooling energies. Combined mean errors for HAP and TRACE were 21.6% and 14.8%

Table 7.82 Statistical summary of system cooling energy rate prediction in CAVRH

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	24695	20828	21584	25624±2983
MEAN(DT)	929	4796	4040	-
MEAN ERROR(%)	3.6	18.7	15.8	±11.6
STDE(DT)	154	505	438	-
RMSE	1762	6873	5880	-
MIN(DT)	-1560	0	0	-
MAX(DT)	5744	12565	12419	-
MIN	0	0	0	0
MAX	52379	45029	47280	55259±6093

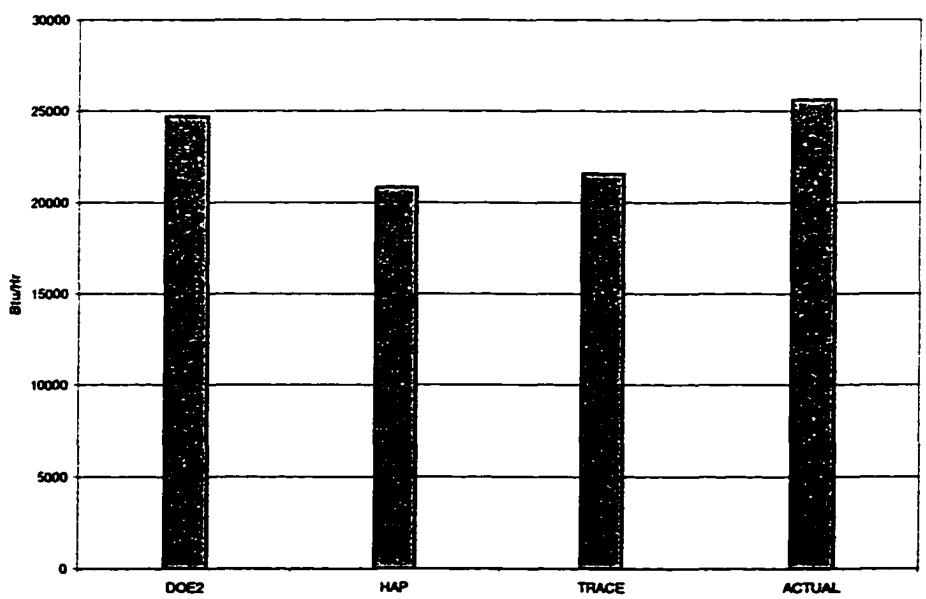


Figure 7.87 Mean of system cooling energy rate for CAVRH tests

Table 7.83 Statistical summary of system heating energy rate prediction in CAVRH

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	32971	29755	28678	28382±846
MEAN(DT)	-4589	-1373	-296	-
MEAN ERROR(%)	-16.2	-4.8	-1.0	±3.0
STDE(DT)	359	584	542	-
RMSE	5770	5859	5288	-
MIN(DT)	-19499	-15001	-13363	-
MAX(DT)	1822	12051	8717	-
MIN	9201	10962	3850	4463±151
MAX	50218	40790	37890	44510±1257

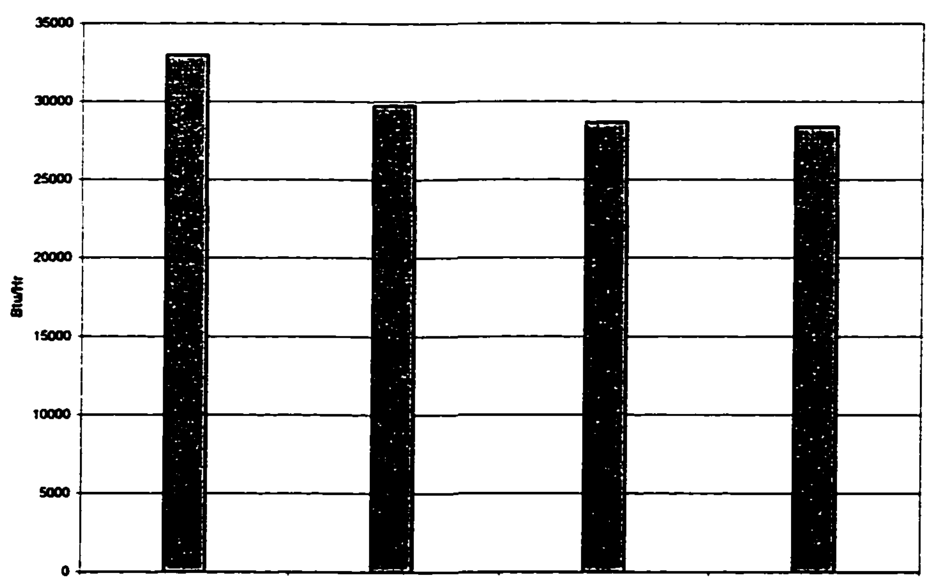


Figure 7.88 Mean of system heating energy rate for CAVRH tests

Table 7.84 Statistical summary of system cooling energy rate prediction in VAVRH

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	13656	11662	12282	14419±2850
MEAN(DT)	762	2756	2136	-
MEAN ERROR(%)	5.3	19.1	14.8	±19.7
STDE(DT)	135	301	246	-
RMSE	1524	4027	3211	-
MIN(DT)	-1995	0	0	-
MAX(DT)	5720	9520	9305	-
MIN	0	0	0	0
MAX	31347	25462	28320	34700±5580

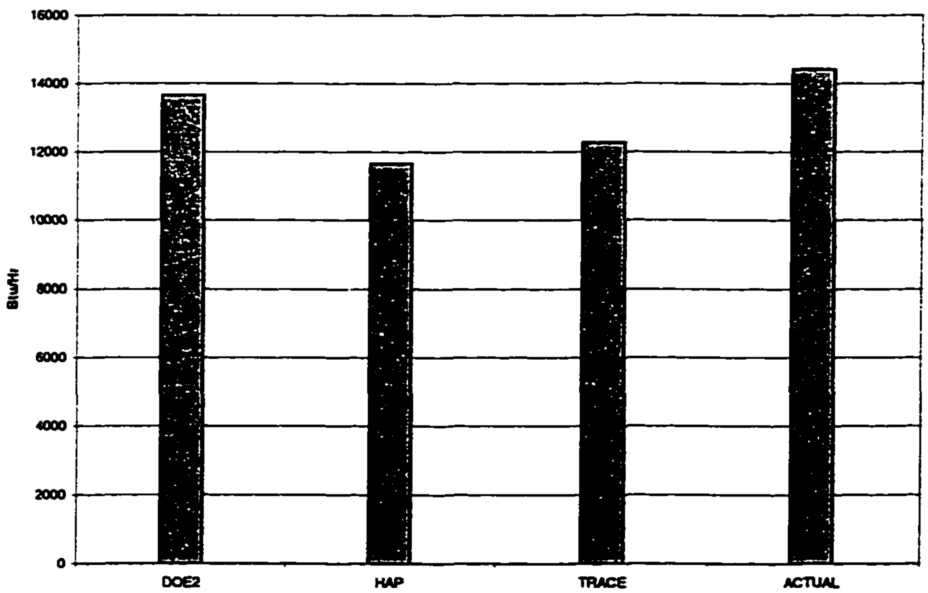


Figure 7.89 Mean of system cooling energy rate for VAVRH tests

Table 7.85 Statistical summary of system heating energy rate prediction in VAVRH

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	12635	11331	12983	13743±410
MEAN(DT)	1108	2412	760	-
MEAN ERROR(%)	8.1	17.6	5.5	±3.0
STDE(DT)	375	503	483	-
RMSE	3816	5460	4766	-
MIN(DT)	-7929	-5709	-13765	-
MAX(DT)	16895	16895	14053	-
MIN	0	0	0	0
MAX	34792	23859	26940	38465±1178

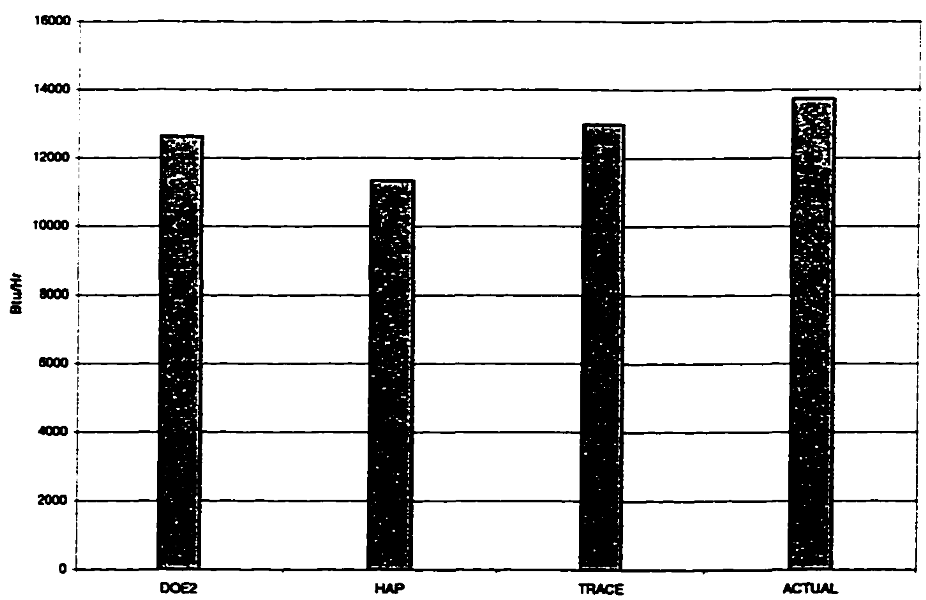


Figure 7.90 Mean of system heating energy rate for VAVRH tests

Table 7.86 Statistical summary of system cooling energy rate prediction in 4PFCU

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	5184	2288	3934	4343±800
MEAN(DT)	-842	2055	409	-
MEAN ERROR(%)	-19.4	47.3	9.4	±18.4
STDE(DT)	384	338	367	-
RMSE	3838	3879	3596	-
MIN(DT)	-9931	-4875	-8525	-
MAX(DT)	11967	13078	13078	-
MIN	0	0	0	0
MAX	22655	15390	21960	13515±1794

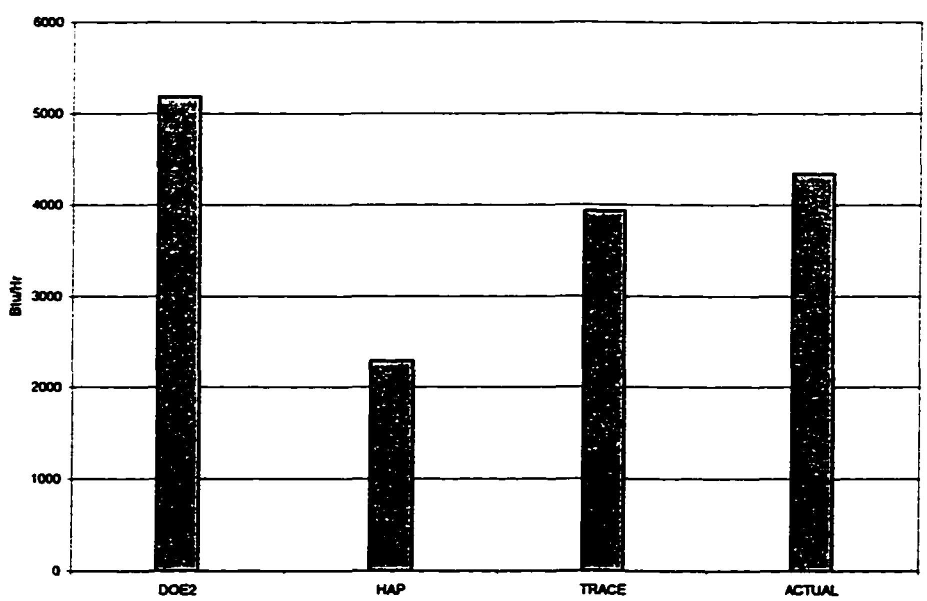


Figure 7.91 Mean of system cooling energy rate for 4PFCU tests

Table 7.87 Statistical summary of system heating energy rate prediction in 4PFCU

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	1416	555	2600	2131±620
MEAN(DT)	714	1576	-469	-
MEAN ERROR(%)	33.5	74.0	-22.0	±29.1
STDE(DT)	174	245	263	-
RMSE	1836	2857	2605	-
MIN(DT)	-3049	-1219	-9565	-
MAX(DT)	7724	12641	6745	-
MIN	0	0	0	0
MAX	12611	7694	14530	20335±1722

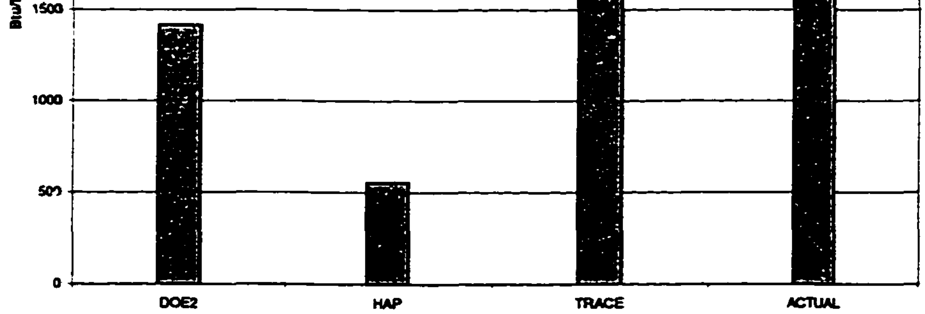


Figure 7.92 Mean of system heating energy rate for 4PFCU tests

Table 7.88 Statistical summary of total cooling energy rate prediction in whole tests

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	14512	11593	12600	14795±2210
MEAN(DT)	283	3202	2195	-
MEAN ERROR(%)	1.9	21.6	14.8	±14.2
STDE(DT)	152	235	224	-
RMSE	2592	5115	4390	-
MIN(DT)	-9931	-4875	-8525	-
MAX(DT)	11967	13078	13078	-
MIN	0	0	0	0
MAX	52379	45029	47280	55259±6093

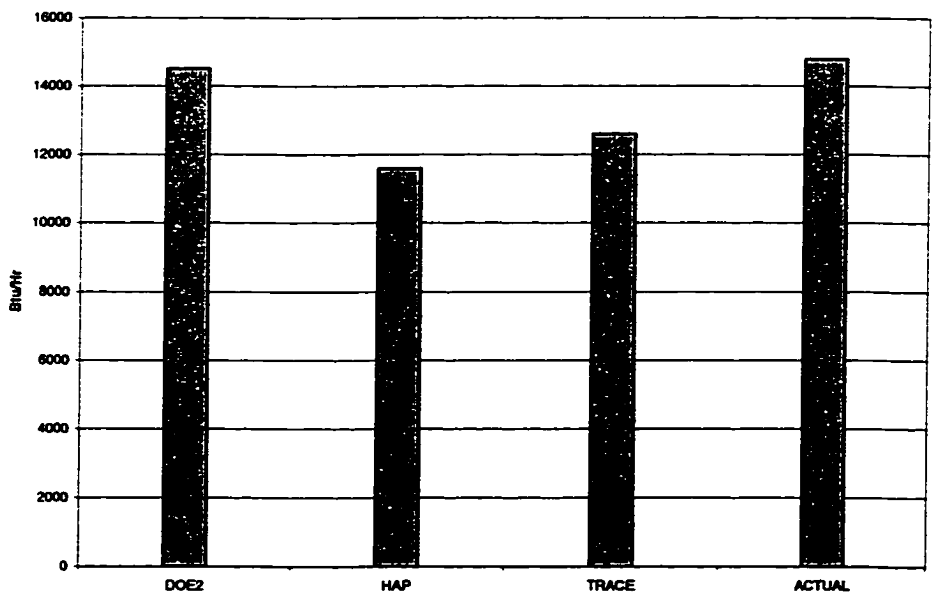


Figure 7.93 Mean of system cooling energy rate for whole tests

respectively. Since the uncertainty values is so big, HAP and TRACE also predicted their cooling energies well considering the uncertainty. Figure 7.94 and Table 7.89 present comparison results for heating energy prediction. All three programs predicted their heating energies very well. TRACE showed the smallest mean error, -0.01%, and DOE2 showed the largest mean error, -6.3%. However, DOE2 showed the smallest RMSE among the programs.

Table 7.89 Statistical summary of total heating energy rate prediction in whole tests

Statistics	DOE2	HAP	TRACE	ACTUAL
MEAN	15674	13880	14754	14752±624
MEAN(DT)	-922	872	-2	-
MEAN ERROR(%)	-6.3	5.9	-0.01	±4.2
STDE(DT)	238	285	258	-
RMSE	4132	4910	4377	-
MIN(DT)	-19499	-15001	-13765	-
MAX(DT)	16895	16895	14053	-
MIN	0	0	0	0
MAX	50218	40790	37890	44510±1722

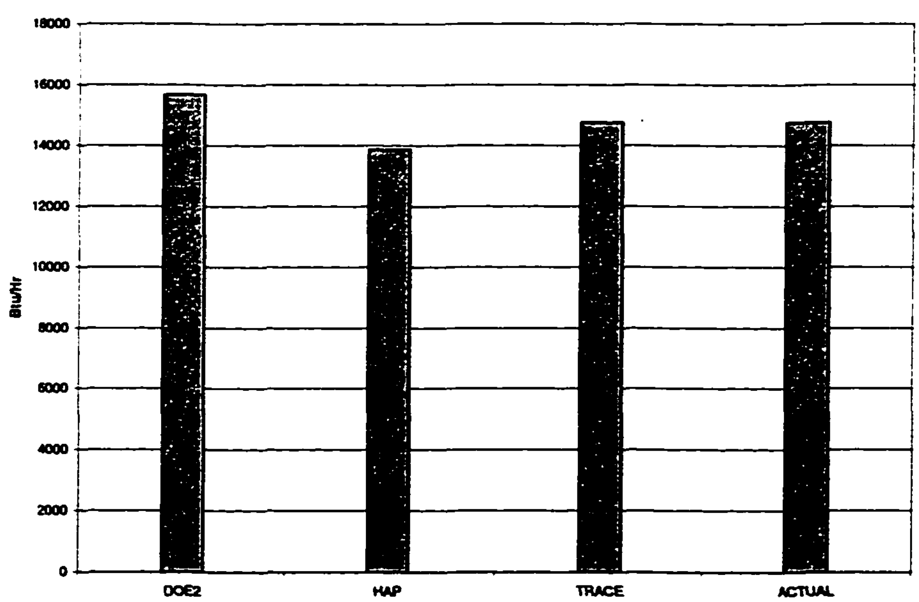


Figure 7.94 Mean of system heating energy rate for whole tests

8 CONCLUSIONS AND RECOMMENDATION

Results from this research project show that for some cases the building energy computer programs can vary considerably in the predicted thermal loads for a building while for other cases the programs agree quite well with the measured data. Due to the complex calculations performed by the programs and the fact that a building and its HVAC system is a complex thermal system to model, determining the reason for discrepancies between the models and the building data is difficult.

Validation of a simulation program using the empirical method requires several important tasks. The program user must have a through understanding of the input parameters required by the program. Misinterpretation or misuse of a single input parameter can have a significant impact on the output. For example at the beginning of the project a mistake was made in specifying the heat loss through the slab foundation in one of the programs. This mistake resulted in a heat load prediction of five times that predicted from the other programs. It is necessary for the user to develop a verification report to confirm whether the computer model has the same physical and thermal property data as the building being modeled. This report should include information about the size of the rooms, the orientations of the rooms and walls involved in the model. Verification of the U-values of all surfaces and the amount and type of fenestration. In addition, it is important that the weather data used in the simulations represents with the weather conditions during the test. Finally the control set points and building operation schedules for all relevant systems must be verified to assure the model is simulating the actual building operation. For an empirical validation study, the modeler usually needs to know the capacity of the cooling and heating equipment in order to match the model with the actual building system.

Besides have an accurate model for an empirical validation study, it is essential to obtain reliable experimental data. Sensor calibration must be done before a test to minimize instrumentation errors, and the calibration results should be checked periodically. A reliable set of experimental data also depends on the stability of the building control system. This includes the ability of the control system to maintain each set point during the test. Since HVAC systems have many control parameters and complicated water and air distribution systems, it is difficult to detect whether the test was conducted according to the test protocol. An affective way to detect problems in the system operation or errors in the measurement is to use a graphical presentation. The graphical presentation provides a visual image of the building data making it easier to identify the system operation and to spot anomalies in the experimental data. In addition, by performing energy balances on various system components, errors in sensor measurement or system operation may be detected. Known errors from individual sensors such as temperature and flow rate propagate errors when they are used for energy calculations. Any comparison of experimentally obtained energy calculations with model predictions must include an error analysis to account for the experimental uncertainty.

Results from this research project show that the energy simulation programs predict cooling and heating energies better in cases with non-dynamic building operation than in cases with dynamic operation. The results also show that the programs do a better job of predicting heating energy than in predicting cooling energy. This was true for both dynamic and non-dynamic building operation.

Of the three HVAC system types used in the study, the CAVRH system best matched the experimental results for all three programs. All three programs showed significant differences in cooling and heating energy predictions when they used the 4PFCU system. In the VAVRH system the programs predicted the heating energy reasonably well, but did not predict the cooling energy well.

Only the DOE2 program was used for the daylighting validation study. Prediction of lighting energy in the test rooms was very well matched to the measured lighting energy. The prediction of illuminance in the rooms showed differences depending on the orientation of the rooms. The rooms facing east or west showed a good prediction while the south-facing room over-predicted the illuminance for sunny days. For the cloudy day, the predicted illuminance in all rooms was higher than the measured value. The difference between measured and predicted illuminance is most likely due to the method used to measure the room illuminance. Future daylighting studies need to address the measurement of illuminance at the reference point in a way consistent with the calculations performed in the DOE2 program.

In general comparisons, the DOE2 program predicted the cooling energy best among the programs, and all three programs predicted the heating energy similarly.

A brief sensitivity study was conducted using DOE2 to examine the affects small changes in the weather data had on the simulation results. Changes were made to the solar data and outdoor dry-bulb temperature data on the order of a few percent which might be typical errors for the instrumentation used for weather data collection. The dry-bulb temperature change caused the greatest effect when the building system used a lot of outdoor air for ventilation. This affected the system cooling energy predictions the most. It did not have much affect on the system heating energy. This was especially noticed when the system used the air-side economizer mode. The cooling energy predictions made by the programs showed more disagreement than when the ventilation air flow rate was set up to be constant. For example, if the outdoor temperature had a 1.5 °F error, then cooling energy was affected by 2.55% while the heating energy was affected by only 0.14%. A variation in solar data of 3.5% causes the system cooling and heating energies to be affected by only 0.03% and 0.33%, respectively.

One possible explanation for the poor performance of the programs in predicting system cooling energy is an observation that was made with regards to the outdoor air temperature measured where the air enters the air handling unit. During the cooler months the temperature of this air stream was consistently a few degrees warmer than the outdoor air temperature measured by the weather station. It was concluded that there might be duct leakage in this air duct leading to the AHU which would allow some air from inside the mechanical room to mix with the outdoor air and increase it's temperature. This would affect the load on the cooling coil in the actual system which would not be accounted for by the models. Further commissioning work needs to be done on the AHU to assure the systems operates in a manner consistent with the expectations of a properly functioning system.

The thermal mass of a building is an important parameter in building energy simulation because it affects the interaction between instantaneous heat gains/losses and cooling/heating loads. This affect is clearly seen by ploting hourly room temperatures when the building is operated with dynamic loads such as thermostat schedules that involve night set back or scheduled internal loads. If the thermal mass is not properly accounted for, the hourly room temperature profiles will not correspond to the measured data during step changes in room thermostat set point or in sudden changes to the operation of the HVAC system. Results from this research show that all three programs (DOE2, HAP and TRACE) do not properly account for stored energy in the rooms when the HVAC system utilized a fan cycling schedule. The three programs calculated an increase in room temperature when it was physically impossible for the room temperature to increase. Further research should focus on cases where the building has dynamic loads to provide program developers with experimental data empirical validation of the dynamic behavior of the building and its systems.

APPENDIX A ERS SAMPLE TREND DATA

Air handling unit's data points from the data acquisition system

Data points	Description	Value	Units
ODA-TEMP	OUTDOOR AIR TEMPERATURE	90.01	Def F
ODA-HUMD	OUTDOOR AIR HUMIDITY	61.10	% RH
OCCUPIED	OCCUPIED / UNOCCUPIED	YES	
SF-SST	SUP FAN VFD START STOP	ON	
RF-SST	RET FAN VFD START STOP	ON	
SVFD-STS	SUPPLY VFD STATUS	ON	
RVFD-STS	RETURN VFD STATUS	ON	
SVFD-CTL	SUPPLY VFD CONTROL	54.8	% SPD
RVFD-CTL	RETURN VFD CONTROL	49.3	% SPD
DUCT-STC	SUPPLY DUCT STATIC	0.7	IN WC
STC SPT	DUCT STC PRESSURE SETPOINT	0.7	IN WC
DA-TEMP	SUPPLY AIR TEMPERATURE	60.4	Deg F
SUP- SPT	SUPPLY AIR TEMPERATURE SETPOINT	55.0	Deg F
HTG-DAT	HTG COIL DISCHARGE TEMPERATURE	70.6	Deg F
CLG-DAT	CLG COIL DISCHARGE TEMPERATURE	62.5	Deg F
RA-HUMD	RETURN AIR HUMIDITY	70.0	% RH
DA-HUMD	SUPPLY AIR HUMIDITY	97.3	% RH
HWP-AMP	HOT WTR PUMP WATT DRAW	14.6	WATTS
CWP-AMPS	CHILL WTR PUMP WATT DRAW	370.2	WATTS
HW-FLOW	HOT WATER FLOW	0.0	GPM
CHW-FLOW	CHILLED WATER FLOW	25.9	GPM
OA-DMPR	OUTDOOR AIR DAMPER	30.0	% OPEN
RA-DMPR	RETURN AIR DAMPER	30.0	% CLOSE
EA-DMPR	EXHAUST AIR DAMPER	30.0	% OPEN
HTG-VLV	HEATING VALVE CONTROL	100.0	% CLOSE
CLG-VLV	COOLING VALVE CONTROL	100.0	% OPEN
HWP-SST	HOT WATER PUMP STATUS	STOP	
CWP-SST	CHILLED WATER STATUS	START	
SF-AMPS	SUPPLY FAN WATT MEASURE	527.6	WATTS
RF-AMPS	RETURN FAN WATT MEASURE	107.6	WATTS
OA-FLOW	OUTDOOR AIR FLOW RATE	73.4	CFM
SA-FLOW	SUPPLY AIR FLOW RATE	1401.2	CFM
RA-FLOW	RETURN AIR FLOW RATE	1177.25	CFM
FILT-PSI	FILTER DIFF PRESSURE	0.02	IN WC
SVFD-ALM	SUPPLY VFD ALARM	NORMAL	
RVFD-ALM	RETURN VFD ALARM	NORMAL	
LO-LIMIT	FREEZESTAT STATUS	NORMAL	
MIN-ODA	MINIMUM OUTDOOR AIR	30.0	% ODA

MIX-LLIM	MIXED AIR LOW LIMIT SETPOINT	40.0	Deg F
HTG-BTU	HEATING SYSTEM BTU'S/HR	0.0	BTU/HR
CLG-BTU	COOLING SYSTEM BTU'S/HR	16072.9	BTU/HR
CLG-EWT	COOLING COIL ENTER WATER TEMPERATURE	58.4	Deg F
CLG-LWT	COOLING COIL LEAVING WATER TEMP.	59.7	Deg F
RA-TEMP	RETURN AIR TEMPERATURE	71.0	Deg F
MA-TEMP	MIXED AIR TEMPERATURE	70.5	Deg F
HTG-EWT	HEATING COIL ENTER WATER TEMPERATURE	69.1	Deg F
HTG-LWT	HEATING COIL LEAVING WATER TEMP.	69.2	Deg F

Test room's data points from the data acquisition system

Data points	Description	Value	Units
ODA-TEMP	OUTDOOR AIR TEMPERATURE	90.01	Deg F
ODA-HUMD	OUTDOOR AIR HUMIDITY	61.1	% RH
OCC-CTRL	ROOM OCCUPIED CONTROL	OCC	
RM-TEMP	ROOM TEMPERATURE	70.5	Deg F
RM-HUMID	ROOM HUMIDITY	68.6	% RH
VAV-DAT	VAV DISCHARGE AIR TEMPERATURE	69.6	Deg F
VAV-FAN	VAV PARALLEL FAN	OFF	
FAN-AMPS	PARALLEL FAN AMP DRAW	0.0	AMPS
HTG-VALV	HEATING VALVE	100.0	% CLOSE
VAV-HTG1	VAV ELEC. HEAT STSGE1	OFF	
VAV-HTG2	VAV ELEC. HEAT STSGE2	OFF	
VAV-VEL	VAV VELOCITY SENSOR	0.021	IN WG
VAV-CFM	VAV DISCHARGE CFM	250.8	CFM
CFM-SPT	CALCULATED CFM SETPOINT	200.0	CFM
VAV-DMPR	VAV DAMPER CONTROL	0.0	% OPEN
RMCLGSPT	ROOM COOLING SETPOINT	71.0	Deg F
RMHTGSPT	ROOM HEATING SETPOINT	70.0	Deg F
OCC-MIN	OCCUPIED CFM MIN	200.0	CFM
OCC-MAX	OCCUPIED CFM MAX	360.0	CFM
UNOCCMIN	UNOCCUPIED CFM MIN	0.0	CFM
UNOCCMAX	UNOCCUPIED CFM MAX	200	CFM
HEAT-SEL	HEAT SELECT	ELEC	
K-FACTOR	VAV BOX K-FACTOR	0.65	
CLG-BTU	COOLING BTU	55.0	BTU/HR
ODA-TEMP	OUTDOOR AIR TEMPERATURE	89.8	Deg F
ODA-HUMD	OUTDOOR AIR HUMIDITY	59.1	% RH
OCC-CTRL	ROOM OCCUPIED CONTROL	OCC	
RM-TEMP	ROOM TEMPERATURE	72.2	Deg F

RM-HUMID	ROOM HUMIDITY	66.9	% RH
VAV-DAT	VAV DISCHARGE AIR TEMPERATURE	70.6	Deg F
HTG-VALV	HEATING VALVE	100.0	% CLOSE
VAV-HTG1	VAV ELEC. HEAT STSGE1	OFF	
VAV-HTG2	VAV ELEC. HEAT STSGE2	OFF	
VAV-VEL	VAV VELOCITY SENSOR	0.001	IN WG
VAV-CFM	VAV DISCHARGE CFM	36.3	CFM
CFM-SPT	CALCULATED CFM SETPOINT	200.0	CFM
VAV-DMPR	VAV DAMPER CONTROL	0.0	% OPEN
RMCLGSPT	ROOM COOLING SETPOINT	71.0	Deg F
RMHTGSPT	ROOM HEATING SETPOINT	70.0	Deg F
OCC-MIN	OCCUPIED CFM MIN	200.0	CFM
OCC-MAX	OCCUPIED CFM MAX	360.0	CFM
UNOCCMIN	UNOCCUPIED CFM MIN	0.0	CFM
UNOCCMAX	UNOCCUPIED CFM MAX	200	CFM
SYS-SEL	CONTROL SYSTEM SELECT	FAN COIL UNIT	
ECONOMIZ	ECONOMIZER CONTROL	OFF	
HEAT-SEL	HEAT SELECTION	HOT WATER	
FCU-LOW	FAN COIL UNIT LOW SPEED	OFF	
FCU-MED	FAN COIL UNIT MEDIUM SPEED	ON	
FCU-HIGH	FAN COIL UNIT HIGH SPEED	OFF	
FCU-DMPR	FAN COIL UNITMIXED AIR DAMPER	0.0	% OPEN
FCU-HTGV	FAN COIL UNIT HEATING VALVE	100	% CLOSE
FCU-CLGV	FAN COIL UNIT COOLING VALVE	100	% CLOSE
FCU-MIX	FAN COIL UNIT MIXED AIR TEMPERATURE	68.8	%Deg F
FCU-DIS	FAN COIL UNIT DISCHARGE AIR TEMP	70.3	%Deg F
FCU-AMPS	FAN COIL UNIT AMP DRAW	0.8	AMPS
K-FACTOR	VAV BOX K FACTOR	0.41	

SAMPLE DATA FOR AHU - A

DATE	TIME	chw-flow	clg-btu	clg-dat	clg-ewt	clg-lwt	clg-vlv	cwp-amps	cwp-sst	da-humid	da-temp
970501	854	29.0	0	70.2	70.2	69.9	100	390	1	23.5	71.9
970501	856	29.0	0	70.3	70.3	70.0	100	391	1	23.4	72.1
970501	858	29.1	0	70.5	70.5	70.2	100	390	1	23.2	72.4
970501	900	29.0	0	70.6	70.7	70.4	100	390	1	22.9	72.4
970501	902	29.1	0	70.9	70.7	70.5	100	390	1	22.7	72.2
970501	904	29.1	0	71.0	70.8	70.7	100	390	1	22.7	72.7
970501	906	29.1	0	71.2	71.0	70.7	100	390	1	23.0	72.8
970501	908	29.0	0	71.2	71.1	70.9	100	390	1	22.9	72.6
970501	910	29.1	0	71.5	71.3	71.0	100	390	1	23.0	72.6
970501	912	29.0	0	71.3	71.3	71.0	100	389	1	22.5	72.8
970501	914	29.0	0	71.3	71.4	71.0	100	390	1	22.5	73.0
970501	916	29.1	0	71.5	71.4	71.2	100	388	1	22.1	73.5
970501	918	29.1	0	71.5	71.6	71.3	100	388	1	21.9	73.4
970501	920	29.1	0	71.7	71.6	71.3	100	389	1	21.8	73.3
970501	922	29.1	0	71.9	71.7	71.5	100	389	1	21.5	73.7
970501	924	29.1	0	71.9	71.8	71.6	100	390	1	21.5	73.8
970501	926	29.0	0	72.0	72.1	71.7	100	389	1	21.4	73.9
970501	928	29.1	0	72.1	72.0	71.9	100	388	1	21.2	74.1
970501	930	29.0	0	72.2	72.2	71.9	100	388	1	21.3	74.0
970501	932	29.1	0	72.3	72.4	72.0	100	388	1	21.2	74.1
970501	934	29.1	0	72.5	72.4	72.1	100	388	1	21.3	74.3
970501	936	29.0	0	72.5	72.6	72.1	100	388	1	21.1	74.4
970501	938	29.0	0	72.6	72.6	72.3	100	388	1	21.1	74.5
970501	940	29.0	0	72.8	72.7	72.4	100	388	1	21.0	74.7
970501	942	29.0	0	72.8	72.9	72.5	100	387	1	21.0	74.8
970501	944	29.1	0	73.0	73.0	72.6	100	387	1	21.0	74.7
970501	946	29.0	0	73.2	73.1	72.7	100	387	1	21.0	75.0
970501	948	29.1	0	73.3	73.2	72.9	100	387	1	21.0	74.8
970501	950	29.1	0	73.4	73.4	73.1	100	388	1	20.8	75.1
970501	952	29.0	0	73.5	73.4	73.0	100	387	1	20.7	75.3
970501	954	29.1	0	73.5	73.5	73.2	100	388	1	20.3	75.3
970501	956	29.1	0	73.6	73.7	73.2	100	388	1	20.2	75.4
970501	958	29.1	0	73.6	73.5	73.2	100	388	1	20.3	75.5
970501	1000	29.1	0	73.8	73.6	73.4	100	388	1	19.9	75.6
970501	1002	29.1	0	73.8	73.7	73.4	100	388	1	19.6	75.7
970501	1004	29.1	0	73.8	73.7	73.4	100	387	1	19.5	75.7
970501	1006	29.1	0	73.8	73.9	73.4	100	388	1	19.3	75.7
970501	1008	29.1	0	74.0	73.8	73.6	100	388	1	19.5	75.9
970501	1010	29.1	0	74.1	74.0	73.7	100	387	1	19.3	75.7
970501	1012	29.1	0	74.1	74.2	73.8	100	387	1	19.1	76.0
970501	1014	29.1	0	74.4	74.2	73.9	100	387	1	19.2	76.0
970501	1016	29.1	0	74.3	74.2	74.0	100	387	1	18.8	76.0
970501	1018	29.1	0	74.4	74.2	74.0	100	387	1	18.7	75.9
970501	1020	29.1	0	74.5	74.5	74.1	100	387	1	18.6	76.4
970501	1022	29.1	0	74.5	74.5	74.1	100	388	1	18.6	76.3
970501	1024	29.0	0	74.7	74.5	74.2	100	387	1	18.4	76.3
970501	1026	29.1	0	74.6	74.5	74.2	100	387	1	18.2	76.7
970501	1028	29.1	0	74.7	74.7	74.2	100	387	1	18.2	76.6
970501	1030	29.0	0	74.7	74.8	74.4	100	386	1	18.2	75.6
970501	1032	29.1	0	74.8	74.8	74.3	100	387	1	18.1	76.7
970501	1034	29.0	0	74.8	74.8	74.4	100	387	1	18.1	76.5
970501	1036	29.1	0	74.8	75.0	74.4	100	387	1	18.2	76.2
970501	1038	29.1	0	74.9	75.0	74.5	100	387	1	18.0	76.9
970501	1040	29.1	0	75.0	74.9	74.5	100	386	1	17.8	76.7
970501	1042	29.1	0	75.0	74.9	74.6	100	387	1	17.9	76.7

DATE	TIME	duct-stc	htg-btu	htg-dat	htg-ewt	htg-lwt	htg-vlv	hw-flow	hwp-amps	hwp-sst	ma-temp
970501	854	1.4	0	72.3	105.6	101.2	100	0	15.793	0	69.5
970501	856	1.4	0	72.1	105.6	100.9	100	0	15.793	0	69.5
970501	858	1.4	0	71.9	105.3	100.8	100	0	15.793	0	69.6
970501	900	1.4	0	72.1	105.1	100.5	100	0	15.793	0	69.9
970501	902	1.4	0	72.2	104.9	100.1	100	0	15.793	0	69.9
970501	904	2.1	0	72.3	104.7	100.2	100	0	15.793	0	70.2
970501	906	1.9	0	72.5	104.4	100.0	100	0	15.793	0	69.6
970501	908	1.6	0	72.5	104.2	99.8	100	0	15.793	0	69.5
970501	910	1.5	0	72.4	104.0	99.5	100	0	15.793	0	69.3
970501	912	0.9	0	72.1	103.8	99.3	100	0	15.793	0	69.3
970501	914	0.9	0	72.2	103.6	99.0	100	0	15.793	0	69.9
970501	916	0.9	0	72.2	103.4	98.7	100	0	15.793	0	70.2
970501	918	0.9	0	72.3	103.2	98.6	100	0	15.793	0	70.4
970501	920	0.9	0	72.4	102.9	98.5	100	0	15.793	0	70.4
970501	922	0.9	0	72.5	102.9	98.4	100	0	15.793	0	70.7
970501	924	0.9	0	72.4	102.5	98.2	100	0	15.793	0	70.8
970501	926	0.8	0	72.4	102.4	97.9	100	0	15.793	0	70.9
970501	928	0.8	0	72.5	102.1	97.7	100	0	15.793	0	71.1
970501	930	0.8	0	72.7	102.0	97.6	100	0	15.793	0	71.2
970501	932	0.8	0	72.7	101.9	97.3	100	0	15.793	0	71.2
970501	934	0.8	0	72.8	101.5	97.1	100	0	15.793	0	71.4
970501	936	0.8	0	72.7	101.3	97.0	100	0	15.793	0	71.4
970501	938	0.8	0	72.8	101.3	96.8	100	0	15.793	0	71.6
970501	940	0.8	0	73.0	101.1	96.7	100	0	15.793	0	71.7
970501	942	0.8	0	72.9	100.8	96.5	100	0	15.793	0	71.9
970501	944	0.9	0	72.9	100.7	96.3	100	0	15.793	0	72.1
970501	946	1.3	0	73.1	100.4	96.1	100	0	15.793	0	72.2
970501	948	1.3	0	73.2	100.2	95.9	100	0	15.793	0	72.3
970501	950	1.3	0	73.3	100.0	95.7	100	0	15.793	0	72.3
970501	952	1.3	0	73.5	100.0	95.6	100	0	15.793	0	72.2

970501	954	1.3	0	73.5	99.7	95.4	100	0	15.793	0	72.2
970501	956	1.3	0	73.4	99.5	95.2	100	0	15.793	0	72.4
970501	958	1.3	0	73.5	99.3	95.1	100	0	15.793	0	72.3
970501	1000	1.3	0	73.4	99.0	94.8	100	0	15.793	0	72.4
970501	1002	1.3	0	73.5	99.0	94.7	100	0	15.793	0	72.3
970501	1004	1.3	0	73.8	98.7	94.5	100	0	15.793	0	72.2
970501	1006	1.3	0	73.6	98.4	94.3	100	0	15.793	0	72.3
970501	1008	1.3	0	73.8	98.4	94.1	100	0	15.793	0	73.0
970501	1010	1.3	0	74.3	98.2	94.0	100	0	15.793	0	72.8
970501	1012	1.3	0	74.4	97.9	93.8	100	0	15.793	0	72.9
970501	1014	1.4	0	74.5	97.9	93.6	100	0	15.793	0	73.3
970501	1016	1.4	0	74.5	97.6	93.5	100	0	15.793	0	73.2
970501	1018	1.3	0	74.4	97.3	93.2	100	0	15.793	0	72.8
970501	1020	1.4	0	74.1	97.3	93.1	100	0	15.793	0	73.2
970501	1022	1.4	0	74.2	97.1	93.0	100	0	15.793	0	73.3
970501	1024	1.4	0	74.3	97.1	92.8	100	0	15.208	0	73.2
970501	1026	1.4	0	74.3	96.8	92.7	100	0	15.793	0	73.2
970501	1028	1.3	0	74.3	96.8	92.3	100	0	15.793	0	73.3
970501	1030	1.3	0	74.1	96.5	92.2	100	0	15.793	0	73.2
970501	1032	1.4	0	74.1	96.5	92.1	100	0	15.793	0	73.3
970501	1034	1.4	0	74.5	96.2	92.0	100	0	15.793	0	73.4
970501	1036	1.4	0	74.5	96.2	91.7	100	0	15.793	0	73.5
970501	1038	1.4	0	74.4	96.0	91.6	100	0	15.793	0	73.5
970501	1040	1.4	0	74.5	95.9	91.4	100	0	15.793	0	73.5
970501	1042	1.4	0	74.6	95.8	91.3	100	0	15.793	0	73.5

DATE	TIME	min_oda	oa-flow	occupied	ra-flow	ra-humid	ra-temp	rf-amps	sa-flow	sf-amps	stc_spt
970501	854	15	528	1	0	22.9	51.3	805	2811	2420	1.4
970501	856	15	528	1	0	22.8	51.3	790	2849	2502	1.4
970501	858	15	521	1	0	22.7	51.3	809	2913	2615	1.4
970501	900	15	547	1	0	22.6	51.3	835	2936	2667	1.4
970501	902	15	512	1	0	22.5	51.3	836	2944	2671	1.4
970501	904	15	411	1	0	22.4	51.3	578	2132	1693	2.1
970501	906	15	408	1	0	22.4	51.3	519	2099	1518	1.8
970501	908	15	443	1	0	22.4	51.3	493	2131	1484	1.7
970501	910	15	453	1	0	22.2	51.2	501	2154	1453	1.5
970501	912	15	609	1	0	22.1	51.3	639	2818	2188	0.8
970501	914	15	590	1	0	22.2	51.3	858	3113	2852	0.9
970501	916	15	568	1	0	22.1	51.3	872	3172	2940	0.9
970501	918	15	582	1	0	22.0	51.3	874	3203	2962	0.9
970501	920	15	552	1	0	22.0	51.3	911	3219	2980	0.9
970501	922	15	540	1	0	21.8	51.3	910	3226	2968	0.9
970501	924	15	536	1	0	21.8	51.3	886	3239	2991	0.9
970501	926	15	521	1	0	21.7	51.3	902	3235	2975	0.8
970501	928	15	516	1	0	21.6	51.3	913	3230	2990	0.8
970501	930	15	518	1	0	21.6	51.3	895	3239	2994	0.8
970501	932	15	511	1	0	21.5	51.2	898	3242	3006	0.8
970501	934	15	528	1	0	21.5	51.3	907	3242	3003	0.8
970501	936	15	499	1	0	21.3	51.3	915	3242	2982	0.8
970501	938	15	502	1	0	21.3	51.3	898	3246	2996	0.8
970501	940	15	514	1	0	21.3	51.2	895	3236	2960	0.8
970501	942	15	493	1	0	21.3	51.3	890	3239	2987	0.8
970501	944	15	493	1	0	21.2	51.3	895	3223	2957	0.9
970501	946	15	458	1	0	21.4	51.3	842	2944	2674	1.3
970501	948	15	470	1	0	21.1	51.3	835	2925	2640	1.3
970501	950	15	462	1	0	21.1	51.3	821	2932	2651	1.3
970501	952	15	462	1	0	21.1	51.3	840	2926	2645	1.3
970501	954	15	474	1	0	21.1	51.2	818	2925	2643	1.3
970501	956	15	474	1	0	20.9	51.3	829	2923	2641	1.3
970501	958	15	484	1	0	20.9	51.3	827	2936	2630	1.3
970501	1000	15	481	1	0	20.8	51.3	860	2920	2640	1.3
970501	1002	15	493	1	0	20.6	51.3	833	2913	2610	1.3
970501	1004	15	483	1	0	20.4	51.3	830	2920	2616	1.3
970501	1006	15	495	1	0	20.3	51.3	820	2912	2596	1.3
970501	1008	15	452	1	0	20.2	51.3	1259	2964	2680	1.3
970501	1010	15	516	1	0	20.0	51.3	1249	2944	2646	1.3
970501	1012	15	509	1	0	20.0	51.3	1222	2950	2673	1.3
970501	1014	15	467	1	0	19.8	51.3	1255	2985	2723	1.4
970501	1016	15	474	1	0	19.8	51.3	1275	2992	2715	1.4
970501	1018	15	525	1	0	19.6	51.3	1235	2941	2654	1.3
970501	1020	15	477	1	0	19.5	51.2	1261	3001	2736	1.4
970501	1022	15	470	1	0	19.5	51.3	1254	3012	2727	1.4
970501	1024	15	497	1	0	19.4	51.3	1266	2996	2730	1.4
970501	1026	15	483	1	0	19.2	51.2	1286	3015	2736	1.4
970501	1028	15	499	1	0	19.2	51.2	1257	2996	2732	1.3
970501	1030	15	490	1	0	19.1	51.3	1253	2992	2727	1.4
970501	1032	15	506	1	0	19.0	51.3	1249	2993	2734	1.4
970501	1034	15	486	1	0	19.1	51.3	1257	2992	2735	1.3
970501	1036	15	478	1	0	18.9	51.3	1286	2985	2739	1.4
970501	1038	15	497	1	0	18.9	51.3	1249	3012	2732	1.4
970501	1040	15	502	1	0	18.7	51.3	1277	2988	2741	1.4
970501	1042	15	483	1	0	18.7	51.3	1250	3001	2739	1.4

SAMPLE DATA FOR TEST ROOM EAST - A

DATE	TIME	cfm-spt	fan-amps	heat-sel	htg-valv	occ-ctrl	occ-max	occ-min	rm-humid	rm-temp	rmclgspt
970501	854	615	0	0	100	1	1000	200	24	72.6	71
970501	856	633	0	0	100	1	1000	200	23	72.6	71
970501	858	667	0	0	100	1	1000	200	23	72.6	71
970501	900	667	0	0	100	1	1000	200	23	72.6	71
970501	902	693	0	0	100	1	1000	200	23	72.9	71
970501	904	693	0	0	100	1	1000	200	23	72.9	71
970501	906	708	0	0	100	1	1000	200	23	72.9	71
970501	908	727	0	0	100	1	1000	200	23	73.0	71
970501	910	749	0	0	100	1	1000	200	23	73.1	71
970501	912	779	0	0	100	1	1000	200	23	73.3	71
970501	914	824	0	0	100	1	1000	200	23	73.3	71
970501	916	843	0	0	100	1	1000	200	22	73.4	71
970501	918	896	0	0	100	1	1000	200	22	73.6	71
970501	920	915	0	0	100	1	1000	200	22	73.8	71
970501	922	941	0	0	100	1	1000	200	22	73.9	71
970501	924	971	0	0	100	1	1000	200	22	73.9	71
970501	926	1000	0	0	100	1	1000	200	22	73.9	71
970501	928	1000	0	0	100	1	1000	200	22	74.2	71
970501	930	1000	0	0	100	1	1000	200	22	74.3	71
970501	932	1000	0	0	100	1	1000	200	22	74.4	71
970501	934	1000	0	0	100	1	1000	200	21	74.6	71
970501	936	1000	0	0	100	1	1000	200	21	74.7	71
970501	938	1000	0	0	100	1	1000	200	21	74.8	71
970501	940	1000	0	0	100	1	1000	200	22	74.8	71
970501	942	1000	0	0	100	1	1000	200	22	74.9	71
970501	944	1000	0	0	100	1	1000	200	21	74.9	71
970501	946	1000	0	0	100	1	1000	200	21	75.1	71
970501	948	1000	0	0	100	1	1000	200	21	75.1	71
970501	950	1000	0	0	100	1	1000	200	21	75.3	71
970501	952	1000	0	0	100	1	1000	200	21	75.4	71
970501	954	1000	0	0	100	1	1000	200	21	75.4	71
970501	956	1000	0	0	100	1	1000	200	21	75.6	71
970501	958	1000	0	0	100	1	1000	200	21	75.6	71
970501	1000	1000	0	0	100	1	1000	200	20	75.8	71
970501	1002	1000	0	0	100	1	1000	200	20	75.9	71
970501	1004	1000	0	0	100	1	1000	200	20	75.9	71
970501	1006	1000	0	0	100	1	1000	200	20	76.0	71
970501	1008	1000	0	0	100	1	1000	200	20	76.1	71
970501	1010	1000	0	0	100	1	1000	200	20	76.3	71
970501	1012	1000	0	0	100	1	1000	200	20	76.3	71
970501	1014	1000	0	0	100	1	1000	200	19	76.4	71
970501	1016	1000	0	0	100	1	1000	200	19	76.6	71
970501	1018	1000	0	0	100	1	1000	200	19	76.6	71
970501	1020	1000	0	0	100	1	1000	200	19	76.7	71
970501	1022	1000	0	0	100	1	1000	200	19	76.8	71
970501	1024	1000	0	0	100	1	1000	200	19	76.9	71
970501	1026	1000	0	0	100	1	1000	200	19	77.0	71
970501	1028	1000	0	0	100	1	1000	200	18	77.1	71
970501	1030	1000	0	0	100	1	1000	200	18	77.1	71
970501	1032	1000	0	0	100	1	1000	200	18	77.1	71
970501	1034	1000	0	0	100	1	1000	200	18	77.3	71
970501	1036	1000	0	0	100	1	1000	200	18	77.3	71
970501	1038	1000	0	0	100	1	1000	200	18	77.5	71
970501	1040	1000	0	0	100	1	1000	200	18	77.5	71
970501	1042	1000	0	0	100	1	1000	200	18	77.6	71

DATE	TIME	rmhtgspt	rtd-plnt	unoccmax	unoccmin	vav-cfm	vav-dat	vav-fan	vav-htg1	vav-htg2
970501	854	70	72.3	200	0	612	72.9	0	0	0
970501	856	70	72.3	200	0	627	73.1	0	0	0
970501	858	70	72.5	200	0	659	73.4	0	0	0
970501	900	70	72.5	200	0	646	73.4	0	0	0
970501	902	70	72.5	200	0	663	73.6	0	0	0
970501	904	70	72.6	200	0	691	73.8	0	0	0
970501	906	70	72.6	200	0	702	73.8	0	0	0
970501	908	70	72.6	200	0	696	73.8	0	0	0
970501	910	70	72.5	200	0	710	73.8	0	0	0
970501	912	70	72.5	200	0	675	74.0	0	0	0
970501	914	70	72.6	200	0	732	74.3	0	0	0
970501	916	70	72.7	200	0	807	74.6	0	0	0
970501	918	70	72.8	200	0	841	74.8	0	0	0
970501	920	70	72.8	200	0	849	74.8	0	0	0
970501	922	70	72.8	200	0	849	74.9	0	0	0
970501	924	70	72.8	200	0	848	74.9	0	0	0
970501	926	70	73.1	200	0	843	75.2	0	0	0
970501	928	70	73.1	200	0	839	75.3	0	0	0
970501	930	70	73.2	200	0	840	75.3	0	0	0
970501	932	70	73.2	200	0	841	75.4	0	0	0
970501	934	70	73.3	200	0	840	75.6	0	0	0
970501	936	70	73.3	200	0	840	75.6	0	0	0
970501	938	70	73.4	200	0	836	75.9	0	0	0
970501	940	70	73.4	200	0	835	75.9	0	0	0
970501	942	70	73.4	200	0	837	76.1	0	0	0
970501	944	70	73.6	200	0	838	76.1	0	0	0
970501	946	70	73.7	200	0	943	76.3	0	0	0
970501	948	70	73.7	200	0	964	76.3	0	0	0
970501	950	70	73.7	200	0	963	76.4	0	0	0
970501	952	70	73.7	200	0	964	76.5	0	0	0

970501	954	70	73.9	200	0	965	76.5	0	0	0
970501	956	70	73.9	200	0	963	76.6	0	0	0
970501	958	70	74.0	200	0	962	76.8	0	0	0
970501	1000	70	73.9	200	0	962	76.6	0	0	0
970501	1002	70	74.0	200	0	962	77.0	0	0	0
970501	1004	70	74.0	200	0	959	77.0	0	0	0
970501	1006	70	74.0	200	0	961	76.9	0	0	0
970501	1008	70	74.3	200	0	967	77.0	0	0	0
970501	1010	70	74.3	200	0	969	77.1	0	0	0
970501	1012	70	74.3	200	0	971	77.3	0	0	0
970501	1014	70	74.3	200	0	973	77.3	0	0	0
970501	1016	70	74.4	200	0	975	77.3	0	0	0
970501	1018	70	74.5	200	0	972	77.5	0	0	0
970501	1020	70	74.5	200	0	977	77.5	0	0	0
970501	1022	70	74.5	200	0	979	77.6	0	0	0
970501	1024	70	74.5	200	0	977	77.6	0	0	0
970501	1026	70	74.8	200	0	976	77.6	0	0	0
970501	1028	70	74.8	200	0	972	77.6	0	0	0
970501	1030	70	74.8	200	0	975	77.8	0	0	0
970501	1032	70	74.9	200	0	977	77.8	0	0	0
970501	1034	70	74.9	200	0	976	77.9	0	0	0
970501	1036	70	75.1	200	0	978	77.8	0	0	0
970501	1038	70	75.0	200	0	977	77.9	0	0	0
970501	1040	70	75.1	200	0	976	78.1	0	0	0
970501	1042	70	75.2	200	0	977	78.1	0	0	0

APPENDIX B DOE-2 PROGRAM INPUT DATA

```
$*****************************************************************************
$ THIS IS THE INPUT FILE FOR THE TEST OF DAYLIGHTINGS FROM 990328 TO 990331 *
$*****************************************************************************
$Test Period: 990328-990331
$1. System Type: VAVRH (A)WITH DAYLIGHT,VAVRH(B) WITHOUT DAYLIGHT
$2. OA control: Fixed(A:50, B:30CFM)
$3. Thermostat control: fixed; heating (72F), cooling (73F)
$4. Supply air temp control: fixed (58F)
$5.A &B-system VAV set point: OCC [perimeter (max900,min450), inter
(max550,min270)],
$7. Internal loads: light scheduled, (1,6)(0) (7,20)(1) (21,24)(0)
$8. Fan control: fixed (on)
$9. Heat recovery: off
$10. Terminal heat source: electric (2 stages)
$system-a: no daylight, system-b: daylight control

INPUT FOR LOADS
      INPUT-UNITS = ENGLISH     OUTPUT-UNITS = ENGLISH ..
TITLE   LINE-1 *ENTIRE SPACE OF ERS*
        LINE-2 *TEST PERIOD:990328-990331*  ..
ABORT                  IF ERRORS ..

DIAGNOSTIC             WARNINGS
                         CAUTIONS ..
RUN-PERIOD   MAR 25 1999 THRU APR 1 1999 ..
BUILDING-LOCATION      LATITUDE=41.71  LONGITUDE=93.61
                       ALTITUDE=0.0  TIME-ZONE=6
                      $ ALTITUDE=938.0  TIME-ZONE=6
                       AZIMUTH=0.0     HOLIDAY=NO
                         DAYLIGHT-SAVINGS=NO  ..
$BUILDING-SHADE

LOADS-REPORT      $      VERIFICATION=(ALL-VERIFICATION)
                         VERIFICATION=(LV-A,LV-B,LV-D,LV-E,LV-F,LV-H)
                    $    SUMMARY=(ALL-SUMMARY)
                         SUMMARY=(LS-A,LS-D)
                       REPORT-FREQUENCY=HOURLY
                         HOURLY-DATA-SAVE=FORMATTED  ..
$**** LAYER DEFINITIONS ************************************************
LAY60     =LAYERS =MAT=(RG01,AR02, AR02,IN47,AR02,AR02,
                      CC02,AL23,CC02) I-F-R=.68 ..
LAY70     =LAYERS =MAT=(CC03,IN43,IN42) I-F-R=.68 ..
LAY71     =LAYERS =MAT=(CC04,IN43,AL21,IN42) I-F-R=.68 ..
LAY-P1     =LAYERS $ interior walls
                   MATERIAL=(GP02,IN13,GP02) ..


$**** CONSTRUCTION TYPES OF ROOF, WALL, CEILING, PARTITION & GROUND FLOOR
ROOFS        =CONSTRUCTION  LAYERS=LAY60  ABSORPTANCE=0.29 ..
WALL-BOTTOM =CONSTRUCTION  LAYERS=LAY70 ABSORPTANCE=0.675 ..
WALL-TOP     =CONSTRUCTION  LAYERS=LAY71 ABSORPTANCE=0.675 ..
WL-INT     =CONSTRUCTION LAYERS=LAY-P1 .. $ FOR DAYLIGHTS CALCULATION
CEIL         =CONSTRUCTION  U-VALUE=0.317 ..    $ CEILING $
FLOORG       =CONSTRUCTION  U-VALUE=0.609 ..   $ GROUND FLOOR $
WINDOWS      =GLASS-TYPE SHADING-COEF=0.85 GLASS-CONDUCTANCE=0.59
                 VIS-TRANS=0.90  PANES=2 ..

$***** INTERNAL LOAD SCHEDULE ****************************************
PPLSCH =SCHEDULE  THRU DEC 31 (ALL) (1,24) (0) ..
LGTSCH =SCHEDULE  THRU DEC 31 (ALL) (1,6)(0) (7,20)(1) (21,24)(0) ..
EQPSCH =SCHEDULE  THRU DEC 31 (ALL) (1,24) (0) ..
```

```
$**** SET DEFAULT VALUES***************************************************
  SET-DEFAULT FOR WINDOW HEIGHT=5  ..
  SET-DEFAULT FOR ROOF CONSTRUCTION=ROOFS ..
  SET-DEFAULT FOR UNDERGROUND-FLOOR CONSTRUCTION=FLOORG ..
  SET-DEFAULT FOR SPACE AREA=275 ..

$**** SPACE CONDTIONS OF TESTROOMS & PLENUMS*****************************
TEST-ROOM  =SPACE-CONDITIONS
                   ZONE-TYPE                =CONDITIONED
                   PEOPLE-SCHEDULE          =PPLSCH
                   AREA/PERSON              =100
                   PEOPLE-HG-LAT            =205
                   PEOPLE-HG-SENS           =245
                   LIGHTING-SCHEDULE        =LGTSCH
                   LIGHTING-TYPE            =REC-FLUOR-NV
                   LIGHT-TO-SPACE           =0.8
               $    LIGHTING-W/SQFT          =2.5: defined in each room
                   EQUIP-SCHEDULE           =EQPSCH
                   EQUIPMENT-KW             =2
                   FLOOR-WEIGHT             =20 ..
PLENUMS    = SPACE-CONDITIONS
                   ZONE-TYPE                =PLENUM ..
$*****SPACE DESCRIPTION OF THE TEST ROOM A *****************************
$**** DESCRIPTION OF PLENUMS IN TEST ROOM A*****************************
P-EAST-A =SPACE
        VOLUME=1512.5  FLOOR-WEIGHT=5
        SPACE-CONDITIONS=PLENUMS ..
  PWALL-EAST-A =EXTERIOR-WALL   X=68.3 Y=40.1 Z=8.5
        HEIGHT=5.5 WIDTH=15.07  AZIMUTH=  90 CONSTRUCTION=WALL-TOP ..
  ROOF-EAST-A =ROOF
        HEIGHT=15.07 WIDTH=17.9 Z=14 AZIMUTH=180 TILT=0 GND-REFLECTANCE=0 ..

P-SOUTH-A =SPACE
         VOLUME=1512.5  FLOOR-WEIGHT=5
         SPACE-CONDITIONS=PLENUMS ..
  PWALL-SOUTH-A =EXTERIOR-WALL  X=18.7 Y=0  Z=8.5
         HEIGHT=5.5 WIDTH=15.3 AZIMUTH=  180 CONSTRUCTION=WALL-TOP ..
  ROOF-SOUTH-A  =ROOF
         HEIGHT=19.1 WIDTH=15.3 Z=14 AZIMUTH=180 TILT=0 GND-REFLECTANCE=0 ..

P-WEST-A  =SPACE
         VOLUME=1512.5  FLOOR-WEIGHT=5
         SPACE-CONDITIONS=PLENUMS ..
  PWALL-WEST-A =EXTERIOR-WALL  X=0 Y=55.1  Z=8.5
         HEIGHT=5.5 WIDTH=15.1 AZIMUTH=  270 CONSTRUCTION=WALL-TOP ..
  ROOF-WEST-A =ROOF
         HEIGHT=15.1 WIDTH=18.4 Z=14 AZIMUTH=180 TILT=0 GND-REFLECTANCE=0 ..

P-INTERIOR-A =SPACE
         VOLUME=1512.5  FLOOR-WEIGHT=5
         SPACE-CONDITIONS=PLENUMS ..
  ROOF-INTERIOR-A =ROOF HEIGHT=15.3  WIDTH=17.8  Z=14 AZIMUTH=180  TILT=0
         GND-REFLECTANCE=0 ..

$**** DESCRIPTION OF TEST ROOM A****************************************
EASTROOM-A =SPACE SPACE-CONDITIONS=TEST-ROOM VOLUME=2337.5 L-KW=0.487 ..
  RWALL-EAST-A =EXTERIOR-WALL
          HEIGHT=8.5 WIDTH=15.1  X=68.3  Y=40.1  Z=0
          AZIMUTH=90  CONSTRUCTION=WALL-BOTTOM ..
  WINDOW-EAST-A=WINDOW
```

```
          WIDTH=14.8  GLASS-TYPE=WINDOWS ..
  CEIL-EAST-A =INTERIOR-WALL
          AREA=275  NEXT-TO P-EAST-A CONSTRUCTION=CEIL ..
  FLOOR-EAST-A =UNDERGROUND-FLOOR AREA=15.1 ..

SOUTHROOM-A =SPACE
          SPACE-CONDITIONS=TEST-ROOM VOLUME=2337.5 L-KW=0.497 ..
   RWALL-SOUTH-A=EXTERIOR-WALL
          HEIGHT=8.5 WIDTH=15.27 X=18.7  Y=0  Z=0
          AZIMUTH= 180  CONSTRUCTION=WALL-BOTTOM ..
   WINDOW-SOUTH-A=WINDOW
          WIDTH=14.8  GLASS-TYPE=WINDOWS ..
   CEIL-SOUTH-A =INTERIOR-WALL
          AREA=275  NEXT-TO P-SOUTH-A CONSTRUCTION=CEIL ..
   FLOOR-SOUTH-A=UNDERGROUND-FLOOR AREA=15.1 ..

WESTROOM-A =SPACE
          SPACE-CONDITIONS=TEST-ROOM VOLUME=2337.5 L-KW=0.449 ..
  RWALL-WEST-A =EXTERIOR-WALL
          HEIGHT=8.5 WIDTH=15.1 X=0  Y=55.1  Z=0
          AZIMUTH=270  CONSTRUCTION=WALL-BOTTOM ..
  WINDOW-WEST-A=WINDOW
          WIDTH=14.8  GLASS-TYPE=WINDOWS ..
  CEIL-WEST-A=INTERIOR-WALL
          AREA=275  NEXT-TO P-WEST-A CONSTRUCTION=CEIL ..
  FLOOR-WEST-A=UNDERGROUND-FLOOR AREA=15.1 ..

INTERIOR-ROOM-A =SPACE
         SPACE-CONDITIONS=TEST-ROOM VOLUME=2337.5 L-KW=0.305 ..
  CEIL-INTERIOR-A =INTERIOR-WALL
         AREA=275  NEXT-TO P-INTERIOR-A CONSTRUCTION=CEIL ..
  FLOOR-INTERIOR-A=UNDERGROUND-FLOOR AREA=1 ..


$*****SPACE DESCRIPTION OF THE TEST ROOM B *****************************
$**** DESCRIPTION OF PLENUMS IN TEST ROOM B*****************************
P-EAST-B =SPACE
        VOLUME=1512.5  FLOOR-WEIGHT=5
        SPACE-CONDITIONS=PLENUMS ..
  PWALL-EAST-B =EXTERIOR-WALL   X=68.3 Y=28.1  Z=8.5
        HEIGHT=5.5 WIDTH=15.07  AZIMUTH=  90 CONSTRUCTION=WALL-TOP ..
  ROOF-EAST-B =ROOF
        HEIGHT=15.07 WIDTH=17.9 Z=14 AZIMUTH=180 TILT=0 GND-REFLECTANCE=0 ..

P-SOUTH-B =SPACE
         VOLUME=1512.5  FLOOR-WEIGHT=5
         SPACE-CONDITIONS=PLENUMS ..
  PWALL-SOUTH-B =EXTERIOR-WALL  X=33.7 Y=0  Z=8.5
         HEIGHT=5.5 WIDTH=15.3 AZIMUTH=  180 CONSTRUCTION=WALL-TOP ..
  ROOF-SOUTH-B  =ROOF
         HEIGHT=19.1 WIDTH=15.3 Z=14 AZIMUTH=180 TILT=0 GND-REFLECTANCE=0 ..

P-WEST-B  =SPACE
         VOLUME=1512.5  FLOOR-WEIGHT=5
         SPACE-CONDITIONS=PLENUMS ..
  PWALL-WEST-B =EXTERIOR-WALL  X=0 Y=40.1 Z=8.5
         HEIGHT=5.5 WIDTH=15.1 AZIMUTH=  270 CONSTRUCTION=WALL-TOP ..
  ROOF-WEST-B =ROOF
         HEIGHT=15.1 WIDTH=18.4 Z=14 AZIMUTH=180 TILT=0 GND-REFLECTANCE=0 ..
```

```
P-INTERIOR-B =SPACE
          VOLUME=1512.5  FLOOR-WEIGHT=5
          SPACE-CONDITIONS=PLENUMS ..
  ROOF-INTERIOR-B =ROOF HEIGHT=15.3  WIDTH=17.8  Z=14 AZIMUTH=180  TILT=0
          GND-REFLECTANCE=0 ..

$**** DESCRIPTION OF TEST ROOM A*****************************************
EASTROOM-B =SPACE
           SPACE-CONDITIONS=TEST-ROOM  DAYLIGHTING=YES
           LIGHT-REF-POINT1 (7.3,10.4,2.5)  LIGHT-SET-POINT1=76
           LIGHT-CTRL-TYPE1=CONTINUOUS MIN-POWER-FRAC=0.3018 L-KW=0.487
           MAX-GLARE=100 VOLUME=2337.5 ..
  RWALL-EAST-B =EXTERIOR-WALL
           HEIGHT=8.5 WIDTH=15.1  X=68.3  Y=28.1  Z=0
           AZIMUTH=90  CONSTRUCTION=WALL-BOTTOM ..
  WINDOW-EAST-B=WINDOW
           WIDTH=14.8  GLASS-TYPE=WINDOWS ..
  INT1-EAST-B=INTERIOR-WALL AREA=154 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
  INT2-EAST-B=INTERIOR-WALL AREA=154 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
  INT3-EAST-B=INTERIOR-WALL AREA=128 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
  CEIL-EAST-B =INTERIOR-WALL TILT=0
           AREA=275  NEXT-TO P-EAST-B CONSTRUCTION=CEIL ..
  FLOOR-EAST-B =UNDERGROUND-FLOOR AREA=15.1 ..

SOUTHROOM-B =SPACE
           SPACE-CONDITIONS=TEST-ROOM  DAYLIGHTING=YES
           LIGHT-REF-POINT1 (7.3,10.4,2.5)  LIGHT-SET-POINT1=76
           LIGHT-CTRL-TYPE1=CONTINUOUS MIN-POWER-FRAC=0.3179 L-KW=0.497
           MAX-GLARE=100 VOLUME=2337.5 ..
   RWALL-SOUTH-B=EXTERIOR-WALL
           HEIGHT=8.5 WIDTH=15.27 X=33.7  Y=0  Z=0
           AZIMUTH= 180  CONSTRUCTION=WALL-BOTTOM ..
   WINDOW-SOUTH-B=WINDOW
           WIDTH=14.8  GLASS-TYPE=WINDOWS ..
   INT1-SOUTH-B=INTERIOR-WALL AREA=154 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
   INT2-SOUTH-B=INTERIOR-WALL AREA=154 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
   INT3-SOUTH-B=INTERIOR-WALL AREA=128 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
   CEIL-SOUTH-B =INTERIOR-WALL TILT=0
           AREA=275  NEXT-TO P-SOUTH-B CONSTRUCTION=CEIL ..
   FLOOR-SOUTH-B=UNDERGROUND-FLOOR AREA=15.1 ..

WESTROOM-B =SPACE
           SPACE-CONDITIONS=TEST-ROOM  DAYLIGHTING=YES
           LIGHT-REF-POINT1 (7.3,10.4,2.5)  LIGHT-SET-POINT1=76
           LIGHT-CTRL-TYPE1=CONTINUOUS MIN-POWER-FRAC=0.2650 L-KW=0.449
           MAX-GLARE=100 VOLUME=2337.5 ..
  RWALL-WEST-B =EXTERIOR-WALL
           HEIGHT=8.5 WIDTH=15.1 X=0  Y=40.1  Z=0
           AZIMUTH=270  CONSTRUCTION=WALL-BOTTOM ..
  WINDOW-WEST-B=WINDOW
           WIDTH=14.8  GLASS-TYPE=WINDOWS ..
  INT1-WEST-B=INTERIOR-WALL AREA=154 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
  INT2-WEST-B=INTERIOR-WALL AREA=154 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
  INT3-WEST-B=INTERIOR-WALL AREA=128 CONS=WL-INT I-W-TYPE=ADIABATIC  ..
  CEIL-WEST-B=INTERIOR-WALL TILT=0
           AREA=275  NEXT-TO P-WEST-B CONSTRUCTION=CEIL ..
  FLOOR-WEST-B=UNDERGROUND-FLOOR AREA=15.1 ..

INTERIOR-ROOM-B =SPACE SPACE-CONDITIONS=TEST-ROOM VOLUME=2337.5 L-KW=0.305 ..
  CEIL-INTERIOR-B =INTERIOR-WALL TILT=0
         AREA=275  NEXT-TO P-INTERIOR-B CONSTRUCTION=CEIL ..
```

```
  FLOOR-INTERIOR-B=UNDERGROUND-FLOOR AREA=1 ..

$****HOURLY REPORT SCHEDULE*********************************************
REPORT1-SCHED=SCHEDULE THRU MAR 27 (ALL) (1,24) (0)
                       THRU MAR 31 (ALL)  (1,24) (1)
                       THRU DEC 31 (ALL) (1,24) (0) ..

RB1=R-B V-T=EASTROOM-B  V-L=(49) ..
RB2=R-B V-T=SOUTHROOM-B V-L=(49) ..
RB3=R-B V-T=WESTROOM-B  V-L=(49) ..
RB4=R-B V-T=INTERIOR-ROOM-B  V-L=(49) ..
RB5=R-B V-T=EASTROOM-B  V-L=(57) ..
RB6=R-B V-T=SOUTHROOM-B V-L=(57) ..
RB7=R-B V-T=WESTROOM-B  V-L=(57) ..
RB8=R-B V-T=INTERIOR-ROOM-B V-L=(57) ..

IEA-INPUT-REPORT =HOURLY-REPORT
          REPORT-SCHEDULE=REPORT1-SCHED
          R-B=(RB1,RB2,RB3,RB4,RB5,RB6,RB7,RB8)
          OPTION=PRINT ..

END ..
COMPUTE LOADS ..



INPUT SYSTEMS ..
  SYSTEMS-REPORT  VERIFICATION=(SV-A)
                  SUMMARY =(SS-F,SS-G)
          REPORT-FREQUENCY=HOURLY
          HOURLY-DATA-SAVE=FORMATTED  ..

$**** ZONE CONTROL SCHEDULES *******************************************
HEATTEMPSCH   =SCHEDULE  THRU DEC 31 (ALL) (1,24) (72) ..
COOLTEMPSCH   =SCHEDULE  THRU DEC 31 (ALL) (1,24) (73) ..
$*****ZONE CONTROL *****************************************************
ZCONTROL  = ZONE-CONTROL
                 DESIGN-HEAT-T=72
                 HEAT-TEMP-SCH=HEATTEMPSCH
                 DESIGN-COOL-T=73
                 COOL-TEMP-SCH=COOLTEMPSCH
                 THERMOSTAT-TYPE=PROPORTIONAL
                 THROTTLING-RANGE=2 ..

$*****ZONE AIR**********************************************************
ZAIR-A        =ZONE-AIR
                   ASSIGNED-CFM =900  ..
ZAIR-INTER-A =ZONE-AIR
                   ASSIGNED-CFM =550  ..

ZAIR-B        =ZONE-AIR
                   ASSIGNED-CFM =900  ..
ZAIR-INTER-B =ZONE-AIR
                   ASSIGNED-CFM =550  ..

$****ZONE FANS**********************************************************

$****OPERATION OF ZONE-A************************************************
EASTROOM-A      =ZONE
                 ZONE-CONTROL=ZCONTROL
                 ZONE-TYPE=CONDITIONED
```

```
                 ZONE-AIR=ZAIR-A
                 MIN-CFM-RATIO=0.5
                 TERMINAL-TYPE=SVAV  ..

SOUTHROOM-A     =ZONE LIKE EASTROOM-A ..

WESTROOM-A      =ZONE LIKE EASTROOM-A ..

INTERIOR-ROOM-A =ZONE LIKE EASTROOM-A
                 ZONE-AIR=ZAIR-INTER-A
                 MIN-CFM-RATIO=0.49 ..

P-EAST-A        =ZONE
                 ZONE-TYPE=PLENUM ..
P-SOUTH-A       =ZONE LIKE P-EAST-A ..
P-WEST-A        =ZONE LIKE P-EAST-A ..
P-INTERIOR-A    =ZONE LIKE P-EAST-A ..

$**** OPERATION OF ZONE-B*********************************************
EASTROOM-B      =ZONE
                 ZONE-CONTROL=ZCONTROL
                 ZONE-TYPE=CONDITIONED
                 ZONE-AIR=ZAIR-B
                 MIN-CFM-RATIO=0.5  ..

SOUTHROOM-B     =ZONE LIKE EASTROOM-B ..

WESTROOM-B      =ZONE LIKE EASTROOM-B  ..

INTERIOR-ROOM-B =ZONE LIKE EASTROOM-B
                 ZONE-AIR=ZAIR-INTER-B
                 MIN-CFM-RATIO=0.49  ..

P-EAST-B        =ZONE
                 ZONE-TYPE=PLENUM ..
P-SOUTH-B       =ZONE LIKE P-EAST-B ..
P-WEST-B        =ZONE LIKE P-EAST-B ..
P-INTERIOR-B    =ZONE LIKE P-EAST-B ..

$**** SYSTEM CONTROL SCHEDULES ******************************************
HEATINGSCH  =SCHEDULE  THRU DEC 31 (ALL) (1,24) (1) ..
COOLINGSCH  =SCHEDULE  THRU DEC 31 (ALL) (1,24) (1) ..
SYSFANSCH  =SCHEDULE   THRU DEC 31 (ALL) (1,24) (1) ..

$**** SYSTEM CONTROL ****************************************************
SCONTROL-A =SYSTEM-CONTROL
                 MAX-SUPPLY-T=81
                 MIN-SUPPLY-T=58
                 HEATING-SCHEDULE=HEATINGSCH
                 COOLING-SCHEDULE=COOLINGSCH
                 COOL-CONTROL=CONSTANT
                 COOL-SET-T=58 ..
SCONTROL-B =SYSTEM-CONTROL
                 MAX-SUPPLY-T=81
                 MIN-SUPPLY-T=58
                 HEATING-SCHEDULE=HEATINGSCH
                 COOLING-SCHEDULE=COOLINGSCH
                 COOL-CONTROL=CONSTANT
                 COOL-SET-T=58 ..

$**** SYSTEM AIR********************************************************
```

```
SAIR-A =SYSTEM-AIR
                 SUPPLY-CFM=3250
                 MIN-OUTSIDE-AIR=0.0153
                 DUCT-AIR-LOSS=0
                 DUCT-DELTA-T=0
                 OA-CONTROL=FIXED  ..
SAIR-B =SYSTEM-AIR
                 SUPPLY-CFM=3250
                 MIN-OUTSIDE-AIR=0.00923
                 DUCT-AIR-LOSS=0
                 DUCT-DELTA-T=0
                 OA-CONTROL=FIXED  ..

$**** SYSTEM FANS*****************************************************
SFAN-A     =SYSTEM-FANS
                 FAN-SCHEDULE=SYSFANSCH
                 SUPPLY-DELTA-T=3.37
                 SUPPLY-KW=0.00109
                 RETURN-DELTA-T=0.2
                 RETURN-KW=0.00109
                 FAN-CONTROL=SPEED ..

SFAN-B     =SYSTEM-FANS LIKE SFAN-A ..

$**** SYSTEM TERMINAL*************************************************

$**** SYSTEM OPERATION************************************************
AHU-A           =SYSTEM
                 SYSTEM-TYPE=VAVS
                 SYSTEM-CONTROL=SCONTROL-A
                 SYSTEM-AIR=SAIR-A
                 SYSTEM-FANS=SFAN-A
                 ZONE-HEAT-SOURCE=ELECTRIC
                 SIZING-OPTION=COINCIDENT
                 REHEAT-DELTA-T=55
                 RETURN-AIR-PATH=DUCT
                 ZONE-NAMES=(EASTROOM-A,SOUTHROOM-A,WESTROOM-A,
                             INTERIOR-ROOM-A,P-EAST-A,P-SOUTH-A,
                             P-WEST-A,P-INTERIOR-A) ..
AHU-B           =SYSTEM
                 SYSTEM-TYPE=RHFS
                 SYSTEM-CONTROL=SCONTROL-B
                 SYSTEM-AIR=SAIR-B
                 SYSTEM-FANS=SFAN-B
                 ZONE-HEAT-SOURCE=ELECTRIC
                 SIZING-OPTION=COINCIDENT
                 REHEAT-DELTA-T=55
                 RETURN-AIR-PATH=DUCT
                             ZONE-NAMES=(EASTROOM-B,SOUTHROOM-B,WESTROOM-B,
                             INTERIOR-ROOM-B,P-EAST-B,P-SOUTH-B,
                             P-WEST-B,P-INTERIOR-B) ..

$****HOURLY REPORT SCHEDULE*******************************************
REPORT2-SCHED=SCHEDULE THRU MAR 27 (ALL) (1,24) (0)
                         THRU MAR 31 (ALL) (1,24) (1)
                       THRU DEC 31 (ALL) (1,24) (0) ..

RB1=R-B  V-T=EASTROOM-B  V-L=(6) ..
RB2=R-B  V-T=SOUTHROOM-B  V-L=(6) ..
RB3=R-B  V-T=WESTROOM-B  V-L=(6) ..
RB4=R-B  V-T=INTERIOR-ROOM-B V-L=(6) ..
```

```
RB5=R-B  V-T=EASTROOM-B  V-L=(32) ..
RB6=R-B  V-T=SOUTHROOM-B  V-L=(32) ..
RB7=R-B  V-T=WESTROOM-B  V-L=(32) ..
RB8=R-B  V-T=INTERIOR-ROOM-B V-L=(32) ..

RB9=R-B  V-T=EASTROOM-B  V-L=(14) ..
RB10=R-B  V-T=SOUTHROOM-B  V-L=(14) ..
RB11=R-B  V-T=WESTROOM-B  V-L=(14) ..
RB12=R-B  V-T=INTERIOR-ROOM-B V-L=(14) ..

RBS_B1=REPORT-BLOCK
            VARIABLE-TYPE=AHU-B
            VARIABLE-LIST=(6,7) ..
RBS_B2=REPORT-BLOCK
            VARIABLE-TYPE=AHU-B
            VARIABLE-LIST=(17,39) ..

REPORT_B1 =HOURLY-REPORT
            REPORT-SCHEDULE=REPORT2-SCHED
            REPORT-BLOCK=(RBS_B1,RB5,RB6,RB7,RB8,RBS_B2)
            OPTION=PRINT ..

END ..
COMPUTE SYSTEMS  ..
STOP ..
```

APPENDIX C HAP PROGRAM INPUT DATA

%[SAMPLE INPUT FILE FOR HAP PROGRAM]
% SYSTEM NAME: CAVRH(2)

```
                              AIR SYSTEM INPUT DATA
Name: CAVRH(2)-990223                                                  03-15-99
Type: CONSTANT VOLUME - CAV Reheat                                    HAP v3.22
Prepared by: ISU                                                         Page 1
*******************************************************************************

1. SYSTEM NAME AND TYPE
--------------------------------------------------------------------------------
  Name............: CAVRH(2)-990223
  Type............: CONSTANT VOLUME - CAV Reheat
  Number of Zones.:  4
===============================================================================

2. SYSTEM DESCRIPTION
--------------------------------------------------------------------------------
COOLING SYSTEM DATA
 Supply Air...................:          58.0 F
 Coil Bypass Factor...........:         0.100
 Supply Air Reset.............:       Not Used
OUTDOOR VENTILATION DATA
 Type of Control..............:       Constant Airflow Rate
 Design Ventilation Airflow....:        100.0 CFM
 Dampers Open During Unocc Per.:            Y
SUPPLY DUCT DATA
 Duct Heat Gain...............:             2 %
 Duct Leakage Rate............:             0 %
RETURN PLENUM DATA
 Is a Return Plenum Used.......?            Y
 % Roof Heat Gain to Plenum....:           70 %
 % Wall Heat Gain to Plenum....:            0 %
 % Lighting Heat Gain to Plenum:           20 %
SUPPLY FAN DATA
 Fan Type.....................:       Forward Curved
 Configuration................:       Draw-Thru
 Fan Total Static.............:          1.40 in.wg.
 Fan Efficiency...............:            54 %
RETURN FAN DATA
 Fan Type.....................:       Forward Curved
 Fan Total Static.............:          1.00 in.wg.
 Fan Efficiency...............:            54 %
OUTDOOR AIR ECONOMIZER
 Outdoor Economizer Type.......:      Integrated Dry-Bulb
 OA Upper Cutoff Temp..........:          65.0 F
 OA Lower Cutoff Temp..........:          15.0 F
PREHEAT COIL
 Preheat Coil Used.............?            N
PRECOOL COIL
 Precool Coil Used.............?            N
HUMIDIFICATION
 Humidification System Used....?            N
DEHUMIDIFICATION
 Dehumidification System Used..?            N
VENTILATION HEAT RECLAIM
 Reclaim Unit Type............:       None
SAFETY FACTORS
 Sensible Cooling Factor.......:            0 %
```

Latent Cooling Factor.........: 0 %
Heating Factor................: 0 %

==

AIR SYSTEM INPUT DATA

Name: CAVRH(2)-990223	03-15-99
Type: CONSTANT VOLUME - CAV Reheat	HAP v3.22
Prepared by: ISU	Page 2

****

3. ZONE DATA

ZONE	1	(All Zones the Same)
T-Stat Occupied Cooling....(F):	73.0	
Unoccupied Cooling..(F):	73.0	
Occupied Heating....(F):	72.0	
Unoccupied Heating..(F):	72.0	
Throttling Range....(F):	1.5	
Zone Heating Unit Type........:	None	
Trip Temperature.........(F):	-	
Design Supply Temperature(F):	-	
Fan Total Static....(in.wg.):	-	
Fan Efficiency...........(%):	-	
Zone Terminal Type............:	Diffuser	
Reheat Coil.................?	Y	
Diversity Factor...........(%):	100	
Direct Exhaust Airflow...(CFM):	0.0	
Direct Exhaust Fan kW.....(kW):	0.0	

4. SCHEDULE DATA

HOURLY TSTAT SCHEDULES	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Design Day.............	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weekday................	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Saturday...............	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sunday.................	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Cooling Available During Unoccupied Period ? Y

MONTHLY SCHEDULES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Terminal Heating.......	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Central Cooling........	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX

AIR SYSTEM INPUT DATA

Name: CAVRH(2)-990223	03-15-99
Type: CONSTANT VOLUME - CAV Reheat	HAP v3.22
Prepared by: ISU	Page 1

****

1. SPACE SELECTION

Space Name	Qty	Space Name	Qty
SPACES IN ZONE 1 (Zone 1)			
5. ROOM EAST C2	1		

```
==========================================================================
SPACES IN ZONE  2 (Zone 2)
--------------------------------------------------------------------------
   6. ROOM SOUTH C2             1
==========================================================================
SPACES IN ZONE  3 (Zone 3)
--------------------------------------------------------------------------
   7. ROOM WEST C2              1
==========================================================================
SPACES IN ZONE  4 (Zone 4)
--------------------------------------------------------------------------
   8. ROOM INTER C2             1
==========================================================================
```

```
                          AIR SYSTEM INPUT DATA
Name: CAVRH(2)-990223                                            03-15-99
Type: CONSTANT VOLUME - CAV Reheat                               HAP v3.22
Prepared by: ISU                                                 Page  1
**************************************************************************

1. SYSTEM NAME AND TYPE
--------------------------------------------------------------------------
  Name............: CAVRH(2)-990223
  Type............: CONSTANT VOLUME - CAV Reheat
  Number of Zones.:  4
==========================================================================

2. SYSTEM DESCRIPTION
--------------------------------------------------------------------------
COOLING SYSTEM DATA
 Supply Air....................:         58.0 F
 Coil Bypass Factor............:        0.100
 Supply Air Reset..............:    Not Used
OUTDOOR VENTILATION DATA
 Type of Control...............:    Constant Airflow Rate
 Design Ventilation Airflow....:        100.0 CFM
 Dampers Open During Unocc Per.:            Y
SUPPLY DUCT DATA
 Duct Heat Gain................:            2 %
 Duct Leakage Rate.............:            0 %
RETURN PLENUM DATA
 Is a Return Plenum Used.......?            Y
 % Roof Heat Gain to Plenum....:           70 %
 % Wall Heat Gain to Plenum....:            0 %
 % Lighting Heat Gain to Plenum:           20 %
SUPPLY FAN DATA
 Fan Type......................:    Forward Curved
 Configuration.................:    Draw-Thru
 Fan Total Static..............:         1.40 in.wg.
 Fan Efficiency................:           54 %
RETURN FAN DATA
 Fan Type......................:    Forward Curved
 Fan Total Static..............:         1.00 in.wg.
 Fan Efficiency................:           54 %
OUTDOOR AIR ECONOMIZER
 Outdoor Economizer Type.......:    Integrated Dry-Bulb
 OA Upper Cutoff Temp..........:         65.0 F
 OA Lower Cutoff Temp..........:         15.0 F
PREHEAT COIL
```

Preheat Coil Used............? N
PRECOOL COIL
Precool Coil Used............? N
HUMIDIFICATION
Humidification System Used....? N
DEHUMIDIFICATION
Dehumidification System Used..? N
VENTILATION HEAT RECLAIM
Reclaim Unit Type.............: None
SAFETY FACTORS
Sensible Cooling Factor.......: 0 %
Latent Cooling Factor.........: 0 %
Heating Factor................: 0 %

AIR SYSTEM INPUT DATA

Name: CAVRH(2)-990223	03-15-99
Type: CONSTANT VOLUME - CAV Reheat	HAP v3.22
Prepared by: ISU	Page 2

3. ZONE DATA

ZONE	1	(All Zones the Same)
T-Stat Occupied Cooling....(F):	73.0	
Unoccupied Cooling..(F):	73.0	
Occupied Heating....(F):	72.0	
Unoccupied Heating..(F):	72.0	
Throttling Range....(F):	1.5	
Zone Heating Unit Type.........:	None	
Trip Temperature.........(F):	-	
Design Supply Temperature(F):	-	
Fan Total Static....(in.wg.):	-	
Fan Efficiency...........(%):	-	
Zone Terminal Type............:	Diffuser	
Reheat Coil.................?	Y	
Diversity Factor...........(%):	100	
Direct Exhaust Airflow...(CFM):	0.0	
Direct Exhaust Fan kW.....(kW):	0.0	

4. SCHEDULE DATA

HOURLY TSTAT SCHEDULES	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Design Day.............	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weekday................	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Saturday...............	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sunday.................	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Cooling Available During Unoccupied Period ? Y

MONTHLY SCHEDULES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Terminal Heating.......	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Central Cooling........	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX

AIR SYSTEM INPUT DATA

Name: CAVRH(2)-990223	03-15-99

Type: CONSTANT VOLUME - CAV Reheat HAP v3.22
Prepared by: ISU Page 1

****

1. SPACE SELECTION

Space Name	Qty	Space Name	Qty
SPACES IN ZONE 1 (Zone 1)			
5. ROOM EAST C2	1		
SPACES IN ZONE 2 (Zone 2)			
6. ROOM SOUTH C2	1		
SPACES IN ZONE 3 (Zone 3)			
7. ROOM WEST C2	1		
SPACES IN ZONE 4 (Zone 4)			
8. ROOM INTER C2	1		

SPACE DESCRIPTION
Prepared by: ISU 03-15-99
HAP v3.22 Page 1

****

GENERAL
Name......: ROOM EAST C2
Floor Area......: 275.0 sqft
Building Weight.: 52.0 lb/sqft
Windows Shaded..? N
Partitions Used.? N

LIGHTING
Overhead Fixture: Recessed, Vented
Lamp Wattage....: 2.50 W/sqft
Ballast Mult....: 1.00
Task Lighting...: 0.00 W/sqft

PEOPLE
Occupancy.......: 100.0 sqft/per
Activity Level..: Office Work
Sensible........: 245.0 BTU/hr
Latent..........: 205.0 BTU/hr

OTHER LOADS
Equipment.......: 2000.0 W
Misc. Sensible..: 0.0 BTU/hr
Misc. Latent....: 0.0 BTU/hr

SCHEDULES
Lighting....: ZERO SCH EXCEPT DESIGN
Task Lights.: ZERO SCH EXCEPT DESIGN
People......: ZERO SCH EXCEPT DESIGN
Equipment...: BASE BOARD (2KW) SETBACK
Misc. Sens..: ZERO SCH EXCEPT DESIGN
Misc. Latent: ZERO SCH EXCEPT DESIGN

INFILTRATION
Cooling.....: 0.00 CFM/sqft
Heating.....: 0.00 CFM/sqft
Typical.....: 0.00 CFM/sqft
When Fan On.? N

FLOOR
Type........:Slab On Grade
Perimeter.............: 15.1 ft
Slab Floor Area.......: 275.0 sqft
Floor R-Value.........: 0.81
Insulation R-value....: 5.00

WALL Exp	Gross Area (sqft)	WALL Type	WINDOW Type	WINDOW Qty	WINDOW Shade	WINDOW Type	WINDOW Qty	WINDOW Shade	Any Doors?
E	131.8	1	1	1	-	1	0	-	N
E	85.3	2	1	0	-	1	0	-	N

ROOF Exp	Slope (deg)	Gross Area (sqft)	ROOF Type	SKYLIGHT Type	SKYLIGHT Qty
HOR	-	275.0	1	1	0

```
No partition data for this space.
==========================================================================
_
                            SPACE DESCRIPTION
Prepared by: ISU                                                  03-15-99
HAP v3.22                                                          Page  1
**************************************************************************
GENERAL                               SCHEDULES
 Name......: ROOM SOUTH C2             Lighting....: ZERO SCH EXCEPT DESIGN
 Floor Area......:     275.0 sqft      Task Lights.: ZERO SCH EXCEPT DESIGN
 Building Weight.:      52.0 lb/sqft   People......: ZERO SCH EXCEPT DESIGN
 Windows Shaded..?        N            Equipment...: BASE BOARD (2KW) SETBACK
 Partitions Used.?        N            Misc. Sens..: ZERO SCH EXCEPT DESIGN
LIGHTING                               Misc. Latent: ZERO SCH EXCEPT DESIGN
 Overhead Fixture: Recessed, Vented   INFILTRATION
 Lamp Wattage....:      2.50 W/sqft    Cooling.....:       0.00 CFM/sqft
 Ballast Mult....:      1.00           Heating.....:       0.00 CFM/sqft
 Task Lighting...:      0.00 W/sqft    Typical.....:       0.00 CFM/sqft
PEOPLE                                 When Fan On.?          N
 Occupancy.......:     100.0 sqft/per FLOOR
 Activity Level..: Office Work         Type........:Slab On Grade
 Sensible........:     245.0 BTU/hr    Perimeter.............:      15.1 ft
 Latent..........:     205.0 BTU/hr    Slab Floor Area.......:     275.0 sqft
OTHER LOADS                            Floor R-Value.........:      0.81

 Equipment.......:    2000.0 W         Insulation R-value....:      5.00
 Misc. Sensible..:       0.0 BTU/hr
 Misc. Latent....:       0.0 BTU/hr
==========================================================================
WALL  Gross Area  |  WALL  |      WINDOW       |      WINDOW       |  Any
Exp       (sqft)  |  Type  | Type  Qty  Shade  | Type  Qty  Shade  | Doors?
---------------------------------------------------------------------------
S          131.8  |     1  |  1     1     -    |  1     0     -    |  N
S           85.3  |     2  |  1     0     -    |  1     0     -    |  N
==========================================================================
ROOF  Slope    Gross Area  | ROOF | SKYLIGHT  |
Exp   (deg)        (sqft)  | Type |Type   Qty |
----------------------------------------------|
HOR     -           275.0  |    1 |  1      0 |
==========================================================================
No partition data for this space.
==========================================================================
_
                            SPACE DESCRIPTION
Prepared by: ISU                                                  03-15-99
HAP v3.22                                                          Page  1
**************************************************************************
GENERAL                               SCHEDULES
 Name......: ROOM WEST C2              Lighting....: ZERO SCH EXCEPT DESIGN
 Floor Area......:     275.0 sqft      Task Lights.: ZERO SCH EXCEPT DESIGN
 Building Weight.:      52.0 lb/sqft   People......: ZERO SCH EXCEPT DESIGN
 Windows Shaded..?        N            Equipment...: BASE BOARD (2KW) SETBACK
 Partitions Used.?        N            Misc. Sens..: ZERO SCH EXCEPT DESIGN
LIGHTING                               Misc. Latent: ZERO SCH EXCEPT DESIGN
 Overhead Fixture: Recessed, Vented   INFILTRATION
 Lamp Wattage....:      2.50 W/sqft    Cooling.....:       0.00 CFM/sqft
 Ballast Mult....:      1.00           Heating.....:       0.00 CFM/sqft
 Task Lighting...:      0.00 W/sqft    Typical.....:       0.00 CFM/sqft
PEOPLE                                 When Fan On.?          N
 Occupancy.......:     100.0 sqft/per FLOOR
 Activity Level..: Office Work         Type........:Slab On Grade
```

```
 Sensible........:    245.0 BTU/hr   Perimeter............:     15.1 ft
 Latent..........:    205.0 BTU/hr   Slab Floor Area.......:   275.0 sqft
OTHER LOADS                          Floor R-Value.........:    0.81
 Equipment.......:   2000.0 W        Insulation R-value....:    5.00
 Misc. Sensible..:      0.0 BTU/hr
 Misc. Latent....:      0.0 BTU/hr
=============================================================================
WALL  Gross Area  | WALL  |      WINDOW        |      WINDOW        |  Any
Exp       (sqft)  | Type  | Type  Qty  Shade   | Type  Qty  Shade   | Doors?
------------------------------------------------------------------------------
W          131.8  |     1 |    1    1      -   |    1    0      -   |   N
W           85.3  |     2 |    1    0      -   |    1    0      -   |   N
=============================================================================
ROOF  Slope    Gross Area  | ROOF  | SKYLIGHT  |
Exp   (deg)        (sqft)  | Type  |Type   Qty |
-----------------------------------------------|
HOR     -          275.0   |     1 |  1      0 |
=============================================================================
No partition data for this space.
=============================================================================
_
                             SPACE DESCRIPTION
Prepared by: ISU                                                   03-15-99
HAP v3.22                                                          Page  1
*****************************************************************************
GENERAL                                SCHEDULES
 Name......: ROOM INTER C2              Lighting....: ZERO SCH EXCEPT DESIGN
 Floor Area......:    275.0 sqft        Task Lights.: ZERO SCH EXCEPT DESIGN
 Building Weight.:     52.0 lb/sqft     People......: ZERO SCH EXCEPT DESIGN
 Windows Shaded..?        N             Equipment...: BASE BOARD (2KW) SETBACK
 Partitions Used.?        N             Misc. Sens..: ZERO SCH EXCEPT DESIGN
LIGHTING                                Misc. Latent: ZERO SCH EXCEPT DESIGN
 Overhead Fixture: Recessed, Vented    INFILTRATION
 Lamp Wattage....:     2.50 W/sqft      Cooling.....:      0.00 CFM/sqft
 Ballast Mult....:     1.00             Heating.....:      0.00 CFM/sqft
 Task Lighting...:     0.00 W/sqft      Typical.....:      0.00 CFM/sqft
PEOPLE                                  When Fan On.?        N
 Occupancy.......:    100.0 sqft/per FLOOR
 Activity Level..: Office Work          Type........:Slab On Grade
 Sensible........:    245.0 BTU/hr      Perimeter............:      0.0 ft
 Latent..........:    205.0 BTU/hr      Slab Floor Area.......:   275.0 sqft
OTHER LOADS                             Floor R-Value.........:    0.81
 Equipment.......:   2000.0 W           Insulation R-value....:    0.00
 Misc. Sensible..:      0.0 BTU/hr
 Misc. Latent....:      0.0 BTU/hr
=============================================================================
No external wall or window data for this space.
=============================================================================
ROOF  Slope    Gross Area  | ROOF  | SKYLIGHT  |
Exp   (deg)        (sqft)  | Type  |Type   Qty |
-----------------------------------------------|
HOR     -          275.0   |     1 |  1      0 |
=============================================================================
No partition data for this space.
=============================================================================
_
                              SCHEDULE DATA
    Prepared By: ISU                                             03-15-99
    HAP v3.22                                              Page  1 of  1
    ***********************************************************************
```

Schedule Name: ZERO SCH EXCEPT DESIGN Hourly Percentages

Hour ----->	00	01	02	03	04	05	06	07	08	09	10	11
DESIGN DAY	10	10	10	10	10	10	10	100	100	100	100	100
Weekday	0	0	0	0	0	0	0	0	0	0	0	0
Saturday	0	0	0	0	0	0	0	0	0	0	0	0
Sunday	0	0	0	0	0	0	0	0	0	0	0	0

Hour ----->	12	13	14	15	16	17	18	19	20	21	22	23
DESIGN DAY	100	100	100	100	100	100	100	100	10	10	10	10
Weekday	0	0	0	0	0	0	0	0	0	0	0	0
Saturday	0	0	0	0	0	0	0	0	0	0	0	0
Sunday	0	0	0	0	0	0	0	0	0	0	0	0

Schedule Name: BASE BOARD (2KW) SETBACK Hourly Percentages

Hour ----->	00	01	02	03	04	05	06	07	08	09	10	11
DESIGN DAY	0	0	0	0	0	0	0	0	0	100	100	100
Weekday	0	0	0	0	0	0	0	0	0	100	100	100
Saturday	0	0	0	0	0	0	0	0	0	100	100	100
Sunday	0	0	0	0	0	0	0	0	0	100	100	100

Hour ----->	12	13	14	15	16	17	18	19	20	21	22	23
DESIGN DAY	100	100	100	100	100	100	0	0	0	0	0	0
Weekday	100	100	100	100	100	100	0	0	0	0	0	0
Saturday	100	100	100	100	100	100	0	0	0	0	0	0
Sunday	100	100	100	100	100	100	0	0	0	0	0	0

WALL CONSTRUCTION TYPES

Prepared by: ISU 03-15-99
HAP v3.22 Page 1

WALL TYPE 1: (CUSTOM WALL)

Description...........: WALL-B-TEST
Absorptivity..........: 0.690

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
5/8-in (16 mm) gypsum board	0.63	50.0	0.26	0.56	2.6
Vapor barrier	0.00	0.0	0.00	0.06	0.0
Airspace	0.38	0.0	0.00	0.91	0.0
1.5 in rigid insulation w/ foil	1.50	1.5	0.38	9.39	0.2
4-in (102 mm) HW concrete block	4.00	140.0	0.20	0.44	46.7
Outside surface resistance	-	-	-	0.33	-
Totals	6.50			12.37	49.5

Thickness: in Density: lb/cuft Weight: lb/sqft
R-value : (hr-sqft-F)/BTU Specific Heat: BTU/lb/F

WALL TYPE 2: (CUSTOM WALL)

Description...........: WALL-T-TEST
Absorptivity..........: 0.690

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
5/8-in (16 mm) gypsum board	0.63	50.0	0.26	0.56	2.6
Airspace	0.38	0.0	0.00	0.91	0.0
R-7 (RSI-1.2) board insulation	1.00	1.5	0.38	6.26	0.1
6-in (153 mm) HW concrete block	6.00	140.0	0.20	0.66	70.0
Outside surface resistance	-	-	-	0.33	-
Totals	8.00			9.40	72.7

Thickness: in Density: lb/cuft Weight: lb/sqft
R-value : (hr-sqft-F)/BTU Specific Heat: BTU/lb/F

WALL CONSTRUCTION TYPES

Prepared by: ISU 03-15-99
HAP v3.22 Page 2

****

WALL TYPE 3: (CUSTOM WALL)

Description...........: WALL-B-TYP
Absorptivity..........: 0.690

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
5/8-in (16 mm) gypsum board	0.63	50.0	0.26	0.56	2.6
Vapor barrier	0.00	0.0	0.00	0.06	0.0
R-13 (RSI-2.3) batt insulation	3.50	0.6	0.20	12.96	0.2
Airspace	0.75	0.0	0.00	0.90	0.0
R-7 (RSI-1.2) board insulation	1.00	1.5	0.38	6.26	0.1
4-in (102 mm) HW concrete block	4.00	140.0	0.20	0.44	46.7
Outside surface resistance	-	-	-	0.33	-
Totals	9.88			22.19	49.6

Thickness: in Density: lb/cuft Weight: lb/sqft
R-value : (hr-sqft-F)/BTU Specific Heat: BTU/lb/F

WALL TYPE 4: (CUSTOM WALL)

Description...........: WALL-T-TYP
Absorptivity..........: 0.690

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
5/8-in (16 mm) gypsum board	0.63	50.0	0.26	0.56	2.6
R-13 (RSI-2.3) batt insulation	3.50	0.6	0.20	12.96	0.2
Airspace	0.75	0.0	0.00	0.91	0.0
R-7 (RSI-1.2) board insulation	1.00	1.5	0.38	6.26	0.1
6-in (153 mm) HW concrete block	6.00	140.0	0.20	0.66	70.0
Outside surface resistance	-	-	-	0.33	-

Totals	11.88			22.36	72.9

Thickness: in   Density: lb/cuft   Weight: lb/sqft
R-value : (hr-sqft-F)/BTU   Specific Heat: BTU/lb/F

WALL CONSTRUCTION TYPES

Prepared by: ISU   03-15-99
HAP v3.22   Page 3

WALL TYPE 5: (CUSTOM WALL)

Description...........: WALL-OVERH
Absorptivity..........: 0.690

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
R-13 (RSI-2.3) batt insulation	3.50	0.6	0.20	12.96	0.2
Airspace	0.75	0.0	0.00	0.91	0.0
R-7 (RSI-1.2) board insulation	1.00	1.5	0.38	6.26	0.1
6-in (153 mm) HW concrete block	6.00	140.0	0.20	0.66	70.0
Outside surface resistance	-	-	-	0.33	-
Totals	11.25			21.80	70.3

Thickness: in   Density: lb/cuft   Weight: lb/sqft
R-value : (hr-sqft-F)/BTU   Specific Heat: BTU/lb/F

WALL TYPE 6: (CUSTOM WALL)

Description...........: WALL-CLASS
Absorptivity..........: 0.690

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
3/4-in gypsum board	0.75	50.0	0.26	0.67	3.1
Vapor barrier	0.00	0.0	0.00	0.06	0.0
R-13 (RSI-2.3) batt insulation	3.50	0.6	0.20	12.96	0.2
Airspace	1.38	0.0	0.00	0.91	0.0
R-7 (RSI-1.2) board insulation	1.00	1.5	0.38	6.26	0.1
6-in (153 mm) HW concrete block	6.00	140.0	0.20	0.66	70.0
Outside surface resistance	-	-	-	0.33	-
Totals	12.62			22.54	73.4

Thickness: in   Density: lb/cuft   Weight: lb/sqft
R-value : (hr-sqft-F)/BTU   Specific Heat: BTU/lb/F

WALL CONSTRUCTION TYPES

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WALL TYPE 7: (CUSTOM WALL)

Description...........: WALL-SPANDREL
Absorptivity..........: 0.900

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
5/8-in (16 mm) gypsum board	0.63	50.0	0.26	0.56	2.6
Vapor barrier	0.00	0.0	0.00	0.06	0.0
R-13 (RSI-2.3) batt insulation	3.50	0.6	0.20	12.96	0.2
R-7 (RSI-1.2) board insulation	1.00	1.5	0.38	6.26	0.1
Airspace	4.75	0.0	0.00	0.91	0.0
Insulation glass	1.00	138.0	0.17	2.08	11.5
Outside surface resistance	-	-	-	0.33	-
Totals	10.88			23.84	14.4

Thickness: in   Density: lb/cuft   Weight: lb/sqft
R-value : (hr-sqft-F)/BTU   Specific Heat: BTU/lb/F

ROOF CONSTRUCTION TYPES

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ROOF TYPE 1: (CUSTOM ROOF)

Description...........: ROOF-TYP
Absorptivity..........: 0.290

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
2-in (51 mm) HW concrete block	2.00	140.0	0.20	0.22	23.3
Airspace	4.00	0.0	0.00	0.87	0.0
2-in (51 mm) HW concrete block	2.00	140.0	0.20	0.22	23.3
Vapor barrier	0.00	0.0	0.00	0.06	0.0
R-13 (RSI-2.3) batt insulation	4.00	1.5	0.38	15.06	0.5
3/8 inch felt & membrane	0.00	70.0	0.35	0.44	0.0
1 inch slag or stone	1.00	55.0	0.40	0.10	4.6
Outside surface resistance	-	-	-	0.33	-
Totals	13.00			17.98	51.8

Thickness: in   Density: lb/cuft   Weight: lb/sqft
R-value : (hr-sqft-F)/BTU   Specific Heat: BTU/lb/F

ROOF TYPE 2: (CUSTOM ROOF)

Description...........: ROOF-CLASS
Absorptivity..........: 0.290

Layer Description	Thickness	Density	Spec.Ht	R-Val	Weight
Inside surface resistance	-	-	-	0.68	-
22 gage steel deck	0.03	489.0	0.12	0.00	1.4

R-13 (RSI-2.3) batt insulation	4.00	1.5	0.38	15.06	0.5
3/8 inch felt & membrane	0.00	0.0	0.00	0.44	0.0
1 inch slag or stone	1.00	55.0	0.40	0.10	4.6
Outside surface resistance	-	-	-	0.33	-
Totals	5.03			16.61	6.5

Thickness: in   Density: lb/cuft   Weight: lb/sqft
R-value : (hr-sqft-F)/BTU   Specific Heat: BTU/lb/F

WINDOW TYPE CONSTRUCTIONS

Prepared by: ISU   03-15-99
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****

WINDOW TYPE 1: (PRE-DEFINED WINDOW)

Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" low-e + 1/4" clear
Window Description.....: WIN-TEST
Height.................: 5.00 ft
Width..................: 14.80 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Overall U-value........: 0.570 BTU/hr/sqft/F
Overall Shade Coeff....: 0.649

ÿPredefined Glass Dataÿ

Glass Transmissivity	Glass Reflectivity	Glass Absorptivity	Glass U-Value	Shade Coefficient
0.510	0.148	0.342	0.480	0.700

WINDOW TYPE 2: (PRE-DEFINED WINDOW)

Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray low-e + 1/4" clear
Window Description.....: WIN-OFFICE-EAST
Height.................: 5.00 ft
Width..................: 11.80 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Overall U-value........: 0.570 BTU/hr/sqft/F
Overall Shade Coeff....: 0.384

ÿPredefined Glass Dataÿ

Glass Transmissivity	Glass Reflectivity	Glass Absorptivity	Glass U-Value	Shade Coefficient
0.247	0.319	0.434	0.480	0.380

WINDOW TYPE 3: (PRE-DEFINED WINDOW)

Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray low-e + 1/4" clear
Window Description.....: WIN-OFFICE-SOUTH
Height.................: 5.00 ft
Width..................: 15.30 ft

```
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Overall U-value........:   0.569 BTU/hr/sqft/F
Overall Shade Coeff....:   0.384
------------------------------------------------------------------------
                         ÿPredefined Glass Dataÿ
     Glass            Glass           Glass          Glass        Shade
Transmissivity    Reflectivity    Absorptivity    U-Value    Coefficient
     0.247            0.319           0.434          0.480        0.380
------------------------------------------------------------------------
```

```
                         WINDOW TYPE CONSTRUCTIONS
Prepared by: ISU                                                03-15-99
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************************************************************************

WINDOW TYPE  4: (PRE-DEFINED WINDOW)
------------------------------------------------------------------------
Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray   low-e      + 1/4" clear
Window Description.....: WIN-RECEPTION
Height.................:    5.00 ft
Width..................:    7.90 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Overall U-value........:   0.572 BTU/hr/sqft/F
Overall Shade Coeff....:   0.385
------------------------------------------------------------------------
                         ÿPredefined Glass Dataÿ
     Glass            Glass           Glass          Glass        Shade
Transmissivity    Reflectivity    Absorptivity    U-Value    Coefficient
     0.247            0.319           0.434          0.480        0.380
------------------------------------------------------------------------

WINDOW TYPE  5: (PRE-DEFINED WINDOW)
------------------------------------------------------------------------
Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray   low-e      + 1/4" clear
Window Description.....: WIN-COMPUTER-SOUTH
Height.................:    5.00 ft
Width..................:   15.30 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Overall U-value........:   0.569 BTU/hr/sqft/F
Overall Shade Coeff....:   0.384
------------------------------------------------------------------------
                         ÿPredefined Glass Dataÿ
     Glass            Glass           Glass          Glass        Shade
Transmissivity    Reflectivity    Absorptivity    U-Value    Coefficient
     0.247            0.319           0.434          0.480        0.380
------------------------------------------------------------------------

WINDOW TYPE  6: (PRE-DEFINED WINDOW)
------------------------------------------------------------------------
Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray   low-e      + 1/4" clear
Window Description.....: WIN-COMPUTER-WEST
Height.................:    5.00 ft
Width..................:   24.00 ft
Frame Type.............: Aluminum with thermal breaks
```

```
Interior Shade Type....: No Shades Used
Overall U-value........:   0.569 BTU/hr/sqft/F
Overall Shade Coeff....:   0.384
------------------------------------------------------------------------
                        ÿPredefined Glass Dataÿ
     Glass            Glass            Glass         Glass        Shade
Transmissivity    Reflectivity    Absorptivity    U-Value    Coefficient
     0.247            0.319            0.434         0.480        0.380
------------------------------------------------------------------------
```

```
                        WINDOW TYPE CONSTRUCTIONS
Prepared by: ISU                                                03-15-99
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************************************************************************

WINDOW TYPE  7: (PRE-DEFINED WINDOW)
------------------------------------------------------------------------
Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray   low-e      + 1/4" clear
Window Description.....: WIN-VEST-EAST
Height.................:    5.00 ft
Width..................:    3.00 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Overall U-value........:   0.580 BTU/hr/sqft/F
Overall Shade Coeff....:   0.386
------------------------------------------------------------------------
                        ÿPredefined Glass Dataÿ
     Glass            Glass            Glass         Glass        Shade
Transmissivity    Reflectivity    Absorptivity    U-Value    Coefficient
     0.247            0.319            0.434         0.480        0.380
------------------------------------------------------------------------

WINDOW TYPE  8: (PRE-DEFINED WINDOW)
------------------------------------------------------------------------
Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray   low-e      + 1/4" clear
Window Description.....: WIN-VEST-WEST
Height.................:    5.00 ft
Width..................:    3.00 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Overall U-value........:   0.580 BTU/hr/sqft/F
Overall Shade Coeff....:   0.386
------------------------------------------------------------------------
                        ÿPredefined Glass Dataÿ
     Glass            Glass            Glass         Glass        Shade
Transmissivity    Reflectivity    Absorptivity    U-Value    Coefficient
     0.247            0.319            0.434         0.480        0.380
------------------------------------------------------------------------

WINDOW TYPE  9: (PRE-DEFINED WINDOW)
------------------------------------------------------------------------
Glass Group............: DOUBLE PANE, LOW-e
Glass Type.............: 1/4" gray   low-e      + 1/4" clear
Window Description.....: WIN-CLASS
Height.................:    5.00 ft
Width..................:    7.00 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
```

```
Overall U-value........:   0.572 BTU/hr/sqft/F
Overall Shade Coeff....:   0.385
-----------------------------------------------------------------------
                      ÿPredefined Glass Dataÿ
     Glass            Glass           Glass        Glass        Shade
Transmissivity    Reflectivity    Absorptivity    U-Value    Coefficient
     0.247            0.319           0.434        0.480        0.380
-----------------------------------------------------------------------
```

```
                      WINDOW TYPE CONSTRUCTIONS
Prepared by: ISU                                               03-15-99
HAP v3.22                                                      Page  4
**********************************************************************

WINDOW TYPE 10: (CUSTOM WINDOW)
-----------------------------------------------------------------------
Window Description.....: SKY LIGHT
Height.................:   10.00 ft
Width..................:   1C.00 ft
Frame Type.............: Aluminum with thermal breaks
Interior Shade Type....: No Shades Used
Glass Transmissivity...:   0.200
Number of Pane(s)......:       2
Pane 1 Absorptivity....:   0.030
Pane 2 Absorptivity....:   0.030
Center of Glass U-value:   0.240 BTU/hr/sqft/F
Overall U-value........:   0.370 BTU/hr/sqft/F
Overall Shade Coeff....:   0.261
-----------------------------------------------------------------------
```

APPENDIX D TRACE PROGRAM INPUT DATA

%[SAMPLE INPUT FILE FOR TRACE PROGRAM]

% FILE NAME: 990223

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Alternative #1 Page #1

01 Card - Job Information

Project: ENERGY RESOURCE STATION
Location: ANKENY
Client: FEB 23 CAV SYSTEM WITH ECONO
Comments: 03

Card 08---------------------------- Climatic Information --------------------------------

Weather Code	Summer Clearness Number	Winter Clearness Number	Summer Design Dry Bulb	Summer Design Wet Bulb	Winter Design Dry Bulb	Building Orientation	Summer Ground Reflect	Winter Ground Reflect
A990223								

Card 09------------------- Load Simulation Periods --------------------------

1st Month Cooling Simulation	Last Month Cooling Simulation	Peak Cooling Load Hr	1st Month Summer Period	Last Month Summer Period	1st Month Daylight Savings	Last Month Daylight Savings
FEB	FEB				APR	OCT

Card 10------------- Load Simulation Parameters ----------------------

Cooling Load Method	Heating Load Method	Ventilation Method	Airflow Input Units	Airflow Output Units	Room Circulation Rate	Put Wall RA Load to Room
CLTD-CLF	CLTD-CLF	OADB	ACTUAL	ACTUAL		

Card 11--------- Energy Simulation Parameters ------------------

1st Month Energy Simulation	Last Month Energy Simulation	Level Of Calculation	Holiday Code	Calendar Code	Building Floor Area
FEB	FEB	ROOM			

Card 12--- Resource Utilization Factors ----------

Electricity	Gas	Oil	Steam	Hot Water	Chilled Water	Coal
						1

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Alternative #1 Page #2

--------------------- Load Section Alternative #1 ---------------------

Card 20--- General Room Parameters ---

Room Number	Zone Reference Number	Room Descrip	Floor Length	Floor Width	Const Type	Plenum Height	Acoustic Ceiling Resistance	Floor to Floor Height	Duplicate Floors Multiplier	Duplicate Rooms per Zone	Perimeter Depth
101	101	TEST ROOM EAST-A	275	1	8	5.5		14			
102	102	TESTROOM SOUTH-A	275	1	8	5.5		14			
103	103	TEST ROOM WEST-A	275	1	8	5.5		14			
104	104	TEST ROOM INTE-A	275	1	8	5.5		14			

Card 21---------------------------------- Thermostat Parameters --

Room Number	Cooling Room Design DB	Room Design RH	Cooling T'stat Driftpoint	Cooling T'stat Schedule	Heating Room Design DB	Heating T'stat Driftpoint	Heating T'stat Schedule	T'stat Location Flag	Mass / No. Hrs Average	Carpet On Floor
M101	73	50	80	ERS2-C	72	65	ERS2-H	ROOM	MED70	YES

Card 22-------------------------- Roof Parameters --------------------------------

Room Number	Roof Number	Roof Equal to Floor?	Roof Length	Roof Width	Roof U-Value	Const Type	Roof Direction	Roof Tilt	Roof Alpha
101	1	YES				160			0.9
102	1	YES				160			
103	1	YES				160			
104	1	YES				160			

Card 24---------------------------- Wall Parameters ----------------------------------

Room Number	Wall Number	Wall Length	Wall Height	Wall U-Value	Wall Constuc Type	Wall Direction	Wall Tilt	Wall Alpha	Ground Reflectance Multiplier
101	1	15.1	8		170	90		0.67	
101	2	15.1	6		171	90		0.67	
102	1	15.3	8		170	180		0.67	
102	2	15.3	6		171	180		0.67	
103	1	15.1	8		170	270		0.67	
103	2	15.1	6		171	270		0.67	

Card 25-- Wall/Glass Parameters ---
-

Room Number	Wall Number	Glass Length	Glass Height	Pct Glass or No. of Windows	Glass U-Value	Shading Coefficient	External Shading Type	Internal Shading Type	Percent Solar to Ret. Air	Visible Transmittance	Inside Visible Reflectance
101	1	14.8	5	1	0.38	0.81					
102	1	14.8	5	1	0.38	0.81					
103	1	14.8	5	1	0.38	0.81					

-
TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Alternative #1 Page #3

Card 26-- Schedules --

Room Number	People	Lights	Ventilation	Infiltration	Reheat Minimum	Cooling Fans	Heating Fan	Auxiliary Fan	Room Exhaust	Daylighting Controls
M	ERS-PPL	ERS-LGT1			AVAIL	AVAIL	AVAIL			

Card 27-------------------------------------- People and Lights --

Room Number	People Value	People Units	People Sensible	People Latent	Lighting Value	Lighting Units	Lighting Fixture Type	Ballast Factor	Percent Lights to Ret. Air	--- Daylighting ---- Reference Point 1	Reference Point 2
M101	100	SF-PERS	245	205	2.5	WATT-SF	ASHRAE1	1	20		

Card 28-- Miscellaneous Equipment ---

Room Number	Misc Equipment Number	Equipment Descrip	Energy Consump Value	Energy Consump Units	Schedule Code	Energy Meter Code	Percent of Load Sensible	Percent Misc. Load to Room	Percent Misc. Sens to Ret. Air	Radiant Fraction	Optional Air Path
M101	1	WALL ELE.HEATER	2	KW	ERSBASE						

Card 29-- Room Airflows ---

Room	--------------Ventilation--------------				--------------Infiltration--------------					
	-----Cooling-----		-----Heating-----		-----Cooling-----		-----Heating-----		--Reheat Minimum--	
Number	Value	Units	Value	Units	Value	Units	Value	Units	Value	Units
M101	25	CFM	25	CFM						
104	605	CFM	605	CFM					400	CFM

Card 30----------------------------------- Fan Airflows ---

Room	---------------Main---------------				-------------Auxiliary-----------					
	----Cooling----		----Heating----		----Cooling----		----Heating----		--Room Exhaust--	
Number	Value	Units	Value	Units	Value	Units	Value	Units	Value	Units
M101	700	CFM	700	CFM						
104	400	CFM	400	CFM						

Card 32------------------------------ Exposed Floor Parameters--------------------------------------

Room	Exposed	-----Slab------		-------------------------Exposed Floor------------------------						
Room Number	Floor Number	Perimeter Length	Loss Coefficient	Floor Area	Floor U-Value	Const Type	Temp Flag	Cooling Temp	Heating Temp	Adjacent Room No
101	1	15.1	0.609							
102	1	15.1	0.609							
103	1	15.1	0.609							
104	1	1	0.609							

-
TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Alternative #1 Page #4

-------------------- System Section Alternative #1 --------------------

Card 40----------------------- System Type ------------------------------

System Set	System	------------OPTIONAL VENTILATION SYSTEM------------ Ventil Deck	Cooling	Heating	Cooling	Heating	Fan Static

```
Number  Type     Location  SADBVh   SADBVh   Schedule  Schedule  Pressure
1       TRH


Card 41--------------------------------------------- Zone Assignment ------------------------------------------------
System
Set            Ref #1            Ref #2            Ref #3            Ref #4            Ref #5            Ref #6
Number       Begin     End     Begin     End     Begin     End     Begin     End     Begin     End     Begin     End
1            101       104


Card 42------------------------- Fan SP and Duct Parameters--------------------------------
System  Cool  Heat  Return  Rm Exh  Aux   Rm Exh  Cool      Return   Supply  Supply  Return
Set     Fan   Fan   Fan     Fan     Fan   Fan     Fan Mtr   Fan Mtr  Duct    Duct    Air
Number  SP    SP    SP      SP      SP    SP      Loc       Loc      Ht Gn   Loc     Path
1       1.40  1.40  0.25                          SUPPLY    RETAIR   0       OTHER   PLENUM


Card 43------------------------------- Airflow Design Temperatures --------------------------------------
System  Minimum  Maximum  Minimum  Maximum  Minimum  Maximum  Minimum  Maximum  Minimum  Design   Sys Lvl
Set     Cooling  Cooling  Heating  Heating  Cooling  Cooling  Preheat  Preheat  Room     Ht Rec   Vent
Number  SADB     SADB     SADB     SADB     Lv DB    Lv DB    Lv DB    Lv DB    RH       Diff     Flag
1       58       59       60       82


Card 44--------------------------------------------------- System Options ---------------------------------------------------
-------
System Econ     Econ   Max Pct  Direct   Indirect  1st Stage            ----------------- Exhaust Air Heat Recovery ---------
-------
Set    Type     On     Outside  Evap     Evap      Evap        Fan      -- Effectiveness --  -- Control Type --  -- Exh-Side
Deck --
Number Flag     Point  Air      Cooling  Cooling   Cooling     Cycling  Stage 1    Stage 2  Stage 1   Stage 2  Stage 1
Stage 2
1      DRY-BULB 65     100                                     NO


Card 45-------------------------------------- Equipment Schedules ------------------------------------------
System  Main                    Direct   Indirect  Auxiliary  Main     Main                          Auxiliary
Set     Cooling                 Evap     Evap      Cooling    Heating  Preheat  Reheat  Mech.        Heating
Number  Coil      Economizer    Coil     Coil      Coil       Coil     Coil     Coil    Humidity     Coil
1       AVAIL     AVAIL         NO       NO        NO         NO       NO       AVAIL   NO           NO

-------------------- Equipment Section  Alternative #1 ---------------------
_
TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING                          Alternative #1    Page #5


Card 60--------------------------------------------- Cooling Load Assignment-----------------------------------------------
Load  All Coil  Cooling
Asgn  Loads To  Equipment  -Group 1-  -Group 2-  -Group 3-  -Group 4-  -Group 5-  -Group 6-  -Group 7-  -Group 8-  -Group 9-
Ref   Cool Ref  Sizing     Begin End  Begin End  Begin End  Begin End  Begin End  Begin End  Begin End  Begin End  Begin End
1     1         PKPLANT    1     1


Card 62-------------------------------------- Cooling Equipment Parameters -----------------------------------------
Cool Equip      Num     ------------COOLING------------        ---------HEAT RECOVERY----------       Seq          Demand
Ref  Code       Of      --Capacity--       ----Energy----      --Capacity--       ----Energy----      Order   Seq  Limit
Num  Name       Units   Value  Units       Value    Units      Value  Units       Value    Units      Num     Type Number
1    EQ1113     1


Card 63------------------------------ Cooling Pumps and References ----------------------------------
Cool  ---CHILLED WATER----  -----CONDENSER------  ---HT REC or AUX----  Switch-
Ref   Full Load  Full Load  Full Load  Full Load  Full Load  Full Load  over     Cold     Cooling  Misc.
Num   Value      Units      Value      Units      Value      Units      Control  Storage  Tower    Access.
1


Card 65----------------------------------------- Heating Load Assignment ------------------------------------------------
Load        All Coil
Assignment  Loads To     -Group 1-  -Group 2-  -Group 3-  -Group 4-  -Group 5-  -Group 6-  -Group 7-  -Group 8-  -Group 9-
Reference   Heating Ref  Begin End  Begin End  Begin End  Begin End  Begin End  Begin End  Begin End  Begin End  Begin End
1           1            1     1


Card 67----------------------------------------- Heating Equipment Parameters ---------------------------------------------
Heat    Equip    Number  HW Pmp                            Energy            Seq     Switch                           Demand
Ref     Code     Of      Full Ld           Cap'y           Rate              Order   over      Hot   Misc.           Limit
Number  Name     Units   Value    Units    Value  Units    Value   Units     Number  Control   Strg  Acc.    Cogen   Number
1       EQ2009   1
_
```

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #6

Utility Description Reference Table

```
    Schedules:
        AVAIL  AVAILABLE (100%)
        ERS-LGT1  NO LIGHTS EXCEPT DESIGN DAY
        ERS-PPL  NO PEOPLEE EXCEPT DESIGN DAY
        ERS2-C  ERS FIXED COOL(73F)
        ERS2-H  ERS FIXED HEAT(72F)
        ERSBASE  ERS BASEBOARD(9-18)(2KW)
        NO  ALWAYS OFF
    System:
        TRH  TERMINAL REHEAT SYSTEM
    Equipment:
        Cooling:
            EQ1113  AIR-CLD RECIPROCATING < 15 TONS
        Heating:
            EQ2009  GAS FIRED HOT H20 BOILER WITH TAB FANS
```

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #7

Schedule Name: AVAIL
Project: AVAILABLE (100)
Location:
Client: VERSION 3.0
Program User: C.D.S. MARKETING
Comments: BUILDING TEMPLATE SERIES

Starting Month: JAN   Ending Month: HTG
Starting Day Type: DSGN   Ending Day Type: SUN

```
Hour  Util Percent
----  ------------
  0      100
 24
```

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #8

Schedule Name: ERS-LGT1
Project: NO LIGHTS EXCEPT DESIGN DAY
Location: ANKENY
Client: IOWA ENERGY CENTER
Program User: I S U
Comments: LIGHTS SCHEDULE FOR TEST ROOM

Starting Month: JAN   Ending Month: DEC
Starting Day Type: DSGN   Ending Day Type: DSGN

```
Hour  Util Percent
----  ------------
  0      100
 24
```

Starting Month: JAN   Ending Month: DEC
Starting Day Type: WKDY   Ending Day Type: SUN

```
Hour  Util Percent
----  ------------
  0        0
 24
```

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #9

Schedule Name: ERS-PPL
Project: NO PEOPLEE EXCEPT DESIGN DAY
Location: ANKENY
Client: IOWA ENERGY CENTER
Program User: I S U
Comments: PEOPLE SCHEDULE FOR TEST ROOM

Starting Month: JAN   Ending Month: DEC
Starting Day Type: DSGN   Ending Day Type: DSGN

```
Hour  Util Percent
----  ------------
  0      100
 24
```

Starting Month: JAN   Ending Month: DEC
Starting Day Type: WKDY   Ending Day Type: SUN

```
Hour  Util Percent
----  ------------
  0        0
```

24

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #10

Schedule Name: ERS2-C
Project: ERS FIXED HEAT(72F)
Location: ANKENY
Client: IOWA ENERGY CENTER
Program User: I S U
Comments: COOLING THERMOSTAT FOR TEST RO

Starting Month: JAN Ending Month: DEC
Starting Day Type: DSGN Ending Day Type: SUN

```
Hour  Temperature
----  ------------
  0        73
 24
```

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #11

Schedule Name: ERS2-H
Project: ERS FIXED HEAT(72F)
Location: ANKENY
Client: IOWA ENERGY CENTER
Program User: I S U
Comments: HEATING THERMOSTAT FOR TEST RO

Starting Month: JAN Ending Month: DEC
Starting Day Type: DSGN Ending Day Type: SUN

```
Hour  Temperature
----  ------------
  0        72
 24
```

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #12

Schedule Name: ERSBASE
Project: ERS BASEBOARD(9.18)(2KW)
Location: ANKENY
Client: IOWA ENERGY CENTER
Program User: I S U
Comments: BASE BOARD SCHEDULE (2KW)

Starting Month: JAN Ending Month: HTG
Starting Day Type: DSGN Ending Day Type: DSGN

```
Hour  Util Percent
----  ------------
  0       100
 24
```

Starting Month: JAN Ending Month: DEC
Starting Day Type: WKDY Ending Day Type: SUN

```
Hour  Util Percent
----  ------------
  0         0
  9       100
 18         0
 24
```

TRACE 600 input file C:\CDS\DOCTOR\990223.TM by C.D.S. MARKETING Page #13

Schedule Name: NO
Project: ALWAYS OFF
Location:
Client:
Program User:
Comments:

Starting Month: JAN Ending Month: HTG
Starting Day Type: DSGN Ending Day Type: SUN

```
Hour  Util Percent
----  ------------
  0         0
 24
```

APPENDIX E LISTINGS OF FORTRAN PROGRAMS FOR WEATHER DATA PROCESSING

```
c MAIN.FOR
c Program modified 8/18 1998 to accomodate ERS weather data and build
c *.tmp and *.tmy files.  Tmy files are used by TMYGEN.FOR to build a
c TMY weather file for use with DOE2.

      common /angles/dec,beta,theta,phi
      character*8 inpdate
      character*1 ans
      character*12 ofile1, ofile2, ifile1, errfile
      character*6 header1
      logical errflg,first
      real dec,beta,theta
      integer yr1,mo1,day1,hh1,mm1 ,date,time
      integer ash,asm,isolflg,f1,f2
      istart=0
      errflg = .false.
      first = .true.
      write (*,*) ' Program modified on 8/18/98'
      write (*,'(A\)')' Enter the date of the weather files'
      read (*,100) inpdate
  100 format(a8)
      ifile1 = inpdate // '.wtr'
      ofile1 = inpdate // '.tmy'
      ofile2 = inpdate // '.tmp'
      errfile = inpdate // '.err'
      open (1,file=ifile1)
      open (3,file=ofile1)
      open (4,file=ofile2)
      open (2,file=errfile)

c
c Read header line from ERS file #1
      read (1, 101) header1
  101 format(a6)
  103 format(1x,a6)
c
      write(*,*) 'Building TMP file...'
c
c Loop for reading ERS data
c
      Do while (.not. eof(1))
c
c Read ERS data (#1) line by line
```

```
      read (1,*) date,time,bar,rh,tdb,pyran,pyrhel,wd1,ws1
c
c Convert date to yymmdd and time to hhmm
c
      yr1=date/10000
      mo1=(date-yr1*10000)/100
      day1=(date-yr1*10000-mo1*100)
      hh1=time/100
      mm1=time-hh1*100
c
c Call psychrometrics program to calculate other properties and
c call the solar program to calculate solar angles and solar time
c
      call psychro(tdb,bar,rh,twb,tdp,w)
      call solar(mo1,day1,hh1,mm1,ash,asm,isolflg,dst)

c
cx     write (*,201) yr1,mo1,day1,hh1,mm1,tdb,twb,tdp
cx 201 format(1x,3i2,1x,2i2,3f5.1)
      if (asm.eq. 99) then
        istart = istart + 1
      endif
  301 format(2x,3I2,1x,2f5.2,7F6.1)
        if (pyran.lt.0.0) go to 2
        if (pyran.lt.0.4) pyran=0.0
    2   continue
        if (pyrhel.lt.0.0) go to 4
        if (pyrhel.lt.0.4) pyrhel=0.0
    4   continue
c
c Compute fraction of sky covered based on formula b Lomas et.al.
c
      sc = 0.0
      if (pyran.le.0.0.or.pyrhel.lt.0.0) go to 5
      if (beta.gt.0.0) then
          GDhor = pyrhel*cos(theta*0.017453)
          Gdifuse = pyran-pyrhel*cos(theta*0.017453)
          if(Gdifuse.lt.0.0) then
            if(first) then
              write(2,2004)
2004            format(' Date  Time   PYRHEL   PYRAN    ',
   $               'GD hor    THETA')
              first = .false.
            endif
```

```
          errflg = .true.
          write(2,2003) yr1,mo1,day1,hh1,mm1,pyrhel,pyran,GDhor,
  $                theta
 2003       format(2x,3i2,2x,2i2,2x,4f10.3)
        endif
        sc = (Gdifuse/pyran)**2
        if (sc.gt.1.0) sc = 1.0
    endif
   5 continue
    write (4,4999) yr1,mo1,day1,hh1,mm1,ash,asm,tdb,twb,tdp,rh,
   $     w,bar,wd1,ws1,pyran,pyrhel,dec,beta,theta,phi,sc
 4999 format(2x, 7I3, 4F7.1, F8.5, 9F7.1, F7.2)
    end do
    if(errflg) then
       write(*,*) ' Error caused by neg diffuse radiation'
       close (1)
       close (2)
       close (3)
       close (4)
       stop
    else
      write(*,*) 'Processing TMP file into TMY file...'
    endif
c
c Rewind temp file and process data into TMY format
c
    rewind(4)

    if (isolflg.gt.0) then
        do 30 i=1, istart
        read (4,4999) yr1,mo1,day1,hh1,mm1,ash,asm,tdb,twb,tdp,
   $      rh,w,bar,wd1,ws1,pyran,pyrhel,dec,beta,theta,phi,sc
  30 continue
    if (isolflg.eq.1) iend=24
    if (isolflg.eq.2) iend=23
    do 50 i=1, iend
        icntws =0
        sumws=0.0
        icntwd=0
        sumwd=0.0
        icntyra=0
        sumpyra=0.0
        icntyrh=0
        sumpyrh=0.0
```

```
      icntsc=0
      sumsc=0.0
      do 40 j=1,60
     read (4,4999) yr1,mo1,day1,hh1,mm1,ash,asm,tdb,twb,
    $ tdp,rh,w,bar,wd1,ws1,pyran,pyrhel,dec,beta,theta,phi,sc
     if (ws1.gt.-900.) then
       sumws = sumws + ws1
       icntws = icntws + 1
     endif
     if (wd1.gt.-900.) then
       sumwd = sumwd + wd1
       icntwd = icntwd + 1
     endif
     if (pyran.gt.-900.) then
       sumpyra = sumpyra + pyran
       icntyra = icntyra + 1
     endif
     if (pyrhel.gt.-900.) then
       sumpyrh = sumpyrh + pyrhel
       icntyrh = icntyrh + 1
     endif
     icntsc=icntsc +1
     sumsc = sumsc + sc
     if (hh1.eq.23.and.mm1.eq.58) go to 45
  40 continue
  45 continue
c
c Convert wind speed to m/s and tenths. Make 9999 if missing data
c
    if (icntws.eq.0) then
        iavews = 9999
    else
        iavews = sumws/real (icntws)*4.47
    endif
c
c Enter 999 for missing wind speed direction
c
    if (icntwd.eq.0) then
        iavewd = 999
    else
        iavewd = sumwd/real(icntwd)
    endif
c
c Convert solar fluxes to kJ/m^2. NOTE: Based on 2 min. data
```

```
c f1 and f2 are data flags used by TMY format
c
      if (icntyra.eq.0) then
          iGhor = 9999
          f1=9
          write (*,'(a\)')' MISSING TOTAL HORIZONTAL SOLAR DATA'
          write (*,2000) yr1,mo1,day1,ash,asm
          write (*,'(a\)')' Press Enter to continue'
          read (*,2001) ans
 2001        format(a1)
      else
          iGhor = sumpyra*11.36/real(icntyra)
          f1=0
      endif
      if (icntyrh.eq.0) then
          iGND = 9999
          f2=9
          write (*,'(a\)')' MISSING TOTAL NORMAL SOLR DATA'
          write (*,2000) yr1,mo1,day1,ash,asm
          write (*,'(a\)')' Press Enter to continue'
          read (*,2001) ans
      else
          iGND = sumpyrh*11.36/real(icntyrh)
          f2=0
      endif


 2000 format(' DATE:',3i2,' SOLAR TIME:',2i2)
 2002 format(a1)
c
c Set fluxes to night values if the sun is not up
c
      if (beta.eq.0.0) then
          iGND=9999
          f1=9
          iGhor=0000
          f2=8
      endif
c
c Calculate average sky cover in tenths
c
      iavesc = 0
      if (icntsc.gt.0) then
          iavesc = sumsc/real(icntsc)*10.0
```

```
      endif
      if (iavesc.gt.10) iavesc=10
      if (iavesc.lt.10) iavesc=0
      ash=i
      asm=0
      mm1=mm1+2
      if (mm1.ge.60) then
         mm1=mm1-60
         hh1=hh1+1
      endif
c
c Convert temperatures to deg C and tenths
c
      idb=5.555*(tdb-32.0)
      idp=5.555*(tdp-32.0)
c
c Convert barometric pressure to kPa and hundredths which is
c the same as millibars and tenths
c
      ibar=bar*10
c
c Write values to TMY file
c
c
c Convert local time to standard time
c  Variable dst is set in subroutine solar
c  dst=0 if date is standard time
c  dst=1 if date is for daylight saving time


      hh1 = hh1 - int(dst)

      write(3,3000) yr1,mo1,day1,ash,asm,hh1,mm1,f1,iGND,f2,iGhor,
     $           ibar,idb,idp,iavewd,iavews,iavesc
 3000 format(7i2,i1,i4,i1,i4,i5,4i4,i2)
   50 continue
      if (isolflg.eq.2) then
         ash=24
         asm=0
         hh1=24
      endif
      write(3,3000) yr1,mo1,day1,ash,asm,hh1,mm1,f1,iGND,f2,iGhor,
     $           ibar,idb,idp,iavewd,iavews,iavesc
      else
```

```
      do 70 i=1,24
        icntws =0
        sumws=0.0
        icntwd=0
        sumwd=0.0
        icntyra=0
        sumpyra=0.0
        icntyrh=0
        sumpyrh=0.0
        icntsc=0
        sumsc=0.0
        do 60 j=1,60
      read (4,4999) yr1,mo1,day1,hh1,mm1,ash,asm,tdb,twb,tdp,rh,
     $    w,bar,wd1,ws1,pyran,pyrhel,dec,beta,theta,phi,sc
        if (ws1.ge.-999.) then
            sumws=sumws+ws1
            icntws=icntws+1
        endif
        if (wd1.lt.-900.) then
            sumwd=sumwd+wd1
            icntwd=icntwd+1
        endif
        if (pyran.gt.-900.) then
            sumpyra=sumpyra+pyran
            icntyra=icntyra+1
        endif
        if (pyrhel.gt.-900.) then
            sumpyrh=sumpyrh+pyrhel
            icntyrh=icntyrh+1
        endif
        icntsc=icntsc+1
        sumsc=sumsc+sc
        if (ash.eq.0.and.asm.eq.58) go to 65
  60    continue
  65  continue
c
c Convert wind speed to m/s and tenths. Make 9999 if missing data
c
    if (icntws.eq.0) then
        iavews=9999
    else
        iavews=sumws/real(icntws)*4.47
    endif
c
```

```
c Enter 999 for missing wind direction
c
     if (icntwd.eq.0) then
         iavewd=999
     else
         avewd=sumwd/real(icntwd)
     endif
c
c Convert solar fluxes to kJ/m^2. NOTE: Based on 2 min. data
c
c
     if (icntyra.eq.0) then
         iGhor=9999
         f1=9
         write (*,'(a\)')' MISSING TOTAL HORIZONTAL SOLAR DATA'
         write (*,2000) yr1,mo1,day1,ash,asm
         write (*,'(a\)')' Press ENTER to continue'
         read (*,2001) ans
     else
         ighor=sumpyra*11.36/real(icntyra)
         f1=0
     endif
     if (icntyrh.eq.0) then
         iGND=9999
         f2=9
         write (*,'(a\)')' MISSING DIRECT NORMAL SOLAR DATA'
         write (*,2000) yr1,mo1,day1,ash,asm
         write (*,'(a\)')' Press ENTER to continue'
         read (*,2001) ans
     else
         iGND=sumpyrh*11.36/real(icntyrh)
         f2=0
     endif
c
c Set fluxes to night values if the sun is not up
c
     if (beta.eq.0) then
         iGND=9999
         f1=9
         iGhor=0000
         f2=8
     endif
c
c Compute average sky cover
```

```
c
     iavesc=0
     if (icntsc.gt.0) then
          iavesc=sumsc/real(icntsc)*10.0
     endif
     if (iavesc.lt.0) iavesc=0
     if (iavesc.gt.10) iavesc=10
     ash=i
     asm=0
     mm1=mm1+2
     if (mm1.ge.60) then
          mm1=mm1-60
          hh1=hh1+1
     endif
c
c Convert temperature to deg C and tenths
c
     idp=5.555*(tdb-32.0)
     idp=5.555*(tdp-32.0)
c
c Convert barometric pressure to kPa and hundredths which is
c the same as milibars and tenths
c
     ibar=bar*10
c
c Convert local time to standard time
c  Variable dst is set in subroutine solar
c    dst=0 if date is for standard time
c    dst=1 if date is for daylight saving time

     hh1=hh1-int(dst)

     write(3,3000) yr1,mo1,day1,ash,asm,hh1,mm1,f1,iGND,f2,iGhor,
    $          ibar,idb,idp,iavewd,iavews,iavesc
  70 continue
     endif
     close(1)
     close(3)
     close(4)
     stop
     end
```

```
function psat(tf)
c Function psat calculates the saturation pressure in psia of water
c given the temperature in deg-F.  Temperature must be converted to deg-R
c for use in the equations.

      t=tf+459.67

      c1 = -1.0214165e+04
      c2 = -4.8932428
      c3 = -5.3765794e-03
      c4 =  1.9202377e-07
      c5 =  3.5575832e-10
      c6 = -9.0344688e-14
      c7 =  4.1635019
      c8 = -1.0440397e+04
      c9 = -1.129465e+01
      c10= -2.7022355e-02
      c11=  1.2890360e-05
      c12= -2.4780681e-09
      c13=  6.5459673
      if(tf.lt.32.0) then
        a=c1/t+c2+c3*t+c4*t*t+c5*t**3+c6*t**4+c7*alog(t)
        psat = exp(a)
      else
        a=c8/t+c9+c10*t+c11*t*t+c12*t**3+c13*alog(t)
        psat = exp(a)
      endif
      return
      end
```

```
c Subroutine psychro computes properties of moist air given dry-bulb
c temperature, barometric pressure, and relative humidity.

      subroutine psychro(tdb,bar,rh,twb,tdp,w)

c
c     tdb - dry bulb temperature in F
c     bar - barometric pressure in millibars
c     rh - relative humidity in %
c     twb - wet bulb temperature in F
c     tdp - dew point temperature in F
c     w - humidity ratio lbmw/lbma
c
c     p - atmospheric pressure, in psia
c     t - dry bulb temperature, in R
c     c1-c13 - sat. pressure coeff.
c     pws - sat. pressure of water vapor, in psia
c     pw - partial pressure of water vapor, in psia
c
c Convert temperatures and pressures to new units
c
      t = tdb+459.67
      p = bar*.1/6.895
c
c Calculate sat. pressure using Hyland and Wexler formula
c
      c14= 100.45
      c15= 33.193
      c16= 2.319
      c17= 0.17074
      c18= 1.2063

c
c Compute the saturation pressure
c
      pws =psat(tdb)

c Compute partial pressure of water vapor, pw
      pw=pws*rh/100.

c
c Compute humidity ratio, W
      W = .62198*pw/(p-pw)
```

```
c
c Compute the dew point temperature from Peppers formula
      alpha=alog(pw)
      tdp=c14+c15*alpha+c16*alpha**2+c17*alpha**3+c18*pw**.1984
      if(tdp.lt.32.) tdp=90.12+26.412*alpha+.8927*alpha**2
c
c Determine the wet bulb temperature by iteration
c
      iter=0
      error=1
      t1=tdb
      t2=tdp
      twb = (t1+t2)/2.
      do while (abs(error).gt.0.0001)
      iter=iter+1
      WS=.62198*psat(twb)/(p-psat(twb))
      error=w-((1093-0.556*twb)*ws-.24*(tdb-twb))/
     $     (1093+0.444*tdb-twb)
      if(error.gt.0) then
      t2=twb
      else
      t1=twb
      endif
      if(iter.gt.20)stop
      twb=(t1+t2)/2.
      end do
      return
      end
```

```
SUBROUTINE SOLAR(mm,dd,lh,lm,ash,asm,isolflg,dst)
    common /angles/dec,beta,theta,phi
c Subroutine computes solar time and solar angles based on
c latitude, longitude, date, and standard time
c Definitions
c    lat - latitude (deg)
c    long - longitude (deg)
c    yy - year
c    mm - month
c    dd - day
c    lt - local time (fraction of hours)
c    ast - apparent solar time (fraction of hours)
c    lh,lm - local time (hours, minutes)
c    ash,asm - apparent solar time (hours, minutes)
c    dec - declination angle (deg)
c    beta - solar altitude (deg)
c    phi - solar azimuth (deg)
c    h - hour angle (deg)
c    theta - angle of incidence (deg)
c    isolflg - flag to indicate sign of ast-lt

    real lat,long,beta,dec,h,theta,lt,ast
    integer mm,dd,mo(12),lh,lm,ash,asm,isolflg
    data mo/31,28,31,30,31,30,31,31,30,31,30,31/
    data lat,long/42.7055,93.6092/

    degtrad = 3.14159/180.0

c
c Determine the day number from mm/dd
c
    nday = 0
    do 10 i=2,mm
  10 nday = nday+mo(i-1)
    nday = nday+dd
c
c Calculate the equation of time (minute)
c
    a2 = 360.*(real(nday)-81.)/364*degtrad
    eot = 9.87*sin(a2*2) - 7.53*cos(a2) - 1.5*sin(a2)
c
c Determine if daylight savings time is in effect.
c DST begins April 6. CST begins October 27.
c
```

```
      dst=0
      if (nday.ge.96.and.nday.le.300) dst=1

c
c Convert local hr/min to fraction hours
c
      lt = real(lh) + real(lm)/60.0
c
c Calculate apparent solar time (hours)
c
      ast = lt + (4.0*(90.0-long) + eot)/60.0 - dst
c
c Convert apparent solar time back to hr/mm
c
      ash = int(ast)
      asm = 60.0*(ast-real(ash))
c
c If apparent solar time is negative, the solar time is from the
c previous day. Mark negative times as 99
c
      if (ast.lt.0) then
         ash=99
         asm=99
      endif

c
c Set solar flag (isolflg) to indicate if solar time is ahead or
c behind local time
c isolflg=0 for solar time ahead of local time.
c isolflg=1 for solar time behind local time by less than one hour
c isolflg=2 for solar time behind local time by more than one hour
c
      if (lh.eq.0.and.lm.eq.0) then
         if(ast.gt.0.0) isolflg=0
         if(ast.le.0.0) isolflg=1
         if(ast.le.-1.0) isolflg=2
      endif
c
c Calculate the solar declination angle method from HAP
c
      go = 2*3.14159 * (nday+284) / 365.24
      g = go+0.007133*sin(go)+0.03268*cos(go)-0.000318*sin(2.0*go)
     $     + 0.000145*cos(2.*go)
      decr = asin(0.3979 * sin(g))
```

```
      dec = decr / degtrad
c
c Calculate the hour angle, solar altitude and angle of incidence
c for a horizontal surface
      h = abs(12.0 - ast)*15.0
      c1 = cos(lat*degtrad) * cos(h*degtrad) * cos(decr)
      c2 = sin(lat*degtrad) * sin(decr)
      sbeta = c1 + c2
      ctheta = sbeta
      beta = asin(sbeta) / degtrad
      c3 = sbeta * sin(lat*degtrad) - sin(decr)
      c4 = cos(beta*degtrad) * cos(lat*degtrad)
      phi = acos(c3/c4) / degtrad
      theta = acos(ctheta) / degtrad
c
c If beta < 0 then sun is not up. beta=0 and theta=90
c
      if (beta.lt.0.0) then
         beta = 0
         theta = 90.0
      endif
      return
      end
```

```
c TMYGEN.FOR
c Program to read TMY file and replace specific data from weather
c data collected at the ERS
      character*12 ifile1
      character*10 ifile2
      character*25 j1
      character*40 j2
      character*6 inpdate
      logical match
      integer wban,yy,dd,endt,etr,dn,hor,db,dp,wd,ws,sc1,sc2
      integer YR1,day1,ast,ash,asm,f1,f2
      write (*,'(A\)')' Enter the TMY weather file name: '
      read (*,100) ifile1
      write (*,'(A\)')' Enter the date for the new data: '
      read (*,101) inpdate
  100 format(a12)
  101 format(a6)
      ifile2 = inpdate // '.tmy'
      open (1,file=ifile1)
      open (2,file=ifile2)
      open (3,file='tmynew.txt')
      match = .false.
      ISC2=0
c
c Outer loop is to read each line of replacement data file
c
      do 20 i=1,24
         match =.false.
         read(2,2000) YR1,mo1,day1,ash,asm,ILCH,ILCM,IF1,IGND,IF2,
     $            IGHOR,IBAR,IDB,IDP,IWD,IWS,ISC
 2000 format(7i2,i1,i4,i1,i4,i5,4i4,i2)
      ast=ash*100

c
c Inner loop is to read each line of Des Moines TMY file. Data are
c replaced when a match in date and time is found.
c
c
   10 read(1,110,end=40) wban,yy,mm,dd,endt,lch,lcm,etr,f1,dn,j1,
     $     f2,hor,j2,mbar,db,dp,wd,ws,sc1,sc2,j3
  110 format(i5,3i2,i4,2i2,i4,i1,i4,a25,i1,i4,a40,i5,2i4,i3,i4,2i2,i1)
       if(mo1.eq.mm.and.day1.eq.dd.and.ast.eq.endt) then
          match =.true.
          write(3,110) wban,yr1,mm,dd,endt,ILCH,ILCM,etr,IF1,IGND,j1,
```

```
     $         IF2,IGHOR,j2,IBAR,IDB,IDP,IWD,IWS,ISC,ISC2,j3
        print *,' Match found:', yr1,mm,dd,endt
      else
          match=.false.
          write(3,110) wban,yy,mm,dd,endt,lch,lcm,etr,f1,dn,j1,
     $         f2,hor,j2,mbar,db,dp,wd,ws,sc1,sc2,j3
      endif

      if (.not.match) go to 10
   20 continue

c
c Continue to read and write remainder of Des Moines TMY file until end.
c
      print *,' Processing remainder of TMY file'
  30  read(1,110,end=40) wban,yy,mm,dd,endt,lch,lcm,etr,f1,dn,j1,
     $     f2,hor,j2,mbar,db,dp,wd,ws,sc1,sc2,j3
      write(3,110) wban,yy,mm,dd,endt,lch,lcm,etr,f1,dn,j1,
     $     f2,hor,j2,mbar,db,dp,wd,ws,sc1,sc2,j3
      go to 30
  40  continue
      close(1)
      close(2)
      close(3)
      end
```

```
c Program tranewtr
c This program takes an ERS weather file and processes it into a weather
c file for the TRACE program.
c The ERS weather data is recorded in one-minute intervals for recent files
c and two-minute intervals for older files. The order read is:
c     6-digit date - date
c     4-digit time - time
c     barometric pressure (bars) - bar
c     humidity (%) - rh
c     temperature (F) - tdb
c     direct-normal irradiation (Btu/ft^2/hr) - pyrhel
c     total-horizontal irradiation (Btu/ft^2/hr) - pyran
c     wind direction (degrees) - wd
c     wind speed (miles/hr) - ws1
c
c The weather data required for TRACE is hourly based and includes:
c     dry-bulb temperature (F) - tdb
c     wet-bulb temperature (F) - twb
c     atmospheric pressure (psia) - patm
c     humidity ratio (lbmv/lbma) - w
c     cloud cover modifier (non-dimensional) - ccm
c
c
      common /angles/dec,beta,theta,phi
      character*8 inpdate,citycode
      character*12 ifile1,ifile2,ofile
      character*67 header1
      character*11 head1
      character*3 card,mo
      character*170 str1
      real dec, beta, theta
      integer yy, mm, dd, ash, asm, isoflg
      logical onemin
      dimension tdb(24),rh(24),ws(24),pyran(24),pyrhel(24)
      dimension bar(24),twb(24),w(24),ccm(24),dum(24),p(24),idum(24)
      dimension a(12),b(12),c(12)
      data a/390,385,376,360,350,345,344,351,365,378,387,391/
      data b/.142,.144,.156,.180,.196,.205,.207,.201,.177,.160,.149
     &      ,.142/
      data c/.058,.060,.071,.097,.121,.134,.136,.122,.092,.073,.063
     &      ,.057/
c
c Read input file information
      write (*,'(A\)') ' Enter the date of the weather file '
```

```
      read (*,100) inpdate
  100 format(a8)
      write (*,'(A\)') ' One minute data ? .T. or .F. '
      read (*,99) onemin
   99 format(l1)
      if(onemin) then
        num=60
      else
        num=30
      endif
      ifile1 = inpdate // '.wtr'
      write (*,'(A\)') ' Enter the name of the Trace weather file '
      read (*,100) citycode
      ifile2 = citycode // '.wtr'
      ofile = citycode // '.out'
      open (1,file=ifile1)
      open (2,file=ifile2)
      open (3,file=ofile)
      read (1,101) header1
  101 format(a80)
c
c Outer loop is for 12 hours of the day while inner loop is for number of
c data values in an hour.

      DO 20 I=1,24
        sumbar=0.0
        sumtdb=0.0
        sumpyh=0.0
        sumpyr=0.0
        sumws =0.0
        sumrh = 0.0
        DO 10 j=1,num
          read (1,*)date,time,bar1,rh1,t1,pyran1,pyrhel1,wd,ws1
          sumbar = bar1 + sumbar
          sumrh = rh1 + sumrh
          sumtdb = t1 + sumtdb
          sumpyh = sumpyh + pyran1
          sumpyr = sumpyr + pyrhel1
          sumws = sumws + ws1
   10   CONTINUE
        bar(i)  = sumbar/num
        tdb(i)  = sumtdb/num
        rh(i)   = sumrh/num
        pyran(i) =sumpyh/num
```

```
      pyrhel(i)=sumpyr/num
      ws(i)   =sumws/num
c
c Calculate the psychrometric properties
      call psychro(tdb(i),bar(i),rh(i),twb(i),tdp,w(i))
      print *, bar(i),tdb(i),twb(i),w(i)
      p(i)=bar(i)*0.1/6.895*2.0360

  20  CONTINUE
c
c The cloud cover modifier (CCM) is used to modify the ASHRAE clear-sky model
c to account for cloudiness. This can be determined from total-horizontal
c solar data taken at the ERS. Dividing the pyranometer value by the
c calculated clear-sky value for the same date and time will provide an
c estimate for CCM.
c Solar calculations are performed in subroutine SOLAR
c
c Convert 6-digit date into yy, mm, dd
     yy=date/10000
     mm=(date-yy*10000)/100
     dd=(date-yy*10000-mm*100)
c Loop for 24 hours of the day
     Do 30 i=1,24
      lm = 0
      lh=i
      call solar(mm,dd,lh,lm,ash,asm,isoflg,dst)
      betar=beta*.0174532
      thetar=theta*.0174532
      if(beta.eq.0) then
        GND=0
        GTH=0
        CCM(i)=1
        sc=1
        ccm2=1
        ccm3=1
      else
       GND=a(mm)/exp(b(mm)/sin(betar))
       GTH=GND*(cos(thetar)+c(mm))
       ccm3=pyran(i)/GTH
       ccm2=pyrhel(i)/GND
       sc=((pyran(i)-pyrhel(i)*cos(thetar))/pyran(i))**2
       ccm(i)=1.-sc
      endif
      write (*,1000) mm,dd,lh, GND, pyrhel(i),GTH,pyran(i),
```

```
     & ccm(i),ccm2,ccm3
 1000  format(1x,i2,1x,i2,1x,i2,1x,7f8.2)
  30  Continue
c
c Calculate values for monthly cooling weather data for trace.
c
      tdbmax=tdb(1)
      tdbmin=tdb(1)
      sumrh = 0.0
      sumccm = 0
      sumpress=0
      sumws = 0
      do 31 i=1,24
      if(tdb(i).gt.tdbmax) tdbmax=tdb(i)
      if(tdb(i).lt.tdbmin) tdbmin=tdb(i)
      sumrh = sumrh + rh(i)
      sumpress=sumpress+p(i)
      sumccm = sumccm+ccm(i)
      sumws = sumws + ws(i)
   31 continue
      dayrange=tdbmax-tdbmin
      averh = sumrh/24.
      aveccm = sumccm/24.
      avepress = sumpress/24.
      avews = sumws/24.

c
c Read and echo card 01 through 02
c
      read(2,200)head1
  200 format(a11)
      write(3,200)head1
      do 40 l=1,5
      read (2,201)card,head1
  201 format(a3,a11)
      write(3,201)card,head1
   40 continue
      read (2,202)str1
      write(3,202)str1
  202 format(a170)
c
c Read and replace card 03 data
c
      do 41 i=1,12
```

```
      read(2,300) ic,mo,(dum(j),j=1,6)
  300 format(i2,1x,a3,1x,f4.0,1x,f4.0,1x,f5.0,3(1x,f4.0))
      write(3,301) ic,mo,tdbmax,dayrange,averh,aveccm,avepress,avews
  301 format('0',i1,'/',a3,'/',f4.1,'/',f4.1,'/',f5.2,'/',f4.2,'/',
     &      f4.1,'/',f4.1)
   41 continue
c
c Read and replace cards 04, 05, 06 and 07 data
c
      do 42 m=1,12
      read (2,203) ic,(dum(j),j=1,12)
      write(*,404) ic,(dum(j),j=1,12)
  203 format(i2,12(1x,f4.1))
      write(3,404) ic,(tdb(j),j=1,12)
  204 format(i2,12('/',f4.1))
  404 format('0',i1,12('/',f4.1))
      read (2,203) ic,(dum(j),j=13,24)
      write(*,404) ic,(dum(j),j=13,24)
      write(3,404) ic,(tdb(j),j=13,24)
      read (2,203) ic,(dum(j),j=1,12)
      write(*,404) ic,(dum(j),j=1,12)
      write(3,404) ic,(twb(j),j=1,12)
      read (2,203) ic,(dum(j),j=13,24)
      write(*,404) ic,(dum(j),j=13,24)
      write(3,404) ic,(twb(j),j=13,24)
   42 continue
c
c Read and replace card 08 data
c
      do 43 m = 1,12
      read(2,205) ic,(dum(j),j=1,24)
      write(*,806) ic,(w(j),j=1,24)
      write(3,806) ic,(w(j),j=1,24)
  205 format(i2,24(1x,f6.4))
  206 format(i2,24('/',f6.4))
  806 format('0',i1,24('/',f6.4))
   43 continue
c
c Read and replace card 09 data
c
      do 44 m=1,12
      read(2,900) ic,(idum(j),j=1,24)
      write(*,908) ic,(ccm(j),j=1,24)
      write(3,908) ic,(ccm(j),j=1,24)
```

```
  900 format(i2,24(1x,i1))
  908 format('0',i1,24('/',f4.2))
   44 continue
c
c Read and replace card 10 data
c
      do 45 m=1,12
      read(2,1001)ic,(dum(j),j=1,24)
      write(*,210)ic,(ws(j),j=1,24)
      write(3,210)ic,(ws(j),j=1,24)
 1001 format(i2,24(1x,f3.1))
   45 continue
c
c Read and replace card 11 data
c
      do 46 m=1,12
      read(2,1100) ic,(dum(j),j=1,24)
      write(*,212) ic,(p(j),j=1,24)
      write(3,212) ic,(p(j),j=1,24)
 1100 format(i2,24(1x,f4.1))
   46 continue
c
c Read and replace typical weather data with ERS generated weather data
c Dry bulb and wet bulb temperatures (Cards 12, 13, 14 and 15)
c
      do 50 m=1,12
      read (2,203) ic,(dum(j),j=1,12)
      write(*,204) ic,(dum(j),j=1,12)
      write(3,204) ic,(tdb(j),j=1,12)
      read (2,203) ic,(dum(j),j=13,24)
      write(*,204) ic,(dum(j),j=13,24)
      write(3,204) ic,(tdb(j),j=13,24)
      read (2,203) ic,(dum(j),j=1,12)
      write(*,204) ic,(dum(j),j=1,12)
      write(3,204) ic,(twb(j),j=1,12)
      read (2,203) ic,(dum(j),j=13,24)
      write(*,204) ic,(dum(j),j=13,24)
      write(3,204) ic,(twb(j),j=13,24)
   50 continue
c
c Replace humidity ratio for all hours of all months (Card 16)
c
      do 52 m = 1,12
      read(2,205) ic,(dum(j),j=1,24)
```

```
      write(*,206) ic,(w(j),j=1,24)
      write(3,206) ic,(w(j),j=1,24)
   52 continue

c Replace cloud cover modifier for all hours of all months (Card 17)
c
      do 54 m=1,12
      read(2,207) ic,(dum(j),j=1,24)
      write(*,208) ic,(ccm(j),j=1,24)
      write(3,208) ic,(ccm(j),j=1,24)
  207 format(i2,24(1x,f4.2))
  208 format(i2,24('/',f4.2))
   54 continue
c
c Replace wind speed for all hours of all months (Card 18)
c
      do 56 m=1,12
      read(2,209)ic,(dum(j),j=1,24)
      write(*,210)ic,(ws(j),j=1,24)
      write(3,210)ic,(ws(j),j=1,24)
  209 format(i2,24(1x,f4.1))
  210 format(i2,24('/',f4.1))
   56 continue
c
c Replace barametric pressure for all hours of all months (Card 19)
c
      do 58 m=1,12
      read(2,211) ic,(dum(j),j=1,24)
      write(*,212) ic,(p(j),j=1,24)
      write(3,212) ic,(p(j),j=1,24)
  211 format(i2,24(1x,f5.2))
  212 format(i2,24('/',f5.2))
   58 continue
      stop
      end
```

APPENDIX F SAMPLE REPORT FROM THE ANAYSIS PROGRAM

Test Results for System-A Operating as CAV System from 990223 through 990225

1. Test Conditions

Zone Control

- Design heat temperature: 72 °F
- Design cool temperature: 73 °F
- Internal loads schedule: see Figure F.1
- Span: 1.5 °F

Zone Air

- Exterior test rooms (east, south and west): 700 CFM
- Interior test rooms: 400 CFM

System Control

- Supply air temperature: 58 °F
- Heating schedule: 24 hours available
- Cooling schedule: available
- Cool control: constant (supply air set point, 58 °F from AHU fan)
- Preheat: NOT available
- Humidity control: NOT available
- Economizer: enabled
- Outside air control: temperature (65 °F)

System Air

System airflow rates were:

- Supply air flow: 2400 CFM
- Return air path: Plenum
- Minimum outside air flow: scheduled as shown in Figure F.2
- Outside air control: temperature
- Duct air loss: None
- Duct heat gain: 0.5 °F (increase)

System Fan

- Supply air static pressure: 1.4 inch H2O
- Fan schedule: always on
- Supply air delta T: 3.36 °F (increase)
- Fan control: Speed
- Motor placement: In-Air flow
- Fan placement: Draw-Through
- Fan supply kW: 3.75

Heat Source

- System heat source: Not available
- Zone heat source: electric, max 3.34 KW for exterior rooms and max 2 KW for interior rooms

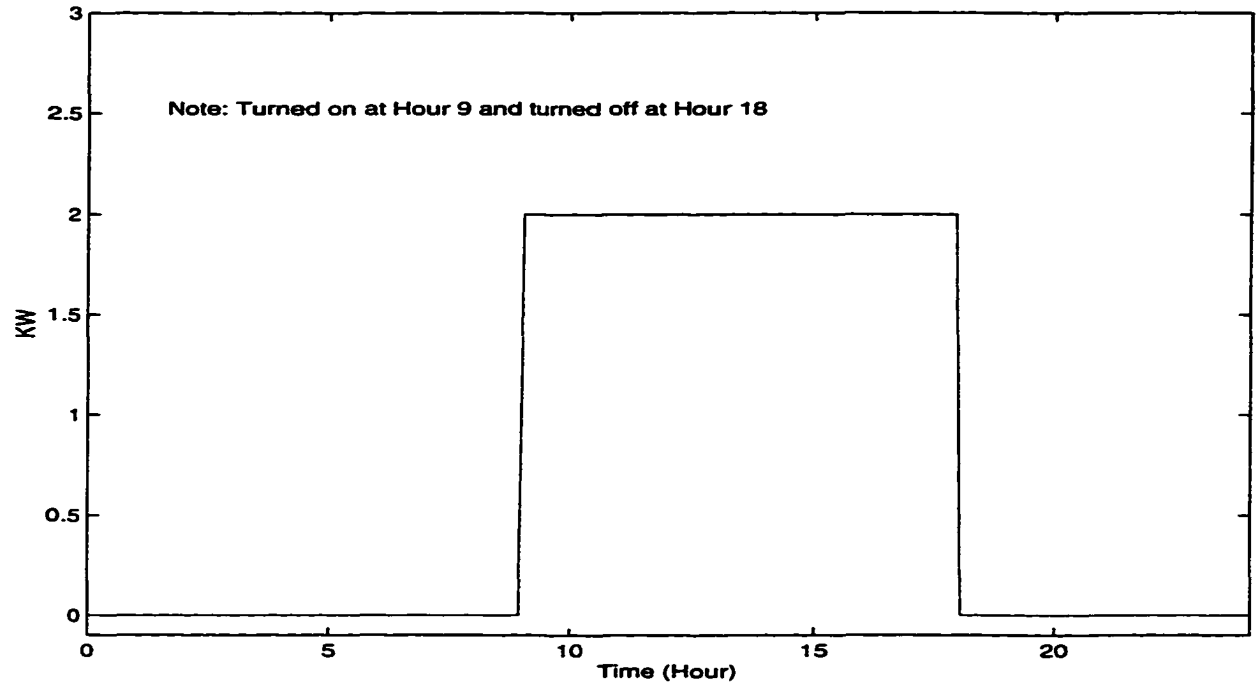

Figure F.1 Each room's baseboard heaters schedule during the test period

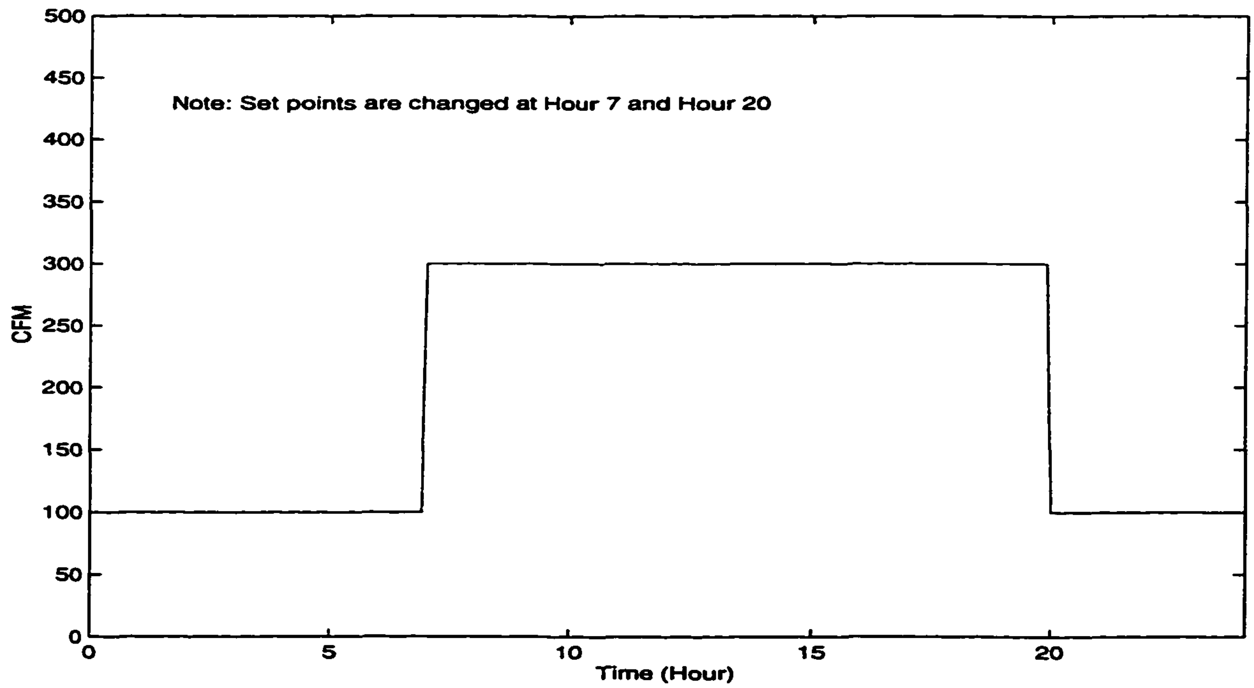

Figure F.2 Minimum outside air flow rate schedule during the test period

2. Test Data Summary

Table F.1 AHU A data summary

Data points measured	unit	Minimum	Average	Maximum
Supply air flow rate	cfm	2401	2410	2420
Outside air flow rate	cfm	753	995	1495
Return air temperature	F	70.3	72.4	73.5
Mixed air temperature	F	55.9	56.5	56.8
Cooling coil leaving air temperature	F	55.6	56.2	56.5
Discharge air temperature	F	58.6	59.0	59.3
Chilled water flow rate	gpm	15.15	15.19	15.25
Chilled water inlet temperature	F	74.9	77.9	81.0
Chilled water outlet temperature	F	72.9	74.5	76.4
Mixed chilled water temperature	F	74.7	77.7	80.8
Cooling energy rate (air side)	Btu/hr	0	0	0
Cooling energy rate (water side)	Btu/hr	0	0	2

Table F.2 System A Zone data summary

Data points measured	unit	East	South	West	Interior
Maximum TAB discharge air flow rate	cfm	701	700	701	400
Average TAB discharge air flow rate	cfm	700	700	700	400
Minimum TAB discharge air flow rate	cfm	699	699	699	400
Maximum TAB discharge air temp.	F	79.0	78.8	80.1	75.6
Average TAB discharge air temp.	F	72.0	71.5	72.5	68.2
Minimum TAB discharge air temp.	F	59.9	59.4	59.4	58.8
Maximum plenum air temperature	F	73.6	74.7	74.7	71.3
Average plenum air temperature	F	72.4	72.7	72.8	70.8
Minimum plenum air temperature	F	67.4	70.6	71.2	67.4
Maximum room air temperature	F	74.0	73.5	73.7	72.4
Average room air temperature	F	71.9	71.9	71.9	71.8
Minimum room air temperature	F	69.0	69.6	69.4	66.8
Maximum heating water flow rate	gpm	0.01	0.02	0.01	0.00
Average heating water flow rate	gpm	0.01	0.02	0.01	0.00
Minimum heating water flow rate	gpm	0.01	0.01	0.01	0.00
Maximum heating water inlet temperature	F	73.4	74.5	73.8	71.4
Average heating water inlet temperature	F	72.6	72.9	72.9	70.5
Minimum heating water inlet temperature	F	68.0	68.0	68.4	65.5
Maximum heating water outlet temperature	F	73.8	74.5	73.7	71.5
Average heating water outlet temperature	F	72.9	72.8	72.7	70.7
Minimum heating water outlet temperature	F	68.4	67.8	68.1	65.5
Maximum reheat energy rate (air side)	Btu/hr	15298	15143	16163	7213
Average reheat energy rate (air side)	Btu/hr	9963	9572	10386	4052
Minimum reheat energy rate (air side)	Btu/hr	553	223	306	70
Maximum reheat energy rate (water side)	Btu/hr	0	4	1	0
Average reheat energy rate (water side)	Btu/hr	0	1	1	0
Minimum reheat energy rate (water side)	Btu/hr	0	0	0	0
Maximum reheat energy rate (elec. side)	Btu/hr	13585	14345	15057	6585
Average reheat energy rate (elec. side)	Btu/hr	8586	8911	9548	3702
Minimum reheat energy rate (elec. side)	Btu/hr	0	0	0	0

3. Graphical Presentation

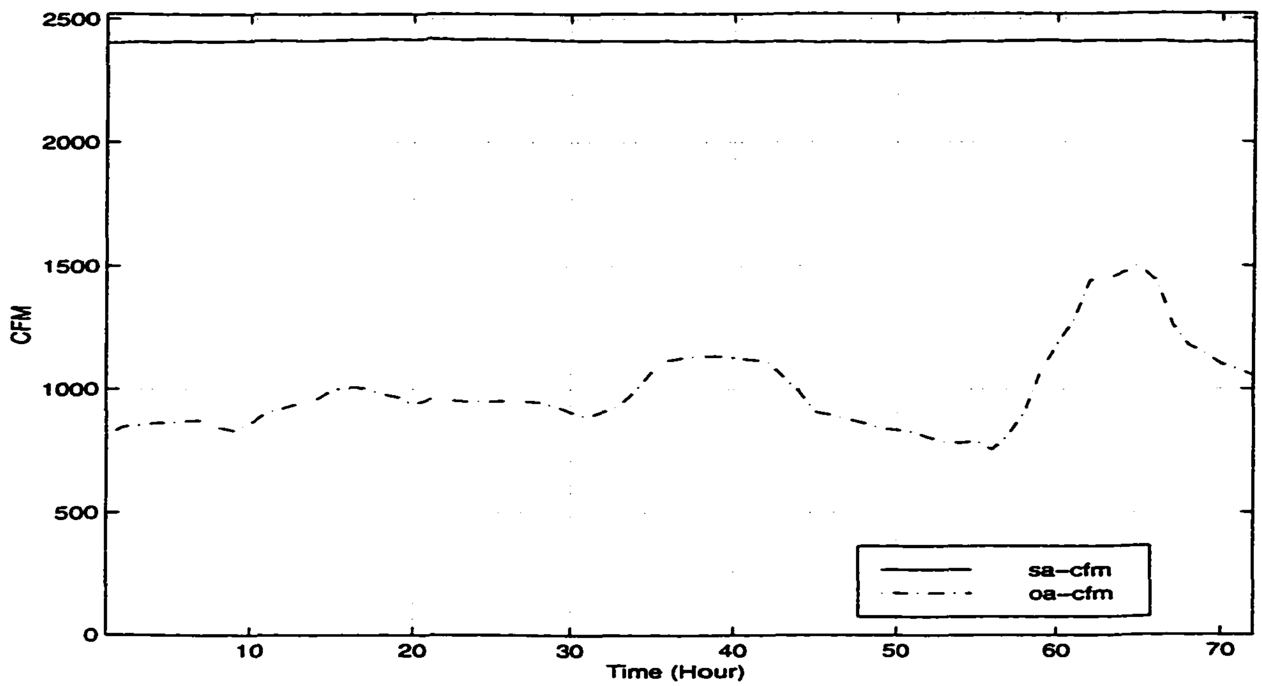

Figure F.3 System-A supply air and outside air flow rates from 990223 through 990225

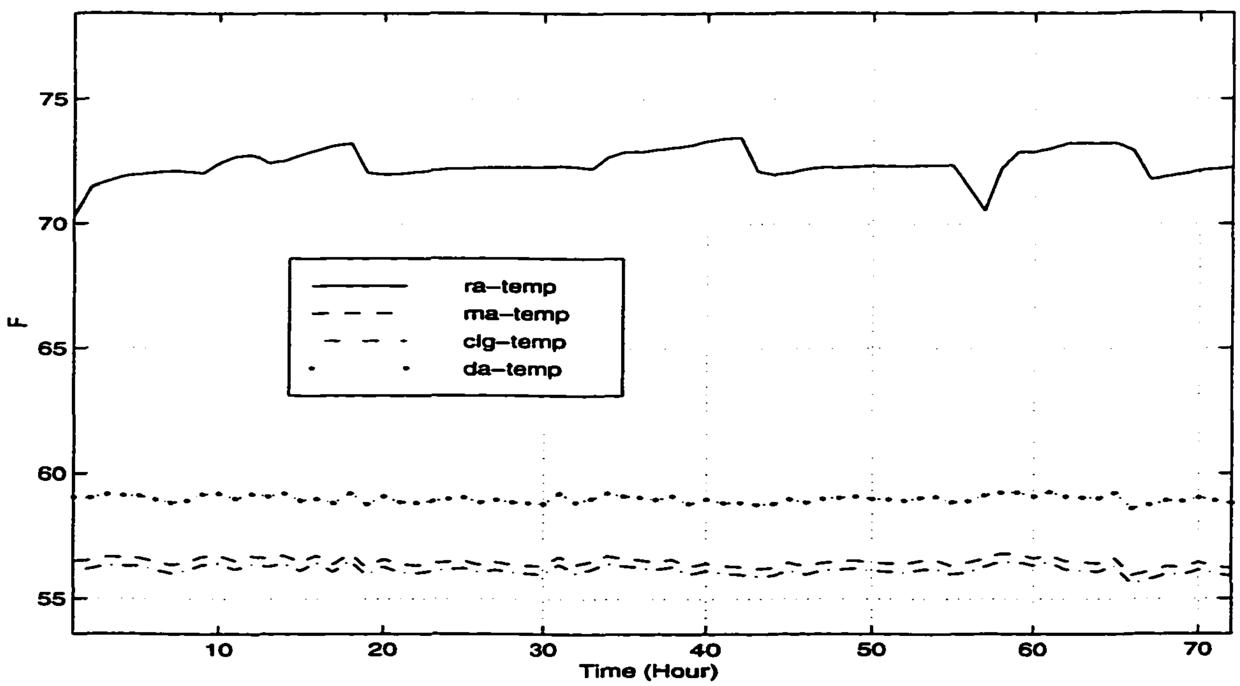

Figure F.4 System-A return, mixed, cooling coil, and discharge air temperatures from 990223 through 990225

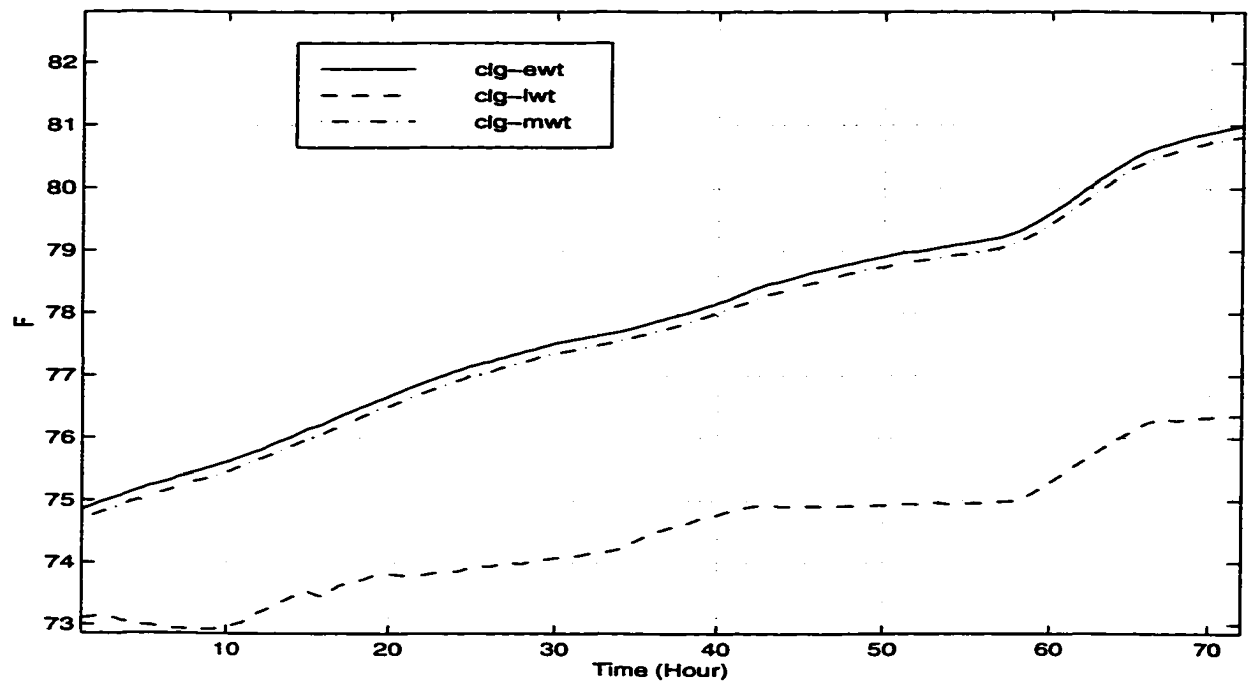

Figure F.5 System-A chilled water entering, leaving and mixing temperatures from 990223 through 990225

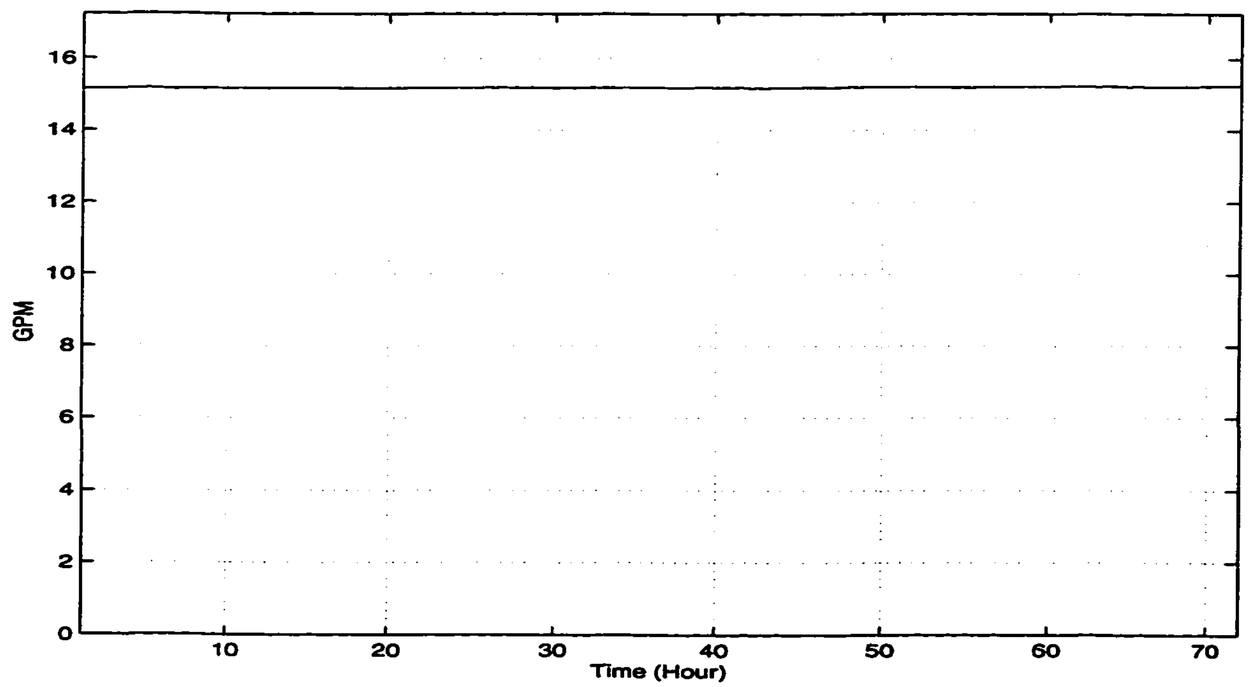

Figure F.6 System-A chilled water flow rate from 990223 through 990225

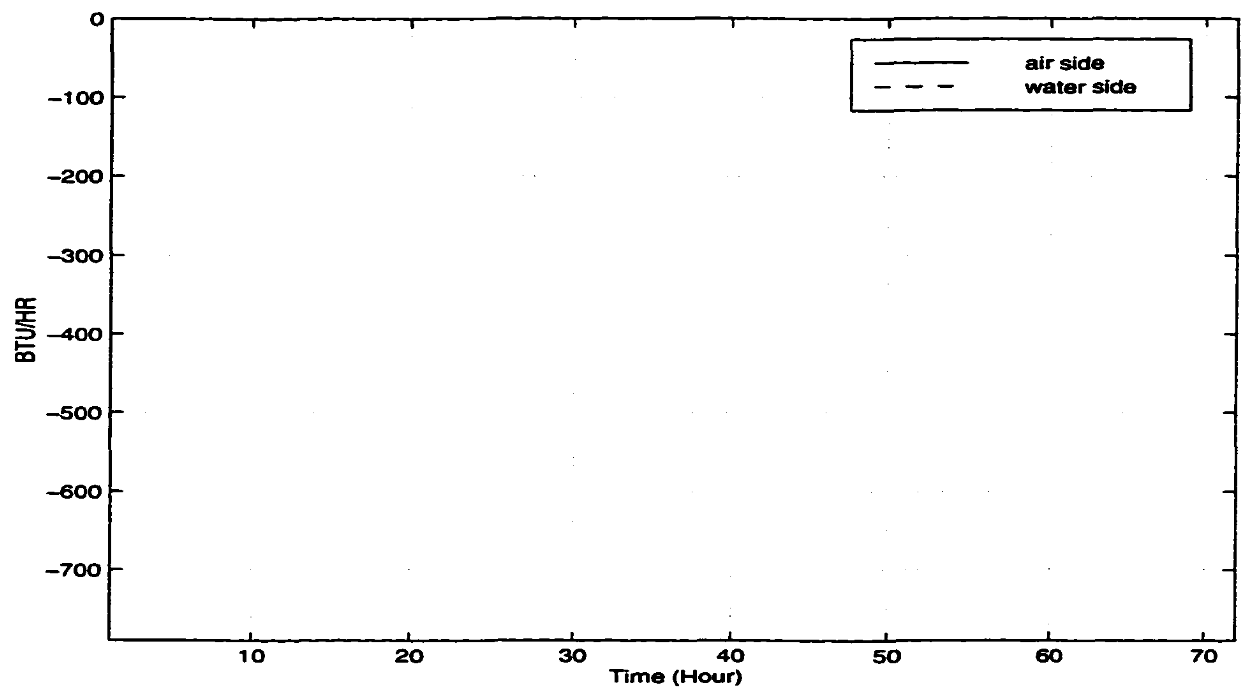

Figure F.7 System-A cooling coil load (air side and water side) from 990223 through 990225

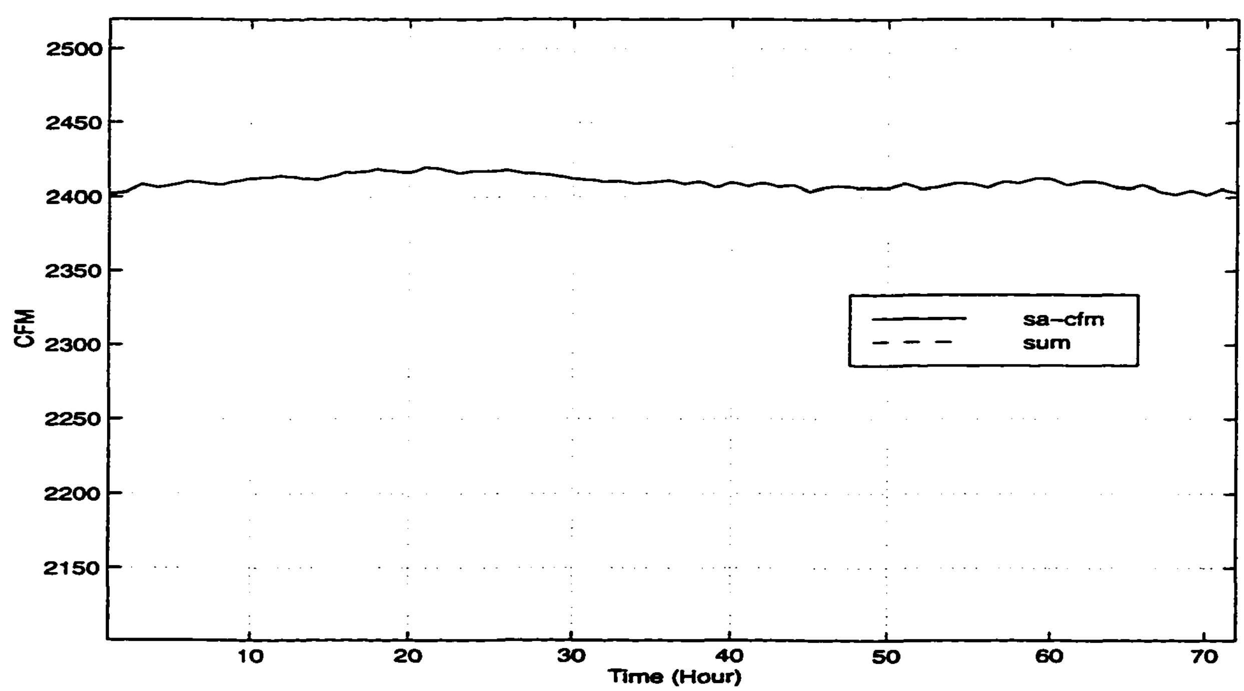

Figure F.8 System-A sum of zone air flow rates vs. AHU' supply air flow rate from 990223 through 990225

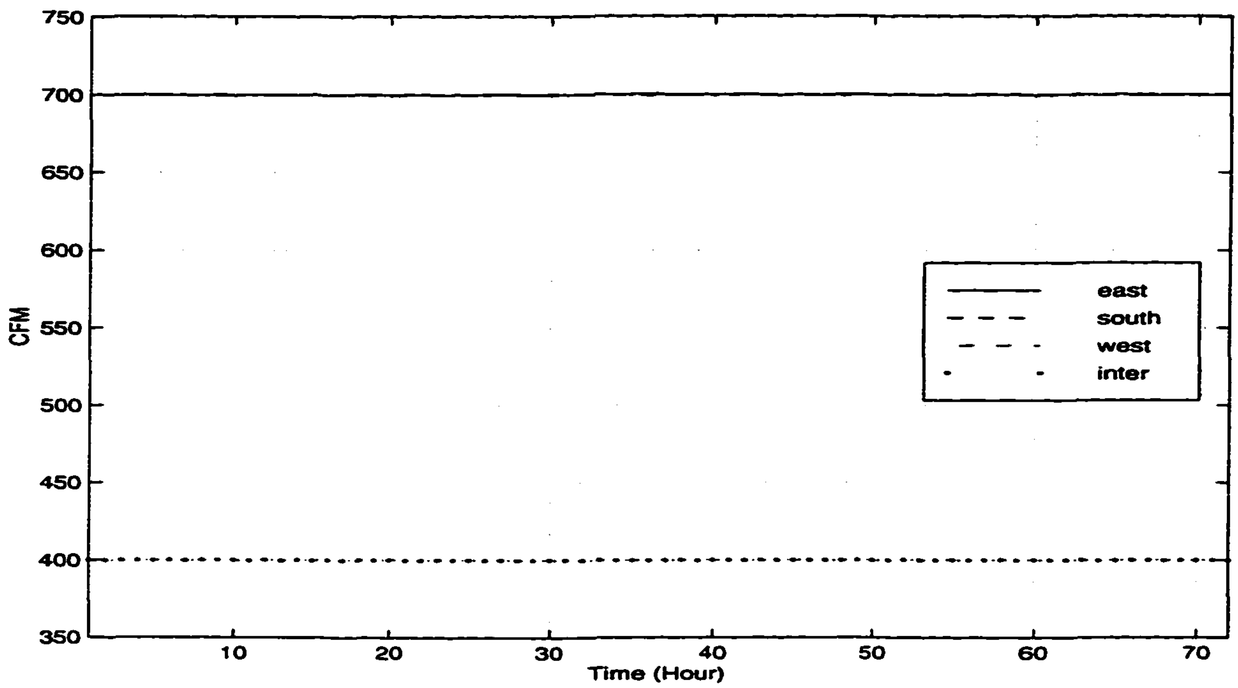

Figure F.9 System-A zone supply air flow rates from 990223 through 990225

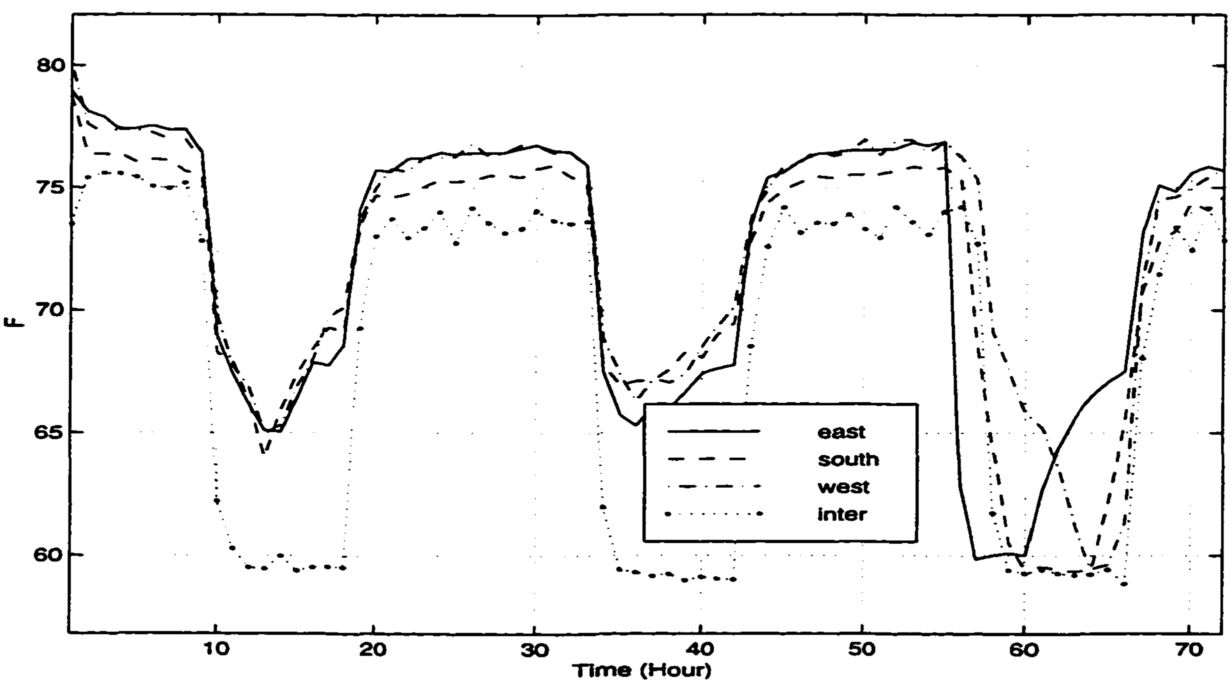

Figure F.10 System-A zone supply air temperatures from 990223 through 990225

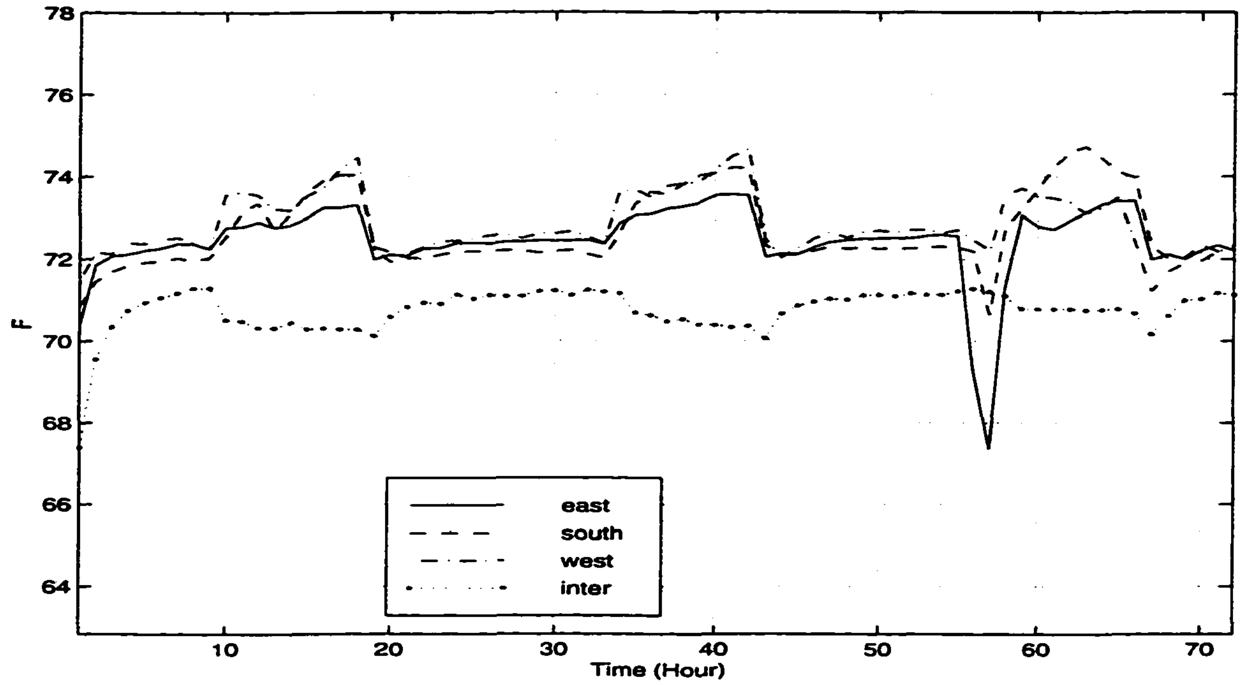

Figure F.11 System-A zone plenum temperatures from 990223 through 990225

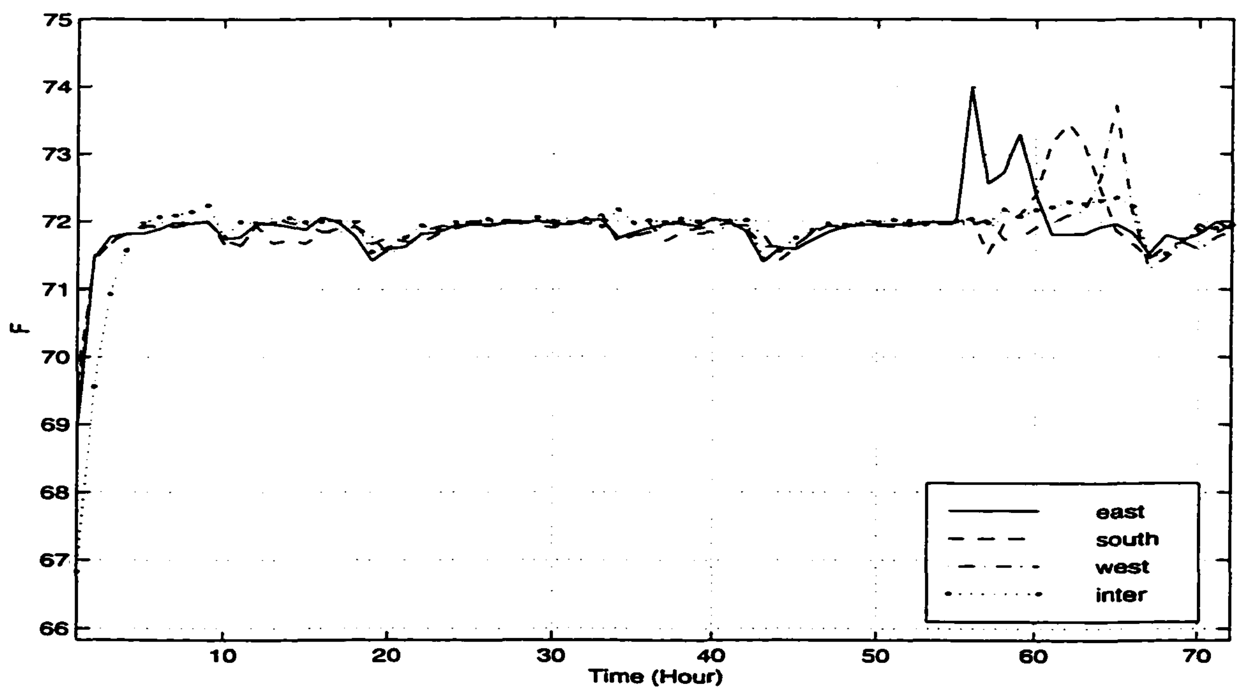

Figure F.12 System-A zone temperatures from 990223 through 990225

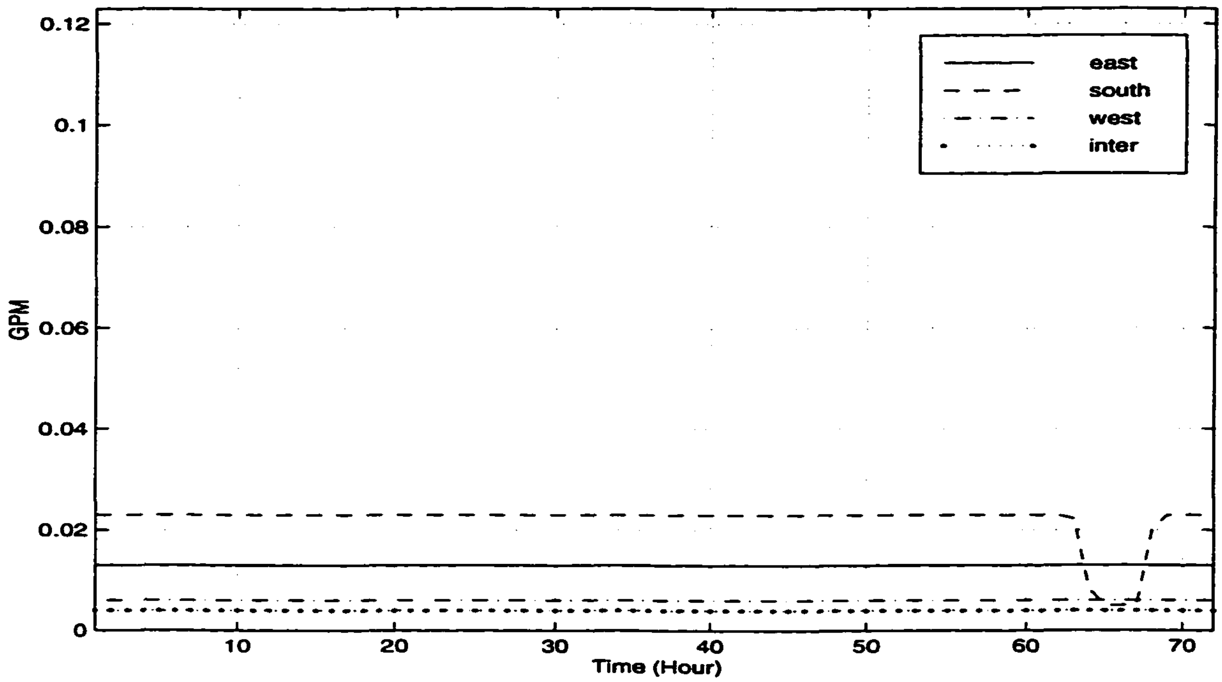

Figure F.13 System-A zone heating water flow rates from 990223 through 990225

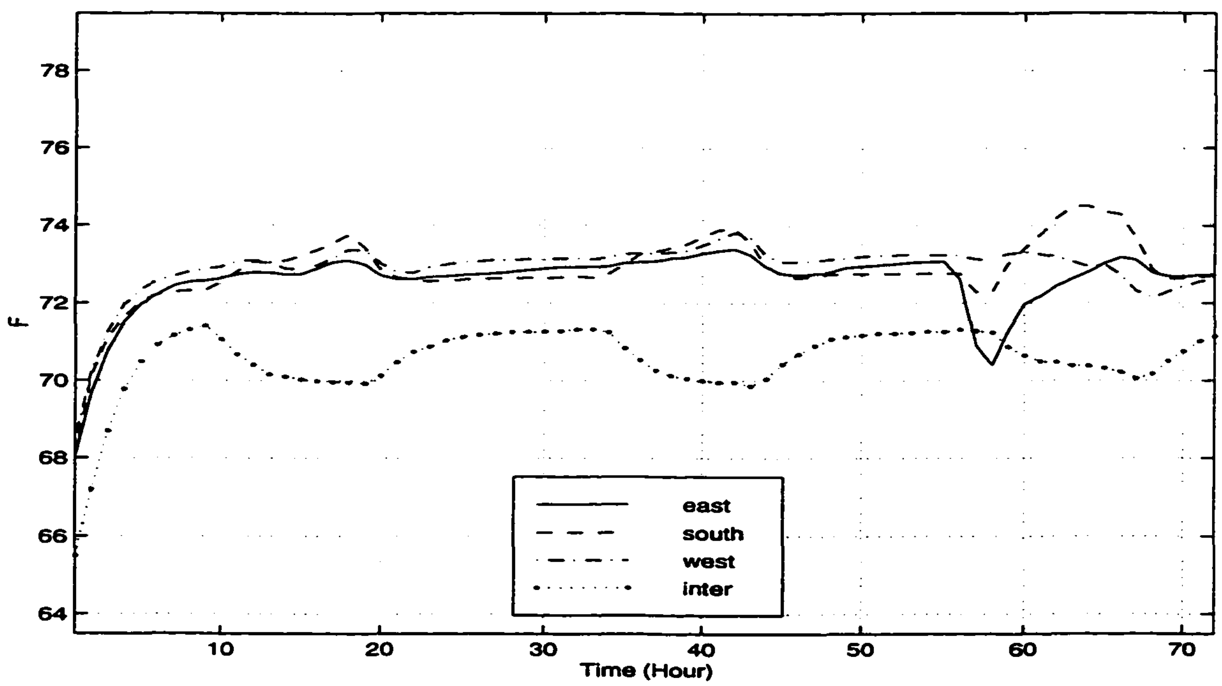

Figure F.14 System-A zone heating water inlet temperatures from 990223 through 990225

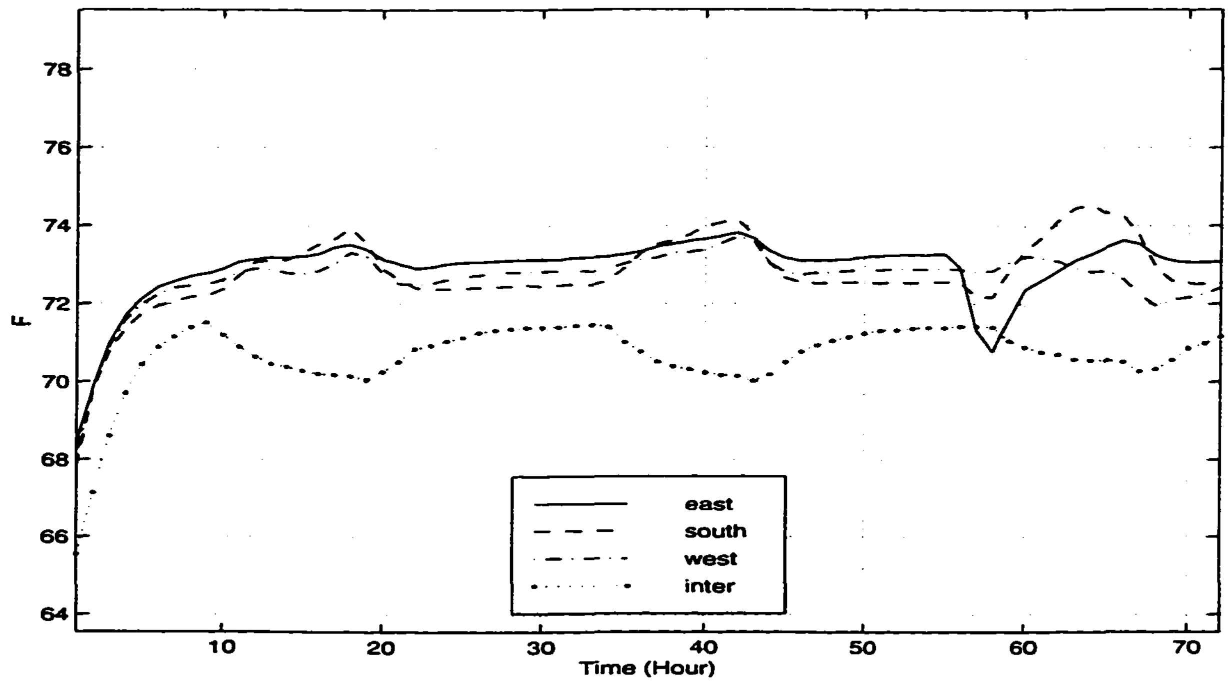

Figure F.15 System-A zone heating water outlet temperatures from 990223 through 990225

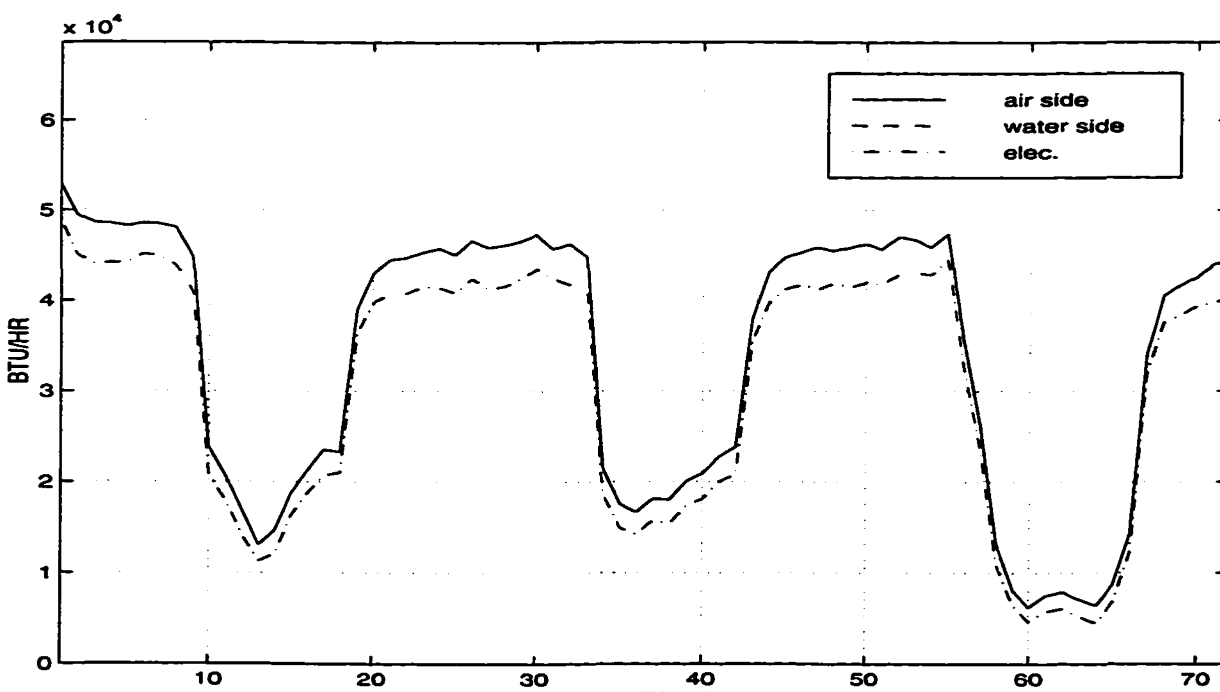

Figure F.16 System-A sum of zone reheat energy rate (air, water, and elec. side) from 990223 through 990225

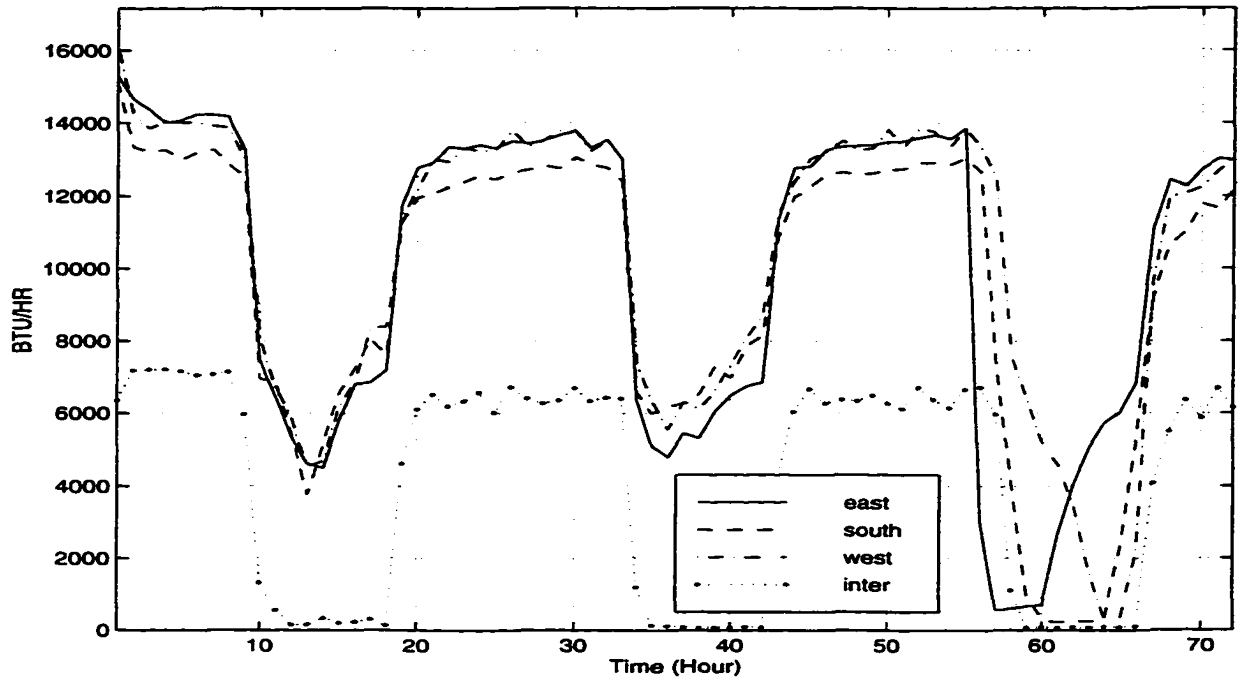

Figure F.17 System-A zone reheat energy rate (air side) from 990223 through 990225

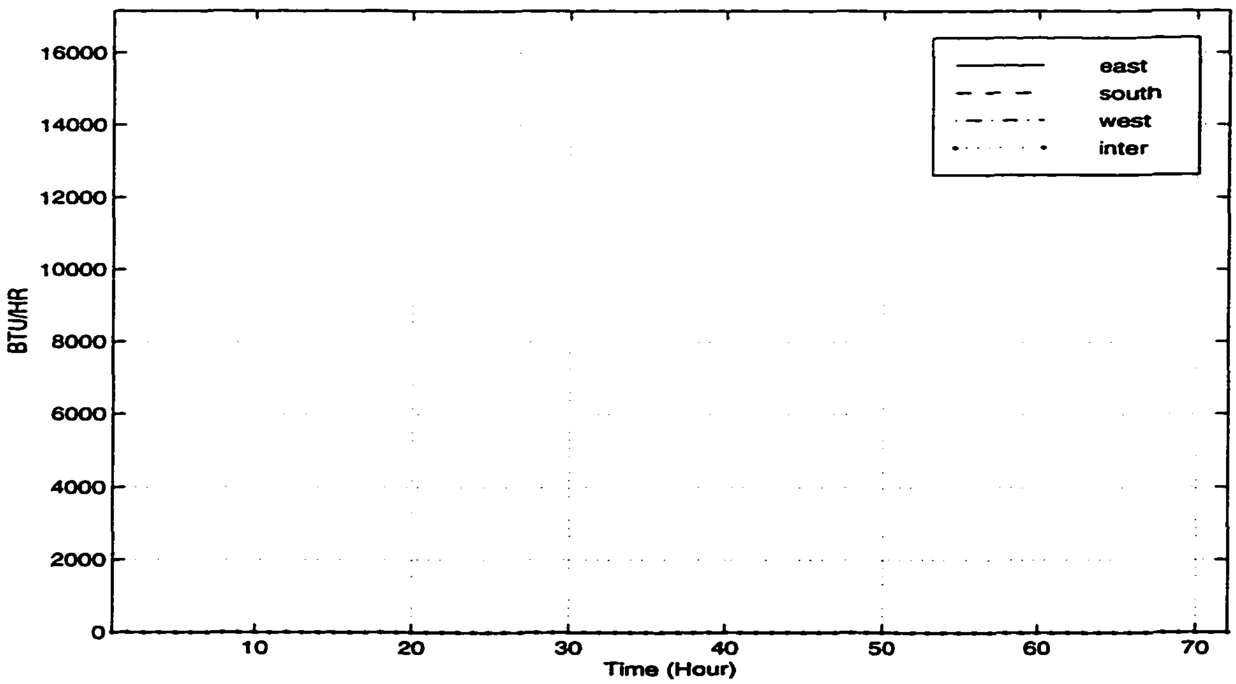

Figure F.18 System-A zone reheat energy rate (water side) from 990223 through 990225

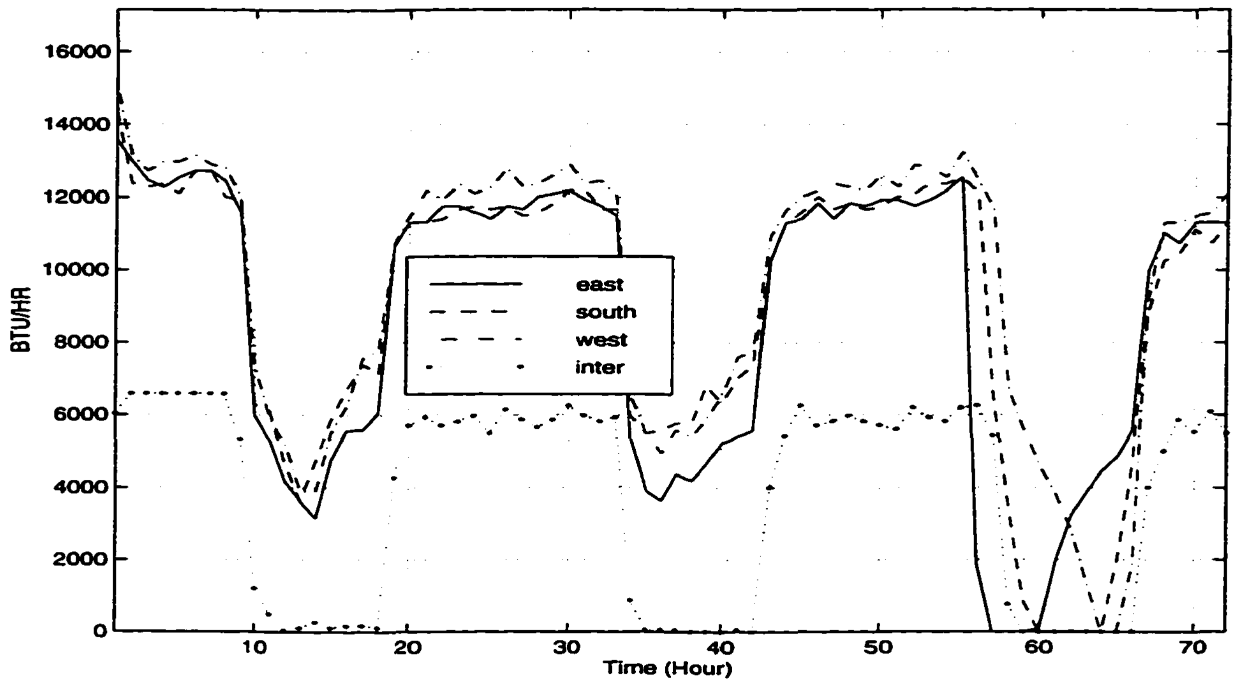

Figure F.19 System-A zone reheat energy rate (elec. side) from 990223 through 990225

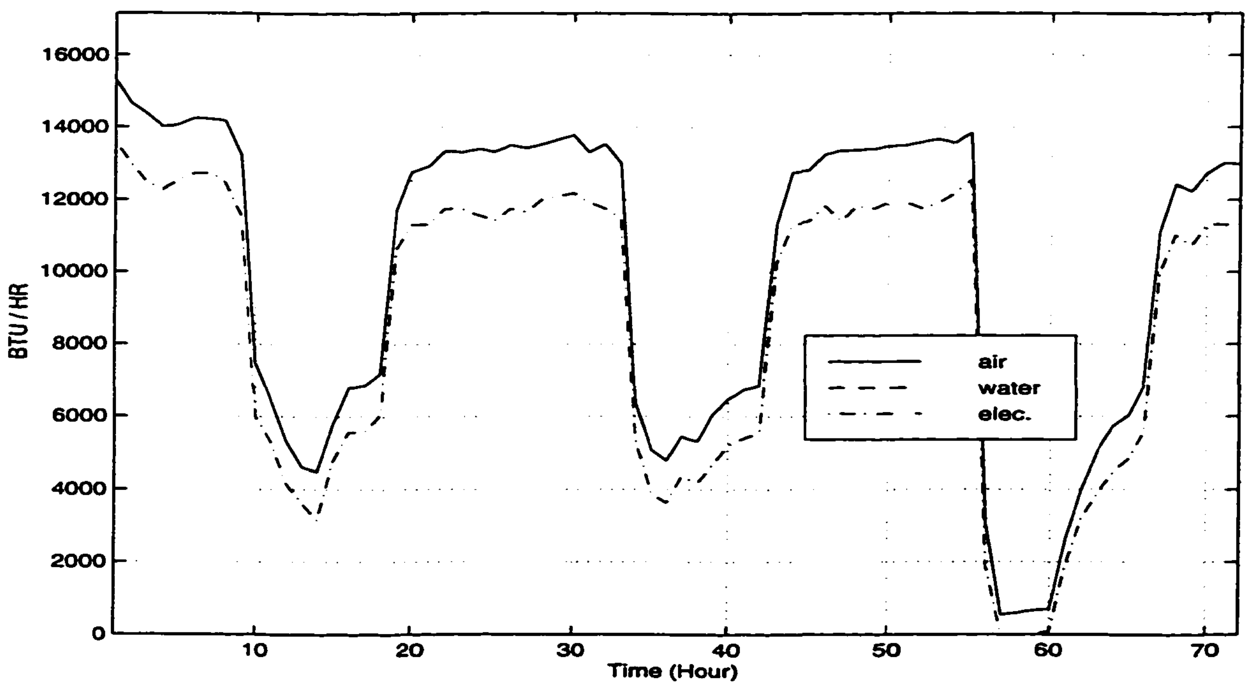

Figure F.20 System-A comparsion of heating energy balance for east testroom from 990223 through 990225

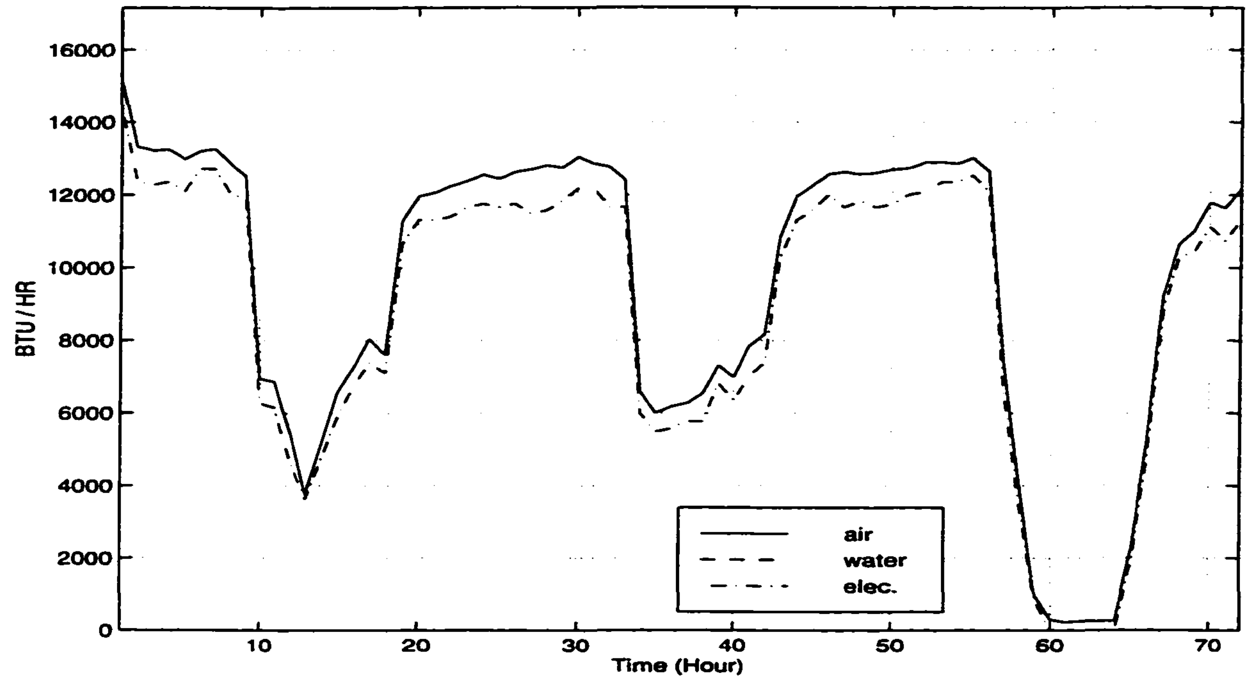

Figure F.21 System-A comparsion of heating energy balance for south testroom from 990223 through 990225

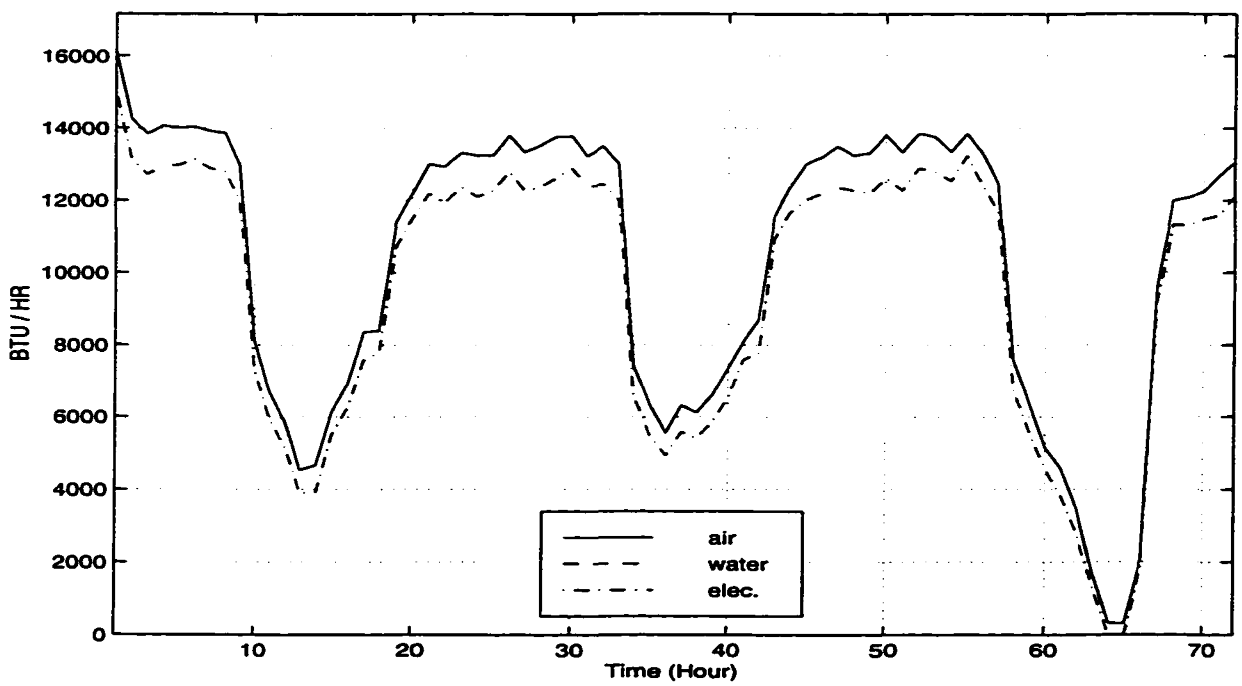

Figure F.22 System-A comparsion of heating energy balance for west testroom from 990223 through 990225

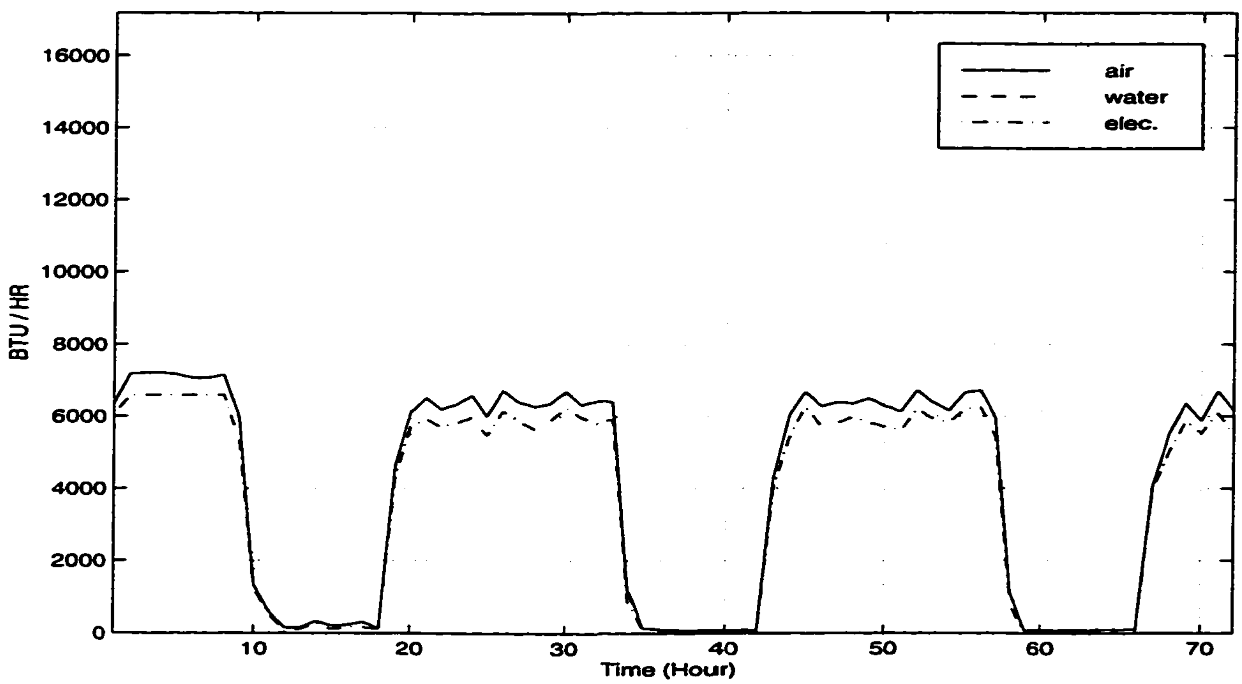

Figure F.23 System-A comparsion of heating energy balance for interior testroom from 990223 through 990225

4. Test Weather

Table F.3 Weather data summary

Data points measured	Units	Minimum	Average	Maximum
Atmosphere pressure	millibar	1012	1017	1022
Relative Humidity	%	55.0	83.6	97.6
Outdoor dry-bulb temperature	°F	18.8	30.0	46.1
Direct normal irradiation	Btu/ft^2.Hr	0.0	31	286
Total horizontal irradiation	Btu/ft^2.Hr	0.0	37	221
Wind speed	MPH	0.00	6.27	20.7

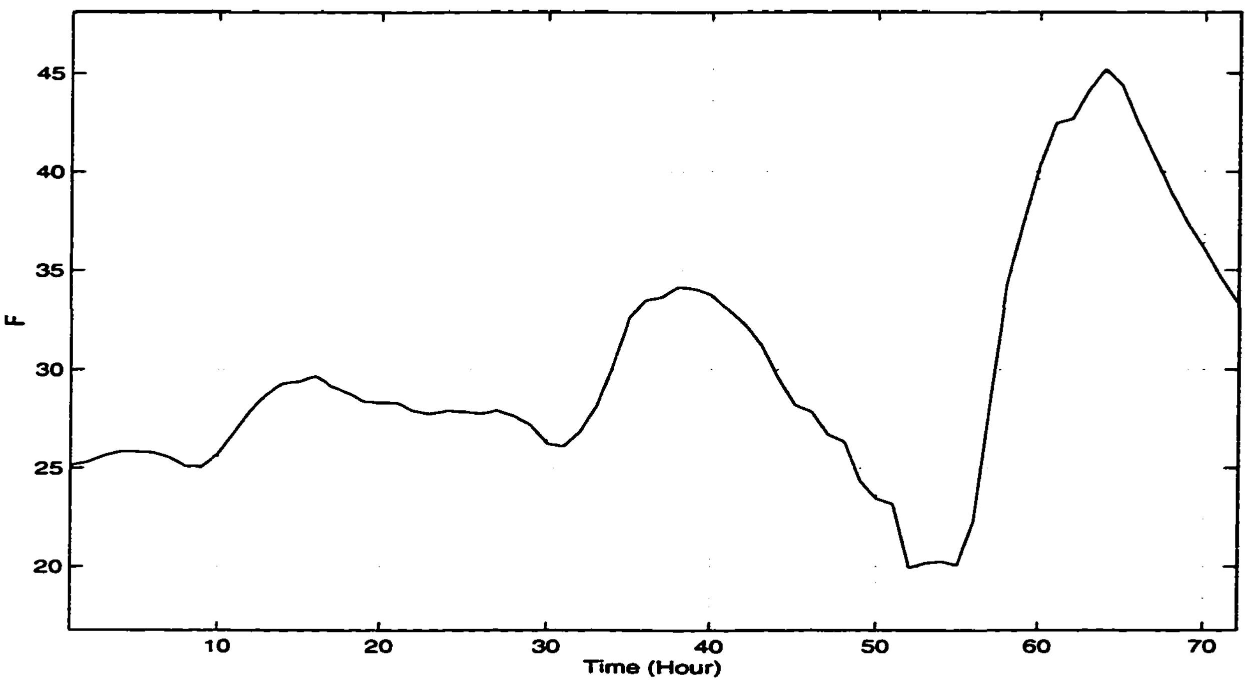

Figure F.24 Outside dry-bulb temperature from 990223 through 990225

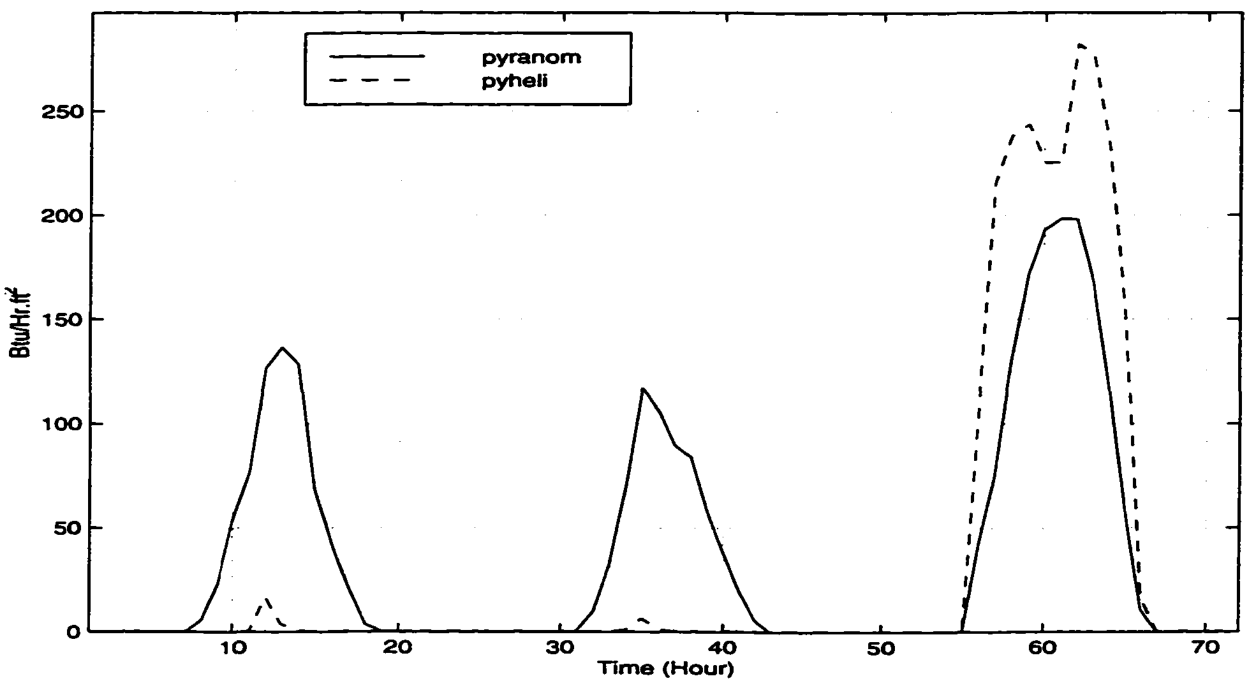

Figure F.25 Solar fluxes from 990223 through 990225

5. Adjacent Room Temperatures

Table F.4 Adjacent room temperature summary

Data points measured	Units	Maximum	Average	Minimum
East vestibule	°F	83.6	73.45	71.52
West vestibule	°F	74.38	71.48	68.85
Office	°F	72.69	70.86	68.63
Reception area	°F	72.83	71.63	70.38
Southwest plenum of media center	°F	71.03	69.69	68.82
Southwest area of media center	°F	72.58	71.07	69.94
Computer room	°F	73.34	71.40	70.53
Display room	°F	73.05	70.94	68.28
Mechanical room	°F	74.55	72.54	61.96
Northeast area of media center	°F	74.05	71.31	70.17
Break room	°F	74.73	69.87	67.00
Northeast plenum of media center	°F	73.07	70.82	69.31

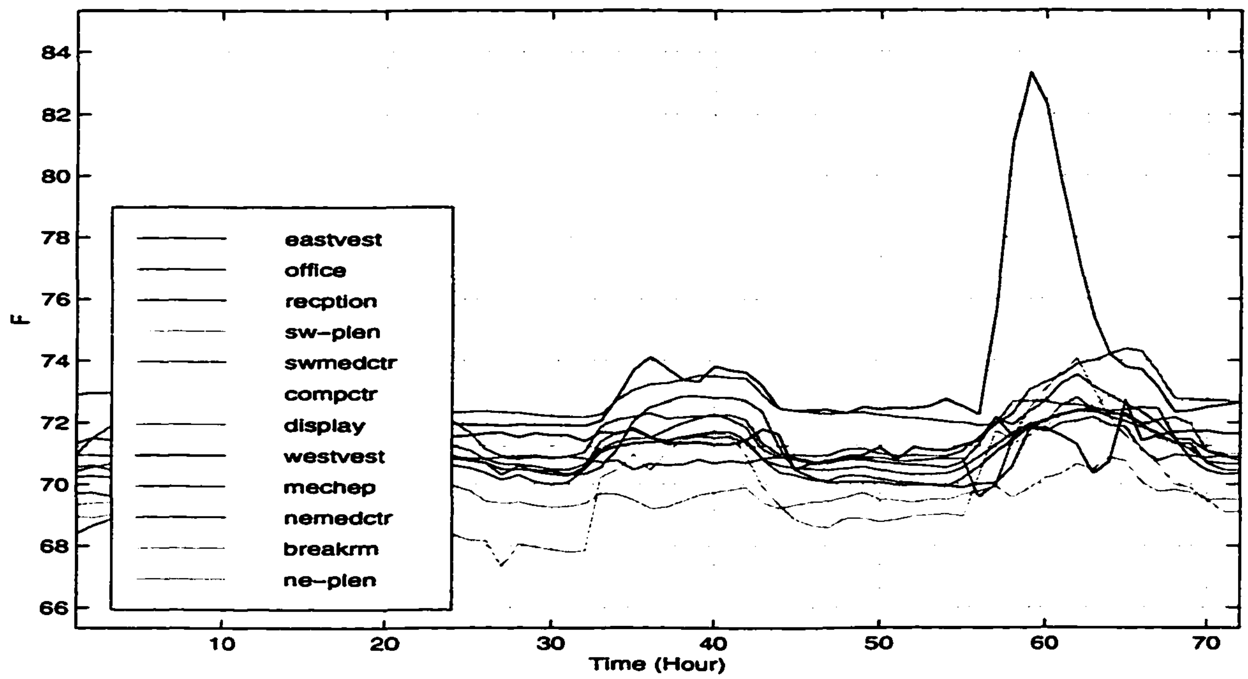

Figure F.26 Adjacent rooms' temperatures from 990223 through 990225

APPENDIX G LISTINGS OF MATLAB PROGRAMS FOR SOLAR FLUXES CACULATION

%[SOLAR PROGRAM]

```
%SOLAR program calculates DNR and THR in ANKENY(ASHRAE Clear Sky Model)
% 1995 ASHRAE Applications Handbook, Chapter 30.
clear all
close all
%set constant numbers
latitude = pi*41.75/180;

%apparent solar irradiation at air mass zero for each month
A=[390 385 376 360 350 345 344 351 365 378 387 391];

%atmospheric extinction coff.
B=[0.142 0.144 0.156 0.180 0.196 0.205 0.207 0.201 0.177 0.160 0.149 0.142];

%ratio of the diffuse radiation on a horizontal surface to the direct %normal irradiation
C=[0.058 0.060 0.071 0.097 0.121 0.134 0.136 0.122 0.092 0.073 0.063 0.057];

nday = 1;
for nday = 1:365
  hr = 0;
  if nday >= 1 & nday <= 31
    m = 1;
  elseif nday >= 32 & nday <= 59
    m = 2;
  elseif nday >= 60 & nday <= 90
    m  = 3;
  elseif nday >= 91 & nday <= 120
    m = 4;
  elseif nday >= 121 & nday <= 151
    m = 5;
  elseif nday >= 152 & nday <= 181
    m = 6;
  elseif nday >= 182 & nday <= 212
    m = 7;
  elseif nday >= 213 & nday <= 243
    m = 8;
  elseif nday >= 244 & nday <= 273
    m = 9;
  elseif nday >= 274 & nday <= 304
    m = 10;
  elseif nday >= 305 & nday <= 334
    m = 11;
  elseif nday >= 335 & nday <= 365
    m = 12;
  end

  for angle = -165:15:180
    hr = hr + 1;
    declination(nday) = pi*23.45/180*sin(pi*360/365/180*(284+nday));
    beta(nday,hr) =          asin(cos(latitude)*cos(angle*pi/180)*cos(declination(nday)) +
         sin(latitude)*sin(declination(nday)));
    if beta(nday,hr) <= 0
      Idn(nday,hr) = 0;
      Ith(nday,hr) = 0;
```

```
        BET(nday,hr) = 0;
      else
        Idn(nday,hr) = A(m)*exp(-B(m)/sin(beta(nday,hr)));
        Ith(nday,hr) = Idn(nday,hr).*sin(beta(nday,hr)) +                    C(m)*Idn(nday,hr);
        BET(nday,hr) = beta(nday,hr)*180/pi;
      end
    end
    nday = nday + 1;
end

month_number=input('Enter the Month you want to look at solar data: ');
mn = month_number;
date_number =input('Enter the Date you want: ');
dn = date_number;

MONTH = [0 31 59 90 120 151 181 212 243 273 304 334];
day_of_year = MONTH(mn) + dn;
dy = day_of_year;
time=1:24;
month = 1:12;

format bank;
sol_day=[Idn(dy,:)' Ith(dy,:)'];

%Solar fluxes and solar altitude for the day of 21st of each month
DNR=[Idn(21,:)' Idn(52,:)' Idn(80,:)' Idn(111,:)' Idn(141,:)' Idn(172,:)' Idn(202,:)' Idn(221,:)'
Idn(233,:)'Idn(264,:)' Idn(294,:)' Idn(325,:)' ];
THR=[Ith(21,:)' Ith(52,:)' Ith(80,:)' Ith(111,:)' Ith(141,:)' Ith(172,:)' Ith(202,:)' Ith(221,:)' Ith(233,:)'Ith(264,:)'
Ith(294,:)' Ith(325,:)' ];
ALT=[BET(21,:)' BET(52,:)' BET(80,:)' BET(111,:)' BET(141,:)' BET(172,:)' BET(202,:)' BET(221,:)'
BET(233,:)'BET(264,:)' BET(294,:)' BET(325,:)' ];
format;

figure
plot(month,max(ALT)),grid,xlabel('Month'),ylabel('solar altitude, degree'),title('Solar Altitude at Noon as a
Function of Month'),
axis([1 12 0 90]);

figure
plot(ALT(:,1),DNR(:,1),ALT(:,2),DNR(:,2),ALT(:,3),DNR(:,3),ALT(:,4),
DNR(:,4),ALT(:,5),DNR(:,5),ALT(:,6),DNR(:,6),...
ALT(:,7),DNR(:,7),ALT(:,8),DNR(:,8),ALT(:,9),DNR(:,9),ALT(:,10),DNR(:,10),ALT(:,11),DNR(:,11),ALT(:,
12),DNR(:,12));
axis([0 90 0 350]),grid,
xlabel('Solar altitude, degree'),
ylabel('irradiation, Btu/hr.sqft'),title('DIRECT IRRADIATION (pyheliometer)'),
text(28,290,'Jan'),text(38,305,'Feb'),text(48,307,'Mar'),
text(49,290,'Oct'),text(60,295,'Apr'),text(68,285,'May'),
text(73,280,'Jun'),text(65,270,'Jul');


figure
plot(ALT(:,1),THR(:,1),ALT(:,2),THR(:,2),ALT(:,3),THR(:,3),ALT(:,4),
THR(:,4),ALT(:,5),THR(:,5),ALT(:,6),THR(:,6),...
```

```
ALT(:,7),THR(:,7),ALT(:,8),THR(:,8),ALT(:,9),THR(:,9),ALT(:,10),THR(:,10),ALT(:,11),THR(:,11),ALT(:,12
),THR(:,12));
axis([0 90 0 350]),grid, xlabel('Solar altitude, degree'),ylabel('irradiation, Btu/hr.sqft'),
title('TOTAL HORIZONTAL IRRADIATION (pyranometer)')
text(21,152,'Jan'),text(31,205,'Feb'),text(43,249,'Mar'),
text(54,285,'Apr'),text(63,295,'May'),text(72,301,'Jun');

figure
subplot(1,2,1),plot(time',DNR),axis([1 24 0 350]),grid,
xlabel('Solar Time'),ylabel('irradiation, Btu/hr.sqft'),
title('DIRECT IRRADIATION'),
text(11,265,'Jun'),text(12,310,'Mar');
subplot(1,2,2),plot(time',THR),axis([1 24 0 350]),grid,
title('TOTAL HORIZONTAL IRRADIATION'),
text(10,130,'Jan,Dec'),text(10,190,'Feb,Nov'),text(10,240,'Mar,Oct'),
text(10,300,'Jun,Jul');

str1='Month=';str2='Date=';str11='    ';str3=num2str(mn);str4=num2str(dn);
str5=strcat({str1},{str3},{str11},{str2},{str4});

figure
plot(time',sol_day),grid,xlabel('Solar Time'),
ylabel('irradiation, Btu/hr.sqft'),
axis([1 24 0 350]),title(str5),legend('pyheilometer','pyranometer',0);


fprintf('Time    DNR     THR\n');
for i=1:24
  fprintf('%6i%10.2f%10.2f\n',time(i),sol_day(i,:));
end
```

APPENDIX H LISTINGS OF MATLAB PROGRAMS FOR HOURLY ENERGY CACULATION

%[THESIS PROGRAM]

%THEISIS program calculates hourly cooling and heating energies using 1 minute interval data.
%This program has total 18 subprograms.

```
%THESIS pogram creates hourly report for THESIS AND IEA REPORT.
clear all;
close all;
path(path,'\sangsoo\project\matlab\Data');
path(path,'\sangsoo\project\matlab2\programs');
programselect=menu('Choose a Program','IEA OUTPUT','THESIS OUTPUT','FCU');
if (programselect == 1) | (programselect == 2)
  systemselect = menu('Choose a System and Test Rooms.','AHU-A and TESTROOM-A','AHU-B and
TESTROOM-B')
end
if programselect == 1
  AHU;
  EAST;
  SOUTH;
  WEST;
  INTER;
  OUTPRINTEXTENDED;
elseif programselect==2
  outputselect=menu('Choose an output format','COMPACT','EXTENDED');
  AHU;
  EAST;
  SOUTH;
  WEST;
  INTER;
  if outputselect==1
    OUTPRINTCOMPACT;
  else
    OUTPRINTEXTENDED;
  end
elseif programselect==3
  FEAST;
  FSOUTH;
  FWEST;
  FINTER;
  FCLG;
  FHTG;
  FCUPLOT;
  FCUPRINT;
end

format compact;
if programselect == 3
  if ((Btime_east~=Btime_south|Etime_east~=Etime_south) |
(Btime_south~=Btime_west|Etime_south~=Etime_west)) |
(Btime_west~=Btime_inter|Etime_west~=Etime_inter)
  disp('Check Beginning and Ending Time!!')
  disp('There was a time difference between trend data')
  disp(' ')
  PROCESSDATE=[Bdate Edate]
  EAST=[BeginningTime_east EndingTime_east]
```

```
  SOUTH=[BeginningTime_south EndingTime_south]
  WEST=[BeginningTime_west EndingTime_west]
  INTER=[BeginningTime_inter EndingTime_inter]
  end

elseif
((Btime~=Btime_east|Etime~=Etime_east)|(Btime_east~=Btime_south|Etime_east~=Etime_south))|((Btime_so
uth~=Btime_west|Etime_south~=Etime_west)|(Btime_west~=Btime_inter|Etime_west~=Etime_inter))
  disp('Check Beginning and Ending Time!!')
  disp('There was a time difference between trend data')
  disp(' ')
  PROCESSDATE=[Bdate Edate]
  AHU=[BeginningTime EndingTime]
  EAST=[BeginningTime_east EndingTime_east]
  SOUTH=[BeginningTime_south EndingTime_south]
  WEST=[BeginningTime_west EndingTime_west]
  INTER=[BeginningTime_inter EndingTime_inter]
end
disp(' ')
disp('All program runs were performed successfully!!')
disp('Current PWD is :')
pwd
```

```
%AHU is an Energy program for AHU.
disp('This program(AHU) analyzes AHU.')

dirname = 10;
filename; % call FILENAME for setting the Bdate, Edate & time interval
format compact;
disp('AHU Data file names are: ')
if systemselect == 1
  dir('\sangsoo\project\matlab\data\*aha.m')
  dirname = 11;
else
  dir('\sangsoo\project\matlab\data\*ahb.m')
  dirname = 21;
end
disp('')
if dirname == 11
  disp('AHU-A is being processed!!')
elseif dirname == 21
  disp('AHU-B is being processed!!')
end

filename; %call data file for AHU
disp(' ')
sys = a;
[r c]=size(sys);
BeginningTime=[sys(1,1) sys(1,2)]
EndingTime=[sys(r,1) sys(r,2)]
```

```
Btime = sys(1,1)+sys(1,2);
Etime = sys(r,1)+sys(r,2);
disp(' ')
Bdate
Edate

% Array variables
kk=0;
for k=1:r
  if sys(k,1) >= Bdate & sys(k,1) <= Edate
    kk=kk+1;
    if systemselect == 1
      varname = 11;
      dirname = 33;
      filename; % call variables
    elseif systemselect == 2
      varname = 21;
      dirname = 33;
      filename; % call variables
    end
  end
end

if varname == 11
  dirname = 11;
else
  dirname = 21;
end

y=kk;
x=f*24;
while y > -1
  y = y-x;
end
if y ~= -x
  disp('');
  disp('Check the time of the trend data');
  SART_TIME=[date(1) time(1)]
  END_TIME=[date(kk) time(kk)]
  error('Error!!!! ---->> Check the starting & ending time of the trend data!!!');
end

AHU_kk = kk;
AHU_end_time=[date(AHU_kk) time(AHU_kk)];
%Properties of Air and Water
% See File program to look at the properties values
C=60/7.48055*rho_cold_wtr*cp_cold_wtr;

%Display initial values
if sa_flow(1) == -999
  SA_CFM=sa_flow(1)
  sa_flow(1) = input('Enter an initial value for supply CFM of AHU: ');
end
if oa_flow(1) == -999
```

```
  OA_CFM=oa_flow(1)
  oa_flow(1) = input('Enter an initial value for outside air CFM of AHU: ');
end
if ra_temp(1) == -999
  RA_TEMP=ra_temp(1)
  ra_temp(1) = input('Enter an initial value for return air temperature of AHU: ');
end
if ma_temp(1) == -999
  MA_TEMP=ma_temp(1)
  ma_temp(1) = input('Enter an initial value for mixed air temperature of AHU: ');
end
if da_temp(1) == -999
  DA_TEMP=da_temp(1)
  da_temp(1) = input('Enter an initial value for discharge air temperature of AHU: ');
end
if chwF(1) == -999
  CHW_GPM=chwF(1)
  chwF = input('Enter an initial value for chilled water GPM of AHU coil: ');
end
if clg_dat(1) == -999
  CLG_DAT=clg_dat(1)
  clg_dat(1) = input('Enter an initial value for clg-dat: ');
end
if clg_ewt(1) == -999
  CHW_EWT=clg_ewt(1)
  clg_ewt(1) = input('Enter an initial value for chilled water entering temp: ');
end
if clg_lwt(1) == -999
  CHW_LWT=clg_lwt(1)
  clg_lwt(1) = input('Enter an initial value for chilled water leaving temp: ');
end
if clg_mwt(1) == -999
  CHW_MWT=clg_mwt(1)
  clg_mwt(1) = input('Enter an initial value for chilled water mixed temp: ');
end

for i=1:kk
  if sa_flow(i) == -999
    sa_flow(i) = sa_flow(i-1);
  end
  if oa_flow(i) == -999
    oa_flow(i) = oa_flow(i-1);
  end
  if ra_temp(i) == -999
    ra_temp(i) = ra_temp(i-1);
  end
  if ma_temp(i) == -999
    ma_temp(i) = ma_temp(i-1);
  end
  if da_temp(i) == -999
    da_temp(i) = da_temp(i-1);
  end
  if chwF(i) == -999
    chwF(i) = chwF(i-1);
```

```
    end
    if chwF(i)> -990 & chwF(i) < 0
      chwF(i) = 0;
    end
    if clg_dat(i) == -999
      clg_dat(i) = clg_dat(i-1);
    end
    if clg_ewt(i) == -999
      clg_ewt(i) = clg_ewt(i-1);
    end
    if clg_lwt(i) == -999
      clg_lwt(i) = clg_lwt(i-1);
    end
    if clg_mwt(i) == -999
      clg_mwt(i) = clg_mwt(i-1);
    end
end


nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    SACFM(nHR,nC) = sa_flow(j);
    OACFM(nHR,nC) = oa_flow(j);
    RATEMP(nHR,nC) = ra_temp(j);
    MATEMP(nHR,nC) = ma_temp(j);
    CLGDAT(nHR,nC) = clg_dat(j);
    DATEMP(nHR,nC) = da_temp(j);
    CHWGPM(nHR,nC) = chwF(j);
    CHWEWT(nHR,nC) = clg_ewt(j);
    CHWLWT(nHR,nC) = clg_lwt(j);
    CHWMWT(nHR,nC) = clg_mwt(j);
    EN_COLDAIR(nHR,nC)= 60*rho_cold_air*cp_cold_air*sa_flow(j).*(ma_temp(j) - da_temp(j));
    EN_COLDWATER(nHR,nC)= C*chwF(j).*(clg_mwt(j) - clg_ewt(j));
    Q(nHR,nC)=EN_COLDWATER(nHR,nC);
    if Q(nHR,nC)< 0
      Q(nHR,nC) = 0;
    end

    %Uncertainity calculation of cooling load
    dQ_dgpm(nHR,nC)=C*(clg_mwt(j)-clg_ewt(j));
    dQ_dmwt(nHR,nC)=C*chwF(j);
    dQ_dewt(nHR,nC)=-C*chwF(j);
    u_Q(nHR,nC)=( (dQ_dgpm(nHR,nC).*u_gpm).^2 + (dQ_dmwt(nHR,nC).*u_mwt).^2 +
(dQ_dewt(nHR,nC).*u_ewt).^2 ).^0.5;

    if Q(nHR,nC) == 0
      u_Q(nHR,nC) = 0;
    end

    %New cooling load calculation
    Q_up(nHR,nC)=Q(nHR,nC) + u_Q(nHR,nC);
```

```
    Q_lo(nHR,nC)=Q(nHR,nC) - u_Q(nHR,nC);

    j = j+1;
  end
  nHR = nHR + 1;
end
Number_of_Hours =nHR - 1;

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MSACFM(nDay,nCC) = mean(SACFM(nHR,:));
    MOACFM(nDay,nCC) = mean(OACFM(nHR,:));
    MRATEMP(nDay,nCC) = mean(RATEMP(nHR,:));
    MMATEMP(nDay,nCC) = mean(MATEMP(nHR,:));
    MCLGDAT(nDay,nCC) = mean(CLGDAT(nHR,:));
    MDATEMP(nDay,nCC) = mean(DATEMP(nHR,:));
    MCHWGPM(nDay,nCC) = mean(CHWGPM(nHR,:));
    MCHWEWT(nDay,nCC) = mean(CHWEWT(nHR,:));
    MCHWLWT(nDay,nCC) = mean(CHWLWT(nHR,:));
    MCHWMWT(nDay,nCC) = mean(CHWMWT(nHR,:));
    MEN_COLDAIR(nDay,nCC)= mean(EN_COLDAIR(nHR,:));
    MQ(nDay,nCC)=mean(Q(nHR,:));
    MQ_lo(nDay,nCC)=mean(Q_lo(nHR,:));
    MQ_up(nDay,nCC)=mean(Q_up(nHR,:));

    nHR = nHR + 1;
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CSACFM(HR) = mean(SACFM(nHR,:));
  COACFM(HR) = mean(OACFM(nHR,:));
  if CSACFM(HR) < 100
    CSACFM(HR) = 0;
    COACFM(HR) = 0;
  end
  CRATEMP(HR) = mean(RATEMP(nHR,:));
  CMATEMP(HR) = mean(MATEMP(nHR,:));
  CCLGDAT(HR) = mean(CLGDAT(nHR,:));
  CDATEMP(HR) = mean(DATEMP(nHR,:));
  CCHWGPM(HR) = mean(CHWGPM(nHR,:));
  CCHWEWT(HR) = mean(CHWEWT(nHR,:));
  CCHWLWT(HR) = mean(CHWLWT(nHR,:));
  CCHWMWT(HR) = mean(CHWMWT(nHR,:));
  CEN_COLDAIR(HR)= mean(EN_COLDAIR(nHR,:));
  CQ(HR)=mean(Q(nHR,:));
  CQ_lo(HR)=mean(Q_lo(nHR,:));
```

```
  CQ_up(HR)=mean(Q_up(nHR,:));
end

if dirname == 11
  disp('AHU-A has been processed!!')
elseif dirname == 21
  disp('AHU-B has been processed!!')
end
disp(' ')



%EAST is an Energy program for test room-A.
disp('This program(EAST) analizes EAST ROOM.')

disp('East Room Data file names are: ')
if systemselect == 1
  dir('\sangsoo\project\matlab\data\*rea.m')
  dirname = 12;
else
  dir('\sangsoo\project\matlab\data\*reb.m')
  dirname = 22;
end
disp('')
if dirname == 12
  disp('EASTROOM-A is being processed!!')
elseif dirname == 22
  disp('EASTROOM-B is being processed!!')
end

filename;% call data file for the eastroom
disp(' ')
east = a;
[r c]=size(east);
BeginningTime_east=[east(1,1) east(1,2)];
EndingTime_east=[east(r,1) east(r,2)];
Btime_east =east(1,1)+east(1,2);
Etime_east =east(r,1)+east(r,2);

if (Btime_east ~= Btime) | (Etime_east ~= Etime)
  disp('There was a time difference between EASTROOM and AHU !!')
end

% Array variables.
kk=0;
for k=1:r
  if east(k,1) >= Bdate & east(k,1) <= Edate
    kk=kk+1;
    if systemselect == 1
      varname = 12;
      dirname = 33;
      filename; % call variables
    elseif systemselect == 2
      varname = 22;
```

```
      dirname = 33;
      filename; % call variables
    end
  end
end

if varname == 12
  dirname = 12;
else
  dirname = 22;
end

EAST_kk = kk;
EAST_end_time=[date(EAST_kk) time(EAST_kk)];
if AHU_kk ~= EAST_kk
  disp('')
  disp('You need to look at the date and time in trend data.')
  AHU_end_time=[date(AHU_kk) time(AHU_kk)]
  EAST_end_time=[date(EAST_kk) time(EAST_kk)]
  error('Error!! ---> Number of rows is different between AHU and EASTROOM')
end

%Properties of air and water
%Properties of air and water and The power of electric coils in TAB
% See The File program to look at the properties values
% See The File program to look at the Power (kW) of electric coil in the TABs

H=60/7.48055*rho_hot_wtr*cp_hot_wtr;

%Display initial values
if airF_east(1) == -999
  VAV_CFM_east = airF_east(1)
  airF_east(1) = input('Enter an initial value for VAV-CFM of east room: ');
end
if vav_dat_east(1) < 0
  VAV_DAT_east = vav_dat_east(1)
  vav_dat_east(1) = input('Enter an initial value for VAV-DAT of east room: ');
end
if pln_temp_east(1) == -999
  PLN_TEMP_east = pln_temp_east(1)
  pln_temp_east(1) = input('Enter an initial value for plenum temp of east room: ');
end
if rm_temp_east(1) == -999
  RM_TEMP_east = rm_temp_east(1)
  rm_temp_east(1) = input('Enter an initial value for room temp of east room: ');
end
if hwF_east(1) == -999
  HOTW_GPM_east = hwF_east(1)
  hwF_east(1) = input('Enter an initial value for hot water GPM of east room: ');
end
if vavhcewt_east(1) == -999
  HOTW_EWT_east = vavhcewt_east(1)
  vavhcewt_east(1) = input('Enter an initial value for hot water entering temp of east room: ');
end
```

```
if vavhclwt_east(1) == -999
  HOTW_LWT_east  = vavhclwt_east(1)
  vavhclwt_east(1) = input('Enter an initial value for hot water leaving temp of east room: ');
end
if vav_htg1_east(1) == -999
  VAV_HTG1_east  = vav_htg1_east(1)
  vav_htg1_east(1) = input('Enter an initial value for vav-htg1 of east room: ');
end
if vav_htg2_east(1) == -999
  VAV_HTG2_east  = vav_htg2_east(1)
  vav_htg2_east(1) = input('Enter an initial value for vav-htg2 of east room: ');
end
if vav_htg3_east(1) == -999
  VAV_HTG3_east  = vav_htg3_east(1)
  vav_htg3_east(1) = input('Enter an initial value for vav-htg3 of east room: ');
end

for i=1:kk
  if airF_east(i) == -999
    airF_east(i) = airF_east(i-1);
  end
  if vav_dat_east(i) < 0
    vav_dat_east(i) = vav_dat_east(i-1);
  end
  if pln_temp_east(i) == -999
    pln_temp_east(i) = pln_temp_east(i-1);
  end
  if rm_temp_east(i) == -999
    rm_temp_east(i) = rm_temp_east(i-1);
  end
  if hwF_east(i) == -999
    hwF_east(i) = hwF_east(i-1);
  end
  if hwF_east(i) > -990 & hwF_east(i) < 0
    hwF_east(i) = 0;
  end
  if vavhcewt_east(i) == -999
    vavhcewt_east(i) = vavhcewt_east(i-1);
  end
  if vavhclwt_east(i) == -999
    vavhclwt_east(i) = vavhclwt_east(i-1);
  end
        if vav_htg1_east(i) == -999
        vav_htg1_east(i) = vav_htg1_east(i-1);
        end
        if vav_htg2_east(i) == -999
        vav_htg2_east(i) = vav_htg2_east(i-1);
        end
        if vav_htg3_east(i) == -999
        vav_htg3_east(i) = vav_htg3_east(i-1);
        end
end

nHR=1;
```

```
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    VAVCFM_east(nHR,nC) = airF_east(j);
    VAVDAT_east(nHR,nC) = vav_dat_east(j);
                PLNTEMP_east(nHR,nC)= pln_temp_east(j);
    RMTEMP_east(nHR,nC) = rm_temp_east(j);
    HOTWGPM_east(nHR,nC) = hwF_east(j);
    HOTWEWT_east(nHR,nC) = vavhcewt_east(j);
    HOTWLWT_east(nHR,nC) = vavhclwt_east(j);
    EN_AIR_east(nHR,nC) = 60*rho_hot_air*cp_hot_air*airF_east(j).*(da_temp(j)-vav_dat_east(j));
    EN_WATER_east(nHR,nC) = H*hwF_east(j).*(vavhclwt_east(j) - vavhcewt_east(j));
    EN_ELEC_east(nHR,nC) = -3411.8*(stg1*vav_htg1_east(j) + stg2*vav_htg2_east(j) +
stg3*vav_htg3_east(j));

    RHW_east(nHR,nC)=EN_WATER_east(nHR,nC);
    if RHW_east(nHR,nC)> 0
      RHW_east(nHR,nC) = 0;
    end

    RHE_east(nHR,nC)=EN_ELEC_east(nHR,nC);

    %Uncertainty calculation of reheat energy for water side
    dRHW_dgpm_east(nHR,nC)=H*(vavhclwt_east(j)-vavhcewt_east(j));
    dRHW_dlwt_east(nHR,nC)=H*hwF_east(j);
    dRHW_dewt_east(nHR,nC)=-H*hwF_east(j);
    u_RHW_east(nHR,nC)=( (dRHW_dgpm_east(nHR,nC).*u_hgpm).^2 +
(dRHW_dlwt_east(nHR,nC).*u_hlwt).^2 + (dRHW_dewt_east(nHR,nC).*u_hewt).^2 ).^0.5;
    if RHW_east(nHR,nC) == 0
      u_RHW_east(nHR,nC) = 0;
    end

    %New reheat energy for water side
    RHW_up_east(nHR,nC)=RHW_east(nHR,nC) - u_RHW_east(nHR,nC);
    RHW_lo_east(nHR,nC)=RHW_east(nHR,nC) + u_RHW_east(nHR,nC);

    %Uncertainty calculation of reheat energy for electric heater side
    u_RHE_east(nHR,nC)=3411.8*( (stg1*u_stg1*vav_htg1_east(j)).^2 + (stg2*u_stg2*vav_htg2_east(j)).^2 +
(stg3*u_stg3*vav_htg3_east(j)).^2 ).^0.5;

    %New reheat energy for electric heater side
    RHE_up_east(nHR,nC)=RHE_east(nHR,nC) - u_RHE_east(nHR,nC);
    RHE_lo_east(nHR,nC)=RHE_east(nHR,nC) + u_RHE_east(nHR,nC);

    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
```

```
    nCC = nCC + 1;
    MVAVCFM_east(nDay,nCC) = mean(VAVCFM_east(nHR,:));
    MVAVDAT_east(nDay,nCC) = mean(VAVDAT_east(nHR,:));
    MPLNTEMP_east(nDay,nCC)= mean(PLNTEMP_east(nHR,:));
            MRMTEMP_east(nDay,nCC) = mean(RMTEMP_east(nHR,:));
    MHOTWGPM_east(nDay,nCC)=mean(HOTWGPM_east(nHR,:));
    MHOTWEWT_east(nDay,nCC)=mean(HOTWEWT_east(nHR,:));
    MHOTWLWT_east(nDay,nCC)=mean(HOTWLWT_east(nHR,:));
    MEN_AIR_east(nDay,nCC) = mean(EN_AIR_east(nHR,:));
    MRHW_east(nDay,nCC)= mean(RHW_east(nHR,:));
    MRHW_up_east(nDay,nCC)= mean(RHW_up_east(nHR,:));
    MRHW_lo_east(nDay,nCC)= mean(RHW_lo_east(nHR,:));
    MRHE_east(nDay,nCC)= mean(RHE_east(nHR,:));
    MRHE_up_east(nDay,nCC)= mean(RHE_up_east(nHR,:));
    MRHE_lo_east(nDay,nCC)= mean(RHE_lo_east(nHR,:));

    nHR = nHR + 1;
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CVAVCFM_east(HR) = mean(VAVCFM_east(nHR,:));
  if CSACFM(HR) == 0
    CVAVCFM_east(HR) = 0;
  end
  CVAVDAT_east(HR) = mean(VAVDAT_east(nHR,:));
  CPLNTEMP_east(HR) =  mean(PLNTEMP_east(nHR,:));
  CRMTEMP_east(HR) =  mean(RMTEMP_east(nHR,:));
  CHOTWGPM_east(HR) =  mean(HOTWGPM_east(nHR,:));
  CHOTEWT_east(HR) =  mean(HOTWEWT_east(nHR,:));
  CHOTLWT_east(HR) =  mean(HOTWLWT_east(nHR,:));
  CEN_AIR_east(HR)= mean(EN_AIR_east(nHR,:));
  CRHW_east(HR)=mean(RHW_east(nHR,:));
  CRHW_up_east(HR)=mean(RHW_up_east(nHR,:));
  CRHW_lo_east(HR)=mean(RHW_lo_east(nHR,:));
  CRHE_east(HR)=mean(RHE_east(nHR,:));
  CRHE_up_east(HR)=mean(RHE_up_east(nHR,:));
  CRHE_lo_east(HR)=mean(RHE_lo_east(nHR,:));
end
disp(' ')
if dirname == 12
  disp('EASTROOM-A has been processed!!')
elseif dirname == 22
  disp('EASTROOM-B has been processed!!')
end
disp(' ')
```

```
%SOUTH is an Energy program for south room-A.
disp('This program(SOUTH) analizes SOUTH ROOM.')

disp('South Room Data file names are: ')
if systemselect == 1
  dir('\sangsoo\project\matlab\data\*rsa.m')
  dirname = 13;
else
  dir('\sangsoo\project\matlab\data\*rsb.m')
  dirname = 23;
end
disp('')
if dirname == 13
  disp('SOUTHROOM-A is being processed!!')
elseif dirname == 23
  disp('SOUTHROOM-B is being processed!!')
end

filename;
disp(' ')
south = a;
[r c]=size(south);
BeginningTime_south=[south(1,1) south(1,2)];
EndingTime_south=[south(r,1) south(r,2)];
Btime_south =south(1,1)+south(1,2);
Etime_south =south(r,1)+south(r,2);

if (Btime_south ~= Btime) | (Etime_south ~= Etime)
  disp('There was a time difference between SOUTHROOM and AHU !!')
end

% Array variables.
kk=0;
for k=1:r
  if south(k,1) >= Bdate & south(k,1) <= Edate
    kk=kk+1;
    if systemselect == 1
      varname = 13;
      dirname = 33;
      filename; % call variables
    elseif systemselect == 2
      varname = 23;
      dirname = 33;
      filename; % call variables
    end
  end
end

if varname == 13
  dirname = 13;
else
  dirname = 23;
end
```

```
SOUTH_kk = kk;
SOUTH_end_time=[date(SOUTH_kk) time(SOUTH_kk)];
if AHU_kk ~= SOUTH_kk
  disp('')
        disp('You need to look at the date and time in trend data.')
  AHU_end_time=[date(AHU_kk) time(AHU_kk)]
        SOUTH_end_time=[date(SOUTH_kk) time(SOUTH_kk)]
  error('Error!! ---> Number of rows is different between AHU and SOUTHROOM')
end

%Properties of air and water
%Properties of air and water and The power of electric coils in TAB
% See The File program to look at the properties values
% See The File program to look at the Power (kW) of electric coil in the TABs

H=60/7.48055*rho_hot_wtr*cp_hot_wtr;

%Display initial values
if airF_south(1) == -999
  VAV_CFM_south  = airF_south(1)
  airF_south(1) = input('Enter an initial value for VAV-CFM of south room: ');
end
if vav_dat_south(1) < 0
  VAV_DAT_south  = vav_dat_south(1)
  vav_dat_south(1) = input('Enter an initial value for VAV-DAT of south room: ');
end
if pln_temp_south(1) == -999
  PLN_TEMP_south  = pln_temp_south(1)
  pln_temp_south(1) = input('Enter an initial value for plenum temp of south room: ');
end
if rm_temp_south(1) == -999
  RM_TEMP_south  = rm_temp_south(1)
  rm_temp_south(1) = input('Enter an initial value for room temp of south room: ');
end
if hwF_south(1) == -999
  HOTW_GPM_south  = hwF_south(1)
  hwF_south(1) = input('Enter an initial value for hot water GPM of south room: ');
end
if vavhcewt_south(1) == -999
  HOTW_EWT_south  = vavhcewt_south(1)
  vavhcewt_south(1) = input('Enter an initial value for hot water entering temp of south room: ');
end
if vavhclwt_south(1) == -999
  HOTW_LWT_south  = vavhclwt_south(1)
  vavhclwt_south(1) = input('Enter an initial value for hot water leaving temp of south room: ');
end
if vav_htg1_south(1) == -999
  VAV_HTG1_south = vav_htg1_south(1)
  vav_htg1_south(1) = input('Enter an initial value for vav-htg1 of south room: ');
end
if vav_htg2_south(1) == -999
  VAV_HTG2_south = vav_htg2_south(1)
  vav_htg2_south(1) = input('Enter an initial value for vav-htg2 of south room: ');
```

```
end
if vav_htg3_south(1) == -999
  VAV_HTG3_south = vav_htg3_south(1)
  vav_htg3_south(1) = input('Enter an initial value for vav-htg3 of south room: ');
end

for i=1:kk
  if airF_south(i) == -999
    airF_south(i) = airF_south(i-1);
  end
  if vav_dat_south(i) < 0
    vav_dat_south(i) = vav_dat_south(i-1);
  end
  if pln_temp_south(i) == -999
    pln_temp_south(i) = pln_temp_south(i-1);
  end
  if rm_temp_south(i) == -999
    rm_temp_south(i) = rm_temp_south(i-1);
  end
  if hwF_south(i) == -999
    hwF_south(i) = hwF_south(i-1);
  end
  if hwF_south(i) > -990 & hwF_south(i) < 0
    hwF_south(i) = 0;
  end
  if vavhcewt_south(i) == -999
    vavhcewt_south(i) = vavhcewt_south(i-1);
  end
  if vavhclwt_south(i) == -999
    vavhclwt_south(i) = vavhclwt_south(i-1);
  end
        if vav_htg1_south(i) == -999
        vav_htg1_south(i) = vav_htg1_south(i-1);
        end
        if vav_htg2_south(i) == -999
        vav_htg2_south(i) = vav_htg2_south(i-1);
        end
        if vav_htg3_south(i) == -999
        vav_htg3_south(i) = vav_htg3_south(i-1);
        end
end

nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    VAVCFM_south(nHR,nC) = airF_south(j);
    VAVDAT_south(nHR,nC) = vav_dat_south(j);
    PLNTEMP_south(nHR,nC)= pln_temp_south(j);
    RMTEMP_south(nHR,nC) = rm_temp_south(j);
    HOTWGPM_south(nHR,nC) = hwF_south(j);
    HOTWEWT_south(nHR,nC) = vavhcewt_south(j);
    HOTWLWT_south(nHR,nC) = vavhclwt_south(j);
```

```
    EN_AIR_south(nHR,nC) = 60*rho_hot_air*cp_hot_air*airF_south(j).*(da_temp(j)-vav_dat_south(j));
    EN_WATER_south(nHR,nC) = H*hwF_south(j).*(vavhclwt_south(j) - vavhcewt_south(j));
    EN_ELEC_south(nHR,nC) = -3411.8*(stg1*vav_htg1_south(j) + stg2*vav_htg2_south(j) +
stg3*vav_htg3_south(j));

    RHW_south(nHR,nC)=EN_WATER_south(nHR,nC);
    RHE_south(nHR,nC)=EN_ELEC_south(nHR,nC);

    if RHW_south(nHR,nC)> 0
      RHW_south(nHR,nC) = 0;
    end

    %Uncertainty calculation of reheat energy for water side
    dRHW_dgpm_south(nHR,nC)=H*(vavhclwt_south(j)-vavhcewt_south(j));
    dRHW_dlwt_south(nHR,nC)=H*hwF_south(j);
    dRHW_dewt_south(nHR,nC)=-H*hwF_south(j);
    u_RHW_south(nHR,nC)=( (dRHW_dgpm_south(nHR,nC).*u_hgpm).^2 +
(dRHW_dlwt_south(nHR,nC).*u_hlwt).^2 + (dRHW_dewt_south(nHR,nC).*u_hewt).^2 ).^0.5;
    if RHW_south(nHR,nC) == 0
      u_RHW_south(nHR,nC) = 0;
    end

    %New reheat energy for water side
    RHW_up_south(nHR,nC)=RHW_south(nHR,nC) - u_RHW_south(nHR,nC);
    RHW_lo_south(nHR,nC)=RHW_south(nHR,nC) + u_RHW_south(nHR,nC);

    %Uncertainty calculation of reheat energy for electric heater side
    u_RHE_south(nHR,nC)=3411.8*( (stg1*u_stg1*vav_htg1_south(j)).^2 +
(stg2*u_stg2*vav_htg2_south(j)).^2 + (stg3*u_stg3*vav_htg3_south(j)).^2 ).^0.5;

    %New reheat energy for electric heater side
    RHE_up_south(nHR,nC)=RHE_south(nHR,nC) - u_RHE_south(nHR,nC);
    RHE_lo_south(nHR,nC)=RHE_south(nHR,nC) + u_RHE_south(nHR,nC);


    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MVAVCFM_south(nDay,nCC) = mean(VAVCFM_south(nHR,:));
    MVAVDAT_south(nDay,nCC) = mean(VAVDAT_south(nHR,:));
    MPLNTEMP_south(nDay,nCC)= mean(PLNTEMP_south(nHR,:));
    MRMTEMP_south(nDay,nCC) = mean(RMTEMP_south(nHR,:));
    MHOTWGPM_south(nDay,nCC)=mean(HOTWGPM_south(nHR,:));
    MHOTWEWT_south(nDay,nCC)=mean(HOTWEWT_south(nHR,:));
    MHOTWLWT_south(nDay,nCC)=mean(HOTWLWT_south(nHR,:));
    MEN_AIR_south(nDay,nCC) = mean(EN_AIR_south(nHR,:));
```

```
    MRHW_south(nDay,nCC)= mean(RHW_south(nHR,:));
    MRHW_up_south(nDay,nCC)= mean(RHW_up_south(nHR,:));
    MRHW_lo_south(nDay,nCC)= mean(RHW_lo_south(nHR,:));
    MRHE_south(nDay,nCC)= mean(RHE_south(nHR,:));
    MRHE_up_south(nDay,nCC)= mean(RHE_up_south(nHR,:));
    MRHE_lo_south(nDay,nCC)= mean(RHE_lo_south(nHR,:));

    nHR = nHR + 1;
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CVAVCFM_south(HR) = mean(VAVCFM_south(nHR,:));
  if CSACFM(HR) == 0
    CVAVCFM_south(HR) = 0;
  end
  CVAVDAT_south(HR) = mean(VAVDAT_south(nHR,:));
  CPLNTEMP_south(HR) =  mean(PLNTEMP_south(nHR,:));
  CRMTEMP_south(HR) =  mean(RMTEMP_south(nHR,:));
  CHOTWGPM_south(HR) =  mean(HOTWGPM_south(nHR,:));
  CHOTEWT_south(HR) =  mean(HOTWEWT_south(nHR,:));
  CHOTLWT_south(HR) =  mean(HOTWLWT_south(nHR,:));
  CEN_AIR_south(HR)= mean(EN_AIR_south(nHR,:));
  CRHW_south(HR)=mean(RHW_south(nHR,:));
  CRHW_up_south(HR)=mean(RHW_up_south(nHR,:));
  CRHW_lo_south(HR)=mean(RHW_lo_south(nHR,:));
  CRHE_south(HR)=mean(RHE_south(nHR,:));
  CRHE_up_south(HR)=mean(RHE_up_south(nHR,:));
  CRHE_lo_south(HR)=mean(RHE_lo_south(nHR,:));

end
disp(' ')
if dirname == 13
  disp('SOUTHROOM-A has been processed!!')
elseif dirname == 23
  disp('SOUTHROOM-B has been processed!!')
end
disp(' ')



%WEST is an Energy program for west room-A.
disp('This program(WEST) analizes WEST ROOM.')

disp('West Room Data file names are: ')
if systemselect == 1
  dir('\sangsoo\project\matlab\data\*rwa.m')
  dirname = 14;
else
  dir('\sangsoo\project\matlab\data\*rwb.m')
```

```
  dirname = 24;
end
disp('')
if dirname == 14
  disp('WESTROOM-A is being processed!!')
elseif dirname == 24
  disp('WESTROOM-B is being processed!!')
end

filename;
disp(' ')
west = a;
[r c]=size(west);
BeginningTime_west=[west(1,1) west(1,2)];
EndingTime_west=[west(r,1) west(r,2)];
Btime_west =west(1,1)+west(1,2);
Etime_west =west(r,1)+west(r,2);

if (Btime_west ~= Btime) | (Etime_west ~= Etime)
  disp('There was a time difference between WESTROOM and AHU !!')
end

% Array variables.
kk=0;
for k=1:r
  if west(k,1) >= Bdate & west(k,1) <= Edate
    kk=kk+1;
    if systemselect == 1
      varname = 14;
      dirname = 33;
      filename; % call variables
    elseif systemselect == 2
      varname = 24;
      dirname = 33;
      filename; % call variables
    end
  end
end

if varname == 14
  dirname = 14;
else
  dirname = 24;
end

WEST_kk = kk;
WEST_end_time=[date(WEST_kk) time(WEST_kk)];
if AHU_kk ~= WEST_kk
  disp('')
  disp('You need to look at the date and time in trend data.')
  AHU_end_time=[date(AHU_kk) time(AHU_kk)]
        WEST_end_time=[date(WEST_kk) time(WEST_kk)]
        error('Error!! ---> Number of rows is different between AHU and WESTROOM')
end
```

```
%Properties of air and water
%Properties of air and water and The power of electric coils in TAB
% See The File program to look at the properties values
% See The File program to look at the Power (kW) of electric coil in the TABs

H=60/7.48055*rho_hot_wtr*cp_hot_wtr;

%Display initial values
if airF_west(1) == -999
  VAV_CFM_west = airF_west(1)
  airF_west(1) = input('Enter an initial value for VAV-CFM of west room: ');
end
if vav_dat_west(1) < 0
  VAV_DAT_west = vav_dat_west(1)
  vav_dat_west(1) = input('Enter an initial value for VAV-DAT of west room: ');
end
if pln_temp_west(1) == -999
  PLN_TEMP_west = pln_temp_west(1)
  pln_temp_west(1) = input('Enter an initial value for plenum temp of west room: ');
end
if rm_temp_west(1) == -999
  RM_TEMP_west = rm_temp_west(1)
  rm_temp_west(1) = input('Enter an initial value for room temp of west room: ');
end
if hwF_west(1) == -999
  HOTW_GPM_west = hwF_west(1)
  hwF_west(1) = input('Enter an initial value for hot water GPM of west room: ');
end
if vavhcewt_west(1) == -999
  HOTW_EWT_west = vavhcewt_west(1)
  vavhcewt_west(1) = input('Enter an initial value for hot water entering temp of west room: ');
end
if vavhclwt_west(1) == -999
  HOTW_LWT_west = vavhclwt_west(1)
  vavhclwt_west(1) = input('Enter an initial value for hot water leaving temp of west room: ');
end
if vav_htg1_west(1) == -999
  VAV_HTG1_west = vav_htg1_west(1)
  vav_htg1_west(1) = input('Enter an initial value for vav-htg1 of west room: ');
end
if vav_htg2_west(1) == -999
  VAV_HTG2_west = vav_htg2_west(1)
  vav_htg2_west(1) = input('Enter an initial value for vav-htg2 of west room: ');
end
if vav_htg3_west(1) == -999
  VAV_HTG3_west = vav_htg3_west(1)
  vav_htg3_west(1) = input('Enter an initial value for vav-htg3 of west room: ');
end

for i=1:kk
  if airF_west(i) == -999
    airF_west(i) = airF_west(i-1);
  end
```

```
  if vav_dat_west(i) < 0
    vav_dat_west(i) = vav_dat_west(i-1);
  end
  if pln_temp_west(i) == -999
    pln_temp_west(i) = pln_temp_west(i-1);
  end
  if rm_temp_west(i) == -999
    rm_temp_west(i) = rm_temp_west(i-1);
  end
  if hwF_west(i) == -999
    hwF_west(i) = hwF_west(i-1);
  end
  if hwF_west(i) > -990 & hwF_west(i) < 0
    hwF_west(i) = 0;
  end
  if vavhcewt_west(i) == -999
    vavhcewt_west(i) = vavhcewt_west(i-1);
  end
  if vavhclwt_west(i) == -999
    vavhclwt_west(i) = vavhclwt_west(i-1);
  end
        if vav_htg1_west(i) == -999
        vav_htg1_west(i) = vav_htg1_west(i-1);
        end
        if vav_htg2_west(i) == -999
        vav_htg2_west(i) = vav_htg2_west(i-1);
        end
        if vav_htg3_west(i) == -999
        vav_htg3_west(i) = vav_htg3_west(i-1);
        end
end

nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    VAVCFM_west(nHR,nC) = airF_west(j);
    VAVDAT_west(nHR,nC) = vav_dat_west(j);
    PLNTEMP_west(nHR,nC)= pln_temp_west(j);
    RMTEMP_west(nHR,nC) = rm_temp_west(j);
    HOTWGPM_west(nHR,nC) = hwF_west(j);
    HOTWEWT_west(nHR,nC) = vavhcewt_west(j);
    HOTWLWT_west(nHR,nC) = vavhclwt_west(j);
    EN_AIR_west(nHR,nC) = 60*rho_hot_air*cp_hot_air*airF_west(j).*(da_temp(j)-vav_dat_west(j));
    EN_WATER_west(nHR,nC) = H*hwF_west(j).*(vavhclwt_west(j) - vavhcewt_west(j));
    EN_ELEC_west(nHR,nC) = -3411.8*(stg1*vav_htg1_west(j) + stg2*vav_htg2_west(j) +
stg3*vav_htg3_west(j));

    RHW_west(nHR,nC)=EN_WATER_west(nHR,nC);
    RHE_west(nHR,nC)=EN_ELEC_west(nHR,nC);
    if RHW_west(nHR,nC)> 0
      RHW_west(nHR,nC) = 0;
    end
```

```
    %Uncertainty calculation of reheat energy for water side
    dRHW_dgpm_west(nHR,nC)=H*(vavhclwt_west(j)-vavhcewt_west(j));
    dRHW_dlwt_west(nHR,nC)=H*hwF_west(j);
    dRHW_dewt_west(nHR,nC)=-H*hwF_west(j);
    u_RHW_west(nHR,nC)=( (dRHW_dgpm_west(nHR,nC).*u_hgpm).^2 +
(dRHW_dlwt_west(nHR,nC).*u_hlwt).^2 + (dRHW_dewt_west(nHR,nC).*u_hewt).^2 ).^0.5;
    if RHW_west(nHR,nC) == 0
      u_RHW_west(nHR,nC) = 0;
    end


    %New reheat energy for water side
    RHW_up_west(nHR,nC)=RHW_west(nHR,nC) - u_RHW_west(nHR,nC);
    RHW_lo_west(nHR,nC)=RHW_west(nHR,nC) + u_RHW_west(nHR,nC);

    %Uncertainty calculation of reheat energy for electric heater side
    u_RHE_west(nHR,nC)=3411.8*( (stg1*u_stg1*vav_htg1_west(j)).^2 + (stg2*u_stg2*vav_htg2_west(j)).^2
+ (stg3*u_stg3*vav_htg3_west(j)).^2 ).^0.5;

    %New reheat energy for electric heater side
    RHE_up_west(nHR,nC)=RHE_west(nHR,nC) - u_RHE_west(nHR,nC);
    RHE_lo_west(nHR,nC)=RHE_west(nHR,nC) + u_RHE_west(nHR,nC);

   j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MVAVCFM_west(nDay,nCC) = mean(VAVCFM_west(nHR,:));
    MVAVDAT_west(nDay,nCC) = mean(VAVDAT_west(nHR,:));
    MPLNTEMP_west(nDay,nCC)= mean(PLNTEMP_west(nHR,:));
    MRMTEMP_west(nDay,nCC) = mean(RMTEMP_west(nHR,:));
    MHOTWGPM_west(nDay,nCC)=mean(HOTWGPM_west(nHR,:));
    MHOTWEWT_west(nDay,nCC)=mean(HOTWEWT_west(nHR,:));
    MHOTWLWT_west(nDay,nCC)=mean(HOTWLWT_west(nHR,:));
    MEN_AIR_west(nDay,nCC) = mean(EN_AIR_west(nHR,:));
    MRHW_west(nDay,nCC)= mean(RHW_west(nHR,:));
    MRHW_up_west(nDay,nCC)= mean(RHW_up_west(nHR,:));
    MRHW_lo_west(nDay,nCC)= mean(RHW_lo_west(nHR,:));
    MRHE_west(nDay,nCC)= mean(RHE_west(nHR,:));
    MRHE_up_west(nDay,nCC)= mean(RHE_up_west(nHR,:));
    MRHE_lo_west(nDay,nCC)= mean(RHE_lo_west(nHR,:));
    nHR = nHR + 1;
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;
```

```
HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CVAVCFM_west(HR) = mean(VAVCFM_west(nHR,:));
  if CSACFM(HR) == 0
    CVAVCFM_west(HR) = 0;
  end

  CVAVDAT_west(HR) = mean(VAVDAT_west(nHR,:));
  CPLNTEMP_west(HR) =  mean(PLNTEMP_west(nHR,:));
  CRMTEMP_west(HR) =  mean(RMTEMP_west(nHR,:));
  CHOTWGPM_west(HR) =  mean(HOTWGPM_west(nHR,:));
  CHOTEWT_west(HR) =  mean(HOTWEWT_west(nHR,:));
  CHOTLWT_west(HR) =  mean(HOTWLWT_west(nHR,:));
  CEN_AIR_west(HR)= mean(EN_AIR_west(nHR,:));
  CRHW_west(HR)=mean(RHW_west(nHR,:));
  CRHW_up_west(HR)=mean(RHW_up_west(nHR,:));
  CRHW_lo_west(HR)=mean(RHW_lo_west(nHR,:));
  CRHE_west(HR)=mean(RHE_west(nHR,:));
  CRHE_up_west(HR)=mean(RHE_up_west(nHR,:));
  CRHE_lo_west(HR)=mean(RHE_lo_west(nHR,:));

end
disp(' ')
if dirname == 14
  disp('WESTROOM-A has been processed!!')
elseif dirname == 24
  disp('WESTROOM-B has been processed!!')
end
disp(' ')



%INTER is an Energy program for interior room.
disp('This program(INTER) analizes INTERIOR ROOM.')

disp('Interior Room Data file names are: ')
if systemselect == 1
  dir('\sangsoo\project\matlab\data\*ria.m')
  dirname = 15;
else
  dir('\sangsoo\project\matlab\data\*rib.m')
  dirname = 25;
end
disp('')
if dirname == 15
  disp('INTERIOR ROOM-A is being processed!!')
elseif dirname == 25
  disp('INTERIOR ROOM-B is being processed!!')
end

filename;
%input('Enter a data file name without extention(m), without quotes:  ');
```

```
disp(' ')
inter = a;
[r c]=size(inter);
BeginningTime_inter=[inter(1,1) inter(1,2)];
EndingTime_inter=[inter(r,1) inter(r,2)];
Btime_inter =inter(1,1)+inter(1,2);
Etime_inter =inter(r,1)+inter(r,2);

if (Btime_inter ~= Btime) | (Etime_inter ~= Etime)
  disp('There was a time difference between INTERROOM and AHU !!')
end

% Array variables.
kk=0;
for k=1:r
  if inter(k,1) >= Bdate & inter(k,1) <= Edate
    kk=kk+1;
    if systemselect == 1
      varname = 15;
      dirname = 33;
      filename; % call variables
    elseif systemselect == 2
      varname = 25;
      dirname = 33;
      filename; % call variables
    end
  end
end

if varname == 15
  dirname = 15;
else
  dirname = 25;
end

INTER_kk = kk;
INTER_end_time=[date(INTER_kk) time(INTER_kk)];
if AHU_kk ~= INTER_kk
  disp('')
  disp('You need to look at the date and time in trend data.')
  AHU_end_time=[date(AHU_kk) time(AHU_kk)]
  INTER_end_time=[date(INTER_kk) time(INTER_kk)]
  error('Error!! ---> Number of rows is different between AHU and INTERROOM')
end

%Properties of air and water
%Properties of air and water and The power of electric coils in TAB
% See The File program to look at the properties values
% See The File program to look at the Power (kW) of electric coil in the TABs

H=60/7.48055*rho_hot_wtr*cp_hot_wtr;

%Display initial values
if airF_inter(1) == -999
```

```
  VAV_CFM_inter  = airF_inter(1)
  airF_inter(1) = input('Enter an initial value for VAV-CFM of interior room: ');
end
if vav_dat_inter(1) < 0
  VAV_DAT_inter  = vav_dat_inter(1)
  vav_dat_inter(1) = input('Enter an initial value for VAV-DAT of interior room: ');
end
if pln_temp_inter(1) == -999
  PLN_TEMP_inter  = pln_temp_inter(1)
  pln_temp_inter(1) = input('Enter an initial value for plenum temp of inter room: ');
end
if rm_temp_inter(1) == -999
  RM_TEMP_inter  = rm_temp_inter(1)
  rm_temp_inter(1) = input('Enter an initial value for room temp of interior room: ');
end
if hwF_inter(1) == -999
  HOTW_GPM_inter  = hwF_inter(1)
  hwF_inter(1) = input('Enter an initial value for hot water GPM of interior room: ');
end
if vavhcewt_inter(1) == -999
  HOTW_EWT_inter  = vavhcewt_inter(1)
  vavhcewt_inter(1) = input('Enter an initial value for hot water entering temp of interior room: ');
end
if vavhclwt_inter(1) == -999
  HOTW_LWT_inter  = vavhclwt_inter(1)
  vavhclwt_inter(1) = input('Enter an initial value for hot water leaving temp of interior room: ');
end
if vav_htg1_inter(1) == -999
  VAV_HTG1_inter  = vav_htg1_inter(1)
  vav_htg1_inter(1) = input('Enter an initial value for vav-htg1 of interior room: ');
end
if vav_htg2_inter(1) == -999
  VAV_HTG2_inter  = vav_htg2_inter(1)
  vav_htg2_inter(1) = input('Enter an initial value for vav-htg2 of interior room: ');
end

for i=1:kk
  if airF_inter(i) == -999
    airF_inter(i) = airF_inter(i-1);
  end
  if vav_dat_inter(i) < 0
    vav_dat_inter(i) = vav_dat_inter(i-1);
  end
  if pln_temp_inter(i) == -999
    pln_temp_inter(i) = pln_temp_inter(i-1);
  end
  if rm_temp_inter(i) == -999
    rm_temp_inter(i) = rm_temp_inter(i-1);
  end
  if hwF_inter(i) == -999
    hwF_inter(i) = hwF_inter(i-1);
  end
  if hwF_inter(i) > -990 & hwF_inter(i) < 0
    hwF_inter(i) = 0;
```

```
  end
  if vavhcewt_inter(i) == -999
    vavhcewt_inter(i) = vavhcewt_inter(i-1);
  end
  if vavhclwt_inter(i) == -999
    vavhclwt_inter(i) = vavhclwt_inter(i-1);
  end
          if vav_htg1_inter(i) == -999
          vav_htg1_inter(i) = vav_htg1_inter(i-1);
          end
          if vav_htg2_inter(i) == -999
          vav_htg2_inter(i) = vav_htg2_inter(i-1);
          end
end

nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    VAVCFM_inter(nHR,nC) = airF_inter(j);
    VAVDAT_inter(nHR,nC) = vav_dat_inter(j);
    PLNTEMP_inter(nHR,nC)= pln_temp_inter(j);
    RMTEMP_inter(nHR,nC) = rm_temp_inter(j);
    HOTWGPM_inter(nHR,nC) = hwF_inter(j);
    HOTWEWT_inter(nHR,nC) = vavhcewt_inter(j);
    HOTWLWT_inter(nHR,nC) = vavhclwt_inter(j);
    EN_AIR_inter(nHR,nC) = 60*rho_hot_air*cp_hot_air*airF_inter(j).*(da_temp(j)-vav_dat_inter(j));
    EN_WATER_inter(nHR,nC) = H*hwF_inter(j).*(vavhclwt_inter(j) - vavhcewt_inter(j));
    EN_ELEC_inter(nHR,nC) = -3411.8*(stgi1*vav_htg1_inter(j) + stgi2*vav_htg2_inter(j));

    RHW_inter(nHR,nC)=EN_WATER_inter(nHR,nC);
    RHE_inter(nHR,nC)=EN_ELEC_inter(nHR,nC);
    if RHW_inter(nHR,nC)> 0
      RHW_inter(nHR,nC) = 0;
    end

    %Uncertainty calculation of reheat energy for water side
    dRHW_dgpm_inter(nHR,nC)=H*(vavhclwt_inter(j)-vavhcewt_inter(j));

    dRHW_dlwt_inter(nHR,nC)=H*hwF_inter(j);
    dRHW_dewt_inter(nHR,nC)=-H*hwF_inter(j);
    u_RHW_inter(nHR,nC)=( (dRHW_dgpm_inter(nHR,nC).*u_hgpm).^2 +
(dRHW_dlwt_inter(nHR,nC).*u_hlwt).^2 + (dRHW_dewt_inter(nHR,nC).*u_hewt).^2 ).^0.5;
    if RHW_inter(nHR,nC) == 0
      u_RHW_inter(nHR,nC) = 0;
    end

    %New reheat energy for water side
    RHW_up_inter(nHR,nC)=RHW_inter(nHR,nC) - u_RHW_inter(nHR,nC);
    RHW_lo_inter(nHR,nC)=RHW_inter(nHR,nC) + u_RHW_inter(nHR,nC);

    %Uncertainty calculation of reheat energy for electric heater side
```

```
    u_RHE_inter(nHR,nC)=3411.8*( (stgi1*u_stgi1*vav_htg1_inter(j)).^2 +
(stgi2*u_stgi2*vav_htg2_inter(j)).^2 ).^0.5;

    %New reheat energy for electric heater side
    RHE_up_inter(nHR,nC)=RHE_inter(nHR,nC) - u_RHE_inter(nHR,nC);
    RHE_lo_inter(nHR,nC)=RHE_inter(nHR,nC) + u_RHE_inter(nHR,nC);

    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MVAVCFM_inter(nDay,nCC) = mean(VAVCFM_inter(nHR,:));
    MVAVDAT_inter(nDay,nCC) = mean(VAVDAT_inter(nHR,:));
    MPLNTEMP_inter(nDay,nCC)= mean(PLNTEMP_inter(nHR,:));
    MRMTEMP_inter(nDay,nCC) = mean(RMTEMP_inter(nHR,:));
    MHOTWGPM_inter(nDay,nCC)=mean(HOTWGPM_inter(nHR,:));
    MHOTWEWT_inter(nDay,nCC)=mean(HOTWEWT_inter(nHR,:));
    MHOTWLWT_inter(nDay,nCC)=mean(HOTWLWT_inter(nHR,:));
    MEN_AIR_inter(nDay,nCC) = mean(EN_AIR_inter(nHR,:));
    MRHW_inter(nDay,nCC)= mean(RHW_inter(nHR,:));
    MRHW_up_inter(nDay,nCC)= mean(RHW_up_inter(nHR,:));
    MRHW_lo_inter(nDay,nCC)= mean(RHW_lo_inter(nHR,:));
    MRHE_inter(nDay,nCC)= mean(RHE_inter(nHR,:));
    MRHE_up_inter(nDay,nCC)= mean(RHE_up_inter(nHR,:));
    MRHE_lo_inter(nDay,nCC)= mean(RHE_lo_inter(nHR,:));

    nHR = nHR + 1;
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CVAVCFM_inter(HR) = mean(VAVCFM_inter(nHR,:));
  if CSACFM(HR) == 0
    CVAVCFM_inter(HR) = 0;
  end

  CVAVDAT_inter(HR) = mean(VAVDAT_inter(nHR,:));
  CPLNTEMP_inter(HR) =  mean(PLNTEMP_inter(nHR,:));
  CRMTEMP_inter(HR) =  mean(RMTEMP_inter(nHR,:));
  CHOTWGPM_inter(HR) =  mean(HOTWGPM_inter(nHR,:));
  CHOTEWT_inter(HR) =  mean(HOTWEWT_inter(nHR,:));
  CHOTLWT_inter(HR) =  mean(HOTWLWT_inter(nHR,:));
  CEN_AIR_inter(HR)= mean(EN_AIR_inter(nHR,:));
  CRHW_inter(HR)=mean(RHW_inter(nHR,:));
```

```
  CRHW_up_inter(HR)=mean(RHW_up_inter(nHR,:));
  CRHW_lo_inter(HR)=mean(RHW_lo_inter(nHR,:));
  CRHE_inter(HR)=mean(RHE_inter(nHR,:));
  CRHE_up_inter(HR)=mean(RHE_up_inter(nHR,:));
  CRHE_lo_inter(HR)=mean(RHE_lo_inter(nHR,:));

  end

disp(' ')
if dirname == 15
  disp('INTERIOR ROOM-A has been processed!!')
elseif dirname == 25
  disp('INTERIOR ROOM-B has been processed!!')
end
disp(' ')


if programselect == 1
  %Array of Calculated data for IEA report
  AHUCMH=[1.69901*CSACFM' 1.69901*COACFM'];
  CMATEMP=(CMATEMP-32)/1.8;
  CCLGDAT=(CCLGDAT-32)/1.8;
  CRATEMP=(CRATEMP-32)/1.8;
  CRMTEMP_east=(CRMTEMP_east-32)/1.8;
  CRMTEMP_south=(CRMTEMP_south-32)/1.8;
  CRMTEMP_west=(CRMTEMP_west-32)/1.8;
  CRMTEMP_inter=(CRMTEMP_inter-32)/1.8;

  AHUTMP=[CMATEMP' CCLGDAT' CRATEMP'];
  SYSCOOL=CQ'*0.293;

  EAST=[CRMTEMP_east' 1.69901*CVAVCFM_east' 0.293*CRHE_east' 0.293*CRHW_east'];
  SOUTH=[CRMTEMP_south' 1.69901*CVAVCFM_south' 0.293*CRHE_south' 0.293*CRHW_south'];
  WEST=[CRMTEMP_west' 1.69901*CVAVCFM_west' 0.293*CRHE_west' 0.293*CRHW_west'];
  INTER=[CRMTEMP_inter' 1.69901*CVAVCFM_inter' 0.293*CRHE_inter' 0.293*CRHW_inter'];

  %For printout
  PRINTOUT=[AHUCMH AHUTMP SYSCOOL EAST SOUTH WEST INTER];

  %OUTPRINT is an program for printout after analysis.
  disp('This program(OUTPRINT) creates outputs.')
  dirname = 32;
  filename; % call FILENAME for output filename
  dirname = 9;
  filename;%call FILENAME for output path
  disp(' ')
  fid=fopen(hourfile,'w');
  fprintf(fid,' DATE  TIME sacfm oacfm ma-temp clg-dat ra-temp coolen rmtemp-e rmcfm-e hele-e hwtr-e
rmtemp-s rmcfm-s hele-s hwtr-s rmtemp-w rmcfm-w hele-w hwtr-w rmtemp-I rmcfm-I hele-I hwtr-I\n');


  nDay=1;
  DATE(1)=Bdate;
  for nHR=1:24:kk/f;
```

```
    nCC = 0;
    while nCC < 24
      nCC = nCC + 1;

fprintf(fid,'%9i%5i%6.0f%6.0f%8.1f%8.1f%8.1f%8.0f%9.1f%8.0f%7.0f%7.0f%9.1f%8.0f%7.0f%7.0f%9.1f%
8.0f%7.0f%7.0f%9.1f%8.0f%7.0f%7.0f\n',DATE(nDay),nCC,PRINTOUT(nHR,:));
      nHR = nHR + 1;
    end
    DATE(nDay+1)=DATE(nDay)+1;
    nDay = nDay + 1;
  end
  Status2=fclose(fid)
  Number_of_Days=nDay-1;


elseif programselect ==2
  %Array of Calculated data for ERS report
  AHUCFM=[CSACFM' COACFM'];
  AHUTMP=[CMATEMP' CCLGDAT' CRATEMP' CDATEMP'];
  SYSCOOL=[CQ'];

  TOT_RHW=CRHW_east' + CRHW_south' + CRHW_west' + CRHW_inter';
  TOT_RHW_LO=CRHW_lo_east' + CRHW_lo_south' + CRHW_lo_west' + CRHW_lo_inter';
  TOT_RHW_UP=CRHW_up_east' + CRHW_up_south' + CRHW_up_west' + CRHW_up_inter';

  TOT_RHE=CRHE_east' + CRHE_south' + CRHE_west' + CRHE_inter';
  TOT_RHE_LO=CRHE_lo_east' + CRHE_lo_south' + CRHE_lo_west' + CRHE_lo_inter';
  TOT_RHE_UP=CRHE_up_east' + CRHE_up_south' + CRHE_up_west' + CRHE_up_inter';

  ROOMTMP=[CRMTEMP_east' CRMTEMP_south' CRMTEMP_west' CRMTEMP_inter'];
  ROOMCFM=[CVAVCFM_east' CVAVCFM_south' CVAVCFM_west' CVAVCFM_inter'];

  RHE_E=[CRHE_east'];
  RHE_S=[CRHE_south'];
  RHE_W=[CRHE_west'];
  RHE_I=[CRHE_inter'];

  RHW_E=[CRHW_lo_east' CRHW_east' CRHW_up_east'];
  RHW_S=[CRHW_lo_south' CRHW_south' CRHW_up_south'];
  RHW_W=[CRHW_lo_west' CRHW_west' CRHW_up_west'];
  RHW_I=[CRHW_lo_inter' CRHW_inter' CRHW_up_inter'];


  %data summary
  UCQ=CQ_up' - CQ';
  UHQ=TOT_RHE - TOT_RHE_UP;
  UEAST=CRHE_east' - CRHE_up_east';
  USOUTH=CRHE_south' - CRHE_up_south';
  UWEST=CRHE_west' - CRHE_up_west';
  UINTER=CRHE_inter' - CRHE_up_inter';
  syscool=[max(CQ') mean(CQ') min(CQ') max(UCQ) mean(UCQ) min(UCQ)];
  sysheat=[-min(TOT_RHE) -mean(TOT_RHE) -max(TOT_RHE) max(UHQ) mean(UHQ) min(UHQ)];
  heast=[-min(CRHE_east') -mean(CRHE_east') -max(CRHE_east') max(UEAST) mean(UEAST)
min(UEAST)];
```

```
  hsouth=[-min(CRHE_south') -mean(CRHE_south') -max(CRHE_south') max(USOUTH) mean(USOUTH)
 min(USOUTH)];
  hwest=[-min(CRHE_west') -mean(CRHE_west') -max(CRHE_west') max(UWEST) mean(UWEST)
 min(UWEST)];
  hinter=[-min(CRHE_inter') -mean(CRHE_inter') -max(CRHE_inter') max(UINTER) mean(UINTER)
 min(UINTER)];

  %hourly report
  systemenergy=[SYSCOOL  TOT_RHE];
  roomenergy=[RHE_E RHE_S RHE_W RHE_I];
  cfm=[AHUCFM ROOMCFM];
  temp=[ROOMTMP];

  %For printout
  PRINTOUT=[systemenergy roomenergy cfm temp];

  %OUTPRINT is an program for printout after analysis.
  disp('This program(OUTPRINT) creates outputs.')
  dirname = 31;
  filename; % call FILENAME for output filename
  dirname = 9;
  filename;%call FILENAME for output path
  disp(' ')
  fid=fopen(datfile,'w');
  fprintf(fid,'ENERGY     MAX  MEAN   MIN  UMAX  UMEAN  UMIN\n');
  fprintf(fid,'SYSCOOL  %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',syscool);
  fprintf(fid,'SYSHEAT  %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',sysheat);
  fprintf(fid,'EAST     %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',heast);
  fprintf(fid,'SOUTH    %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',hsouth);
  fprintf(fid,'WEST     %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',hwest);
  fprintf(fid,'INTER    %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',hinter);
  fclose(fid)

  dirname = 32;
  filename; % call FILENAME for output filename
  %dirname = 9;
  %filename;%call FILENAME for output path
  disp(' ')
  fid=fopen(hourfile,'w');
  fprintf(fid,'  DATE  TIME  cool  h-ele hele-e hele-s hele-w hele-I  sacfm  oacfm rmcfm-e rmcfm-s rmcfm-w
rmcfm-I rmtemp-e rmtemp-s rmtemp-w rmtemp-I\n');
  nDay=1;
  DATE(1)=Bdate;
  for nHR=1:24:kk/f;
    nCC = 0;
    while nCC < 24
      nCC = nCC + 1;

fprintf(fid,'%9i%5i%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%8.0f%8.0f%8.0f%8.0f%9.1f%9.1f%9.1f%
9.1f\n',DATE(nDay),nCC,PRINTOUT(nHR,:));
      nHR = nHR + 1;
    end
    DATE(nDay+1)=DATE(nDay)+1;
    nDay = nDay + 1;
```

```
  end

  Status2=fclose(fid)
  Number_of_Days=nDay-1;
end


cd ..
cd ..
cd programs;

disp('PRINTOUT run has been done!')
disp(' ')



if programselect == 1
  %Array of Calculated data for IEA report
  AHUCMH=[1.69901*CSACFM' 1.69901*COACFM'];
  CMATEMP=(CMATEMP-32)/1.8;
  CCLGDAT=(CCLGDAT-32)/1.8;
  CRATEMP=(CRATEMP-32)/1.8;
  CRMTEMP_east=(CRMTEMP_east-32)/1.8;
  CRMTEMP_south=(CRMTEMP_south-32)/1.8;
  CRMTEMP_west=(CRMTEMP_west-32)/1.8;
  CRMTEMP_inter=(CRMTEMP_inter-32)/1.8;

  AHUTMP=[CMATEMP' CCLGDAT' CRATEMP'];
  SYSCOOL=CQ'*0.293;

  EAST=[CRMTEMP_east' 1.69901*CVAVCFM_east' 0.293*CRHE_east' 0.293*CRHW_east'];
  SOUTH=[CRMTEMP_south' 1.69901*CVAVCFM_south' 0.293*CRHE_south' 0.293*CRHW_south'];
  WEST=[CRMTEMP_west' 1.69901*CVAVCFM_west' 0.293*CRHE_west' 0.293*CRHW_west'];
  INTER=[CRMTEMP_inter' 1.69901*CVAVCFM_inter' 0.293*CRHE_inter' 0.293*CRHW_inter'];

  %For printout
  PRINTOUT=[AHUCMH AHUTMP SYSCOOL EAST SOUTH WEST INTER];

  %OUTPRINT is an program for printout after analysis.
  disp('This program(OUTPRINT) creates outputs.')
  dirname = 32;
  filename; % call FILENAME for output filename
  dirname = 9;
  filename;%call FILENAME for output path
  disp(' ')
  fid=fopen(hourfile,'w');
  fprintf(fid,' DATE   TIME sacfm oacfm ma-temp clg-dat ra-temp  coolen rmtemp-e rmcfm-e hele-e hwtr-e
rmtemp-s rmcfm-s hele-s hwtr-s rmtemp-w rmcfm-w hele-w hwtr-w rmtemp-I rmcfm-I hele-I hwtr-I\n');


  nDay=1;
  DATE(1)=Bdate;
  for nHR=1:24:kk/f;
    nCC = 0;
```

```
    while nCC < 24
      nCC = nCC + 1;

fprintf(fid,'%9i%5i%6.0f%6.0f%8.1f%8.1f%8.1f%8.0f%9.1f%8.0f%7.0f%7.0f%9.1f%8.0f%7.0f%7.0f%9.1f%
8.0f%7.0f%7.0f%9.1f%8.0f%7.0f%7.0f\n',DATE(nDay),nCC,PRINTOUT(nHR,:));
      nHR = nHR + 1;
    end
    DATE(nDay+1)=DATE(nDay)+1;
    nDay = nDay + 1;
  end
  Status2=fclose(fid)
  Number_of_Days=nDay-1;
  cd ..
    cd programs

elseif programselect ==2
  %Array of Calculated data for ERS report
  AHUCFM=[CSACFM' COACFM'];
  AHUTMP=[CMATEMP' CCLGDAT' CRATEMP' CDATEMP'];
  SYSCOOL=[ CQ_lo' CQ'  CQ_up'];

  TOT_RHW=CRHW_east' + CRHW_south' + CRHW_west' + CRHW_inter';
  TOT_RHW_LO=CRHW_lo_east' + CRHW_lo_south' + CRHW_lo_west' + CRHW_lo_inter';
  TOT_RHW_UP=CRHW_up_east' + CRHW_up_south' + CRHW_up_west' + CRHW_up_inter';

  TOT_RHE=CRHE_east' + CRHE_south' + CRHE_west' + CRHE_inter';
  TOT_RHE_LO=CRHE_lo_east' + CRHE_lo_south' + CRHE_lo_west' + CRHE_lo_inter';
  TOT_RHE_UP=CRHE_up_east' + CRHE_up_south' + CRHE_up_west' + CRHE_up_inter';

  ROOMTMP=[CRMTEMP_east' CRMTEMP_south' CRMTEMP_west' CRMTEMP_inter'];
  ROOMCFM=[CVAVCFM_east' CVAVCFM_south' CVAVCFM_west' CVAVCFM_inter'];

  RHE_E=[CRHE_lo_east' CRHE_east' CRHE_up_east'];
  RHE_S=[CRHE_lo_south' CRHE_south' CRHE_up_south'];
  RHE_W=[CRHE_lo_west' CRHE_west' CRHE_up_west'];
  RHE_I=[CRHE_lo_inter' CRHE_inter' CRHE_up_inter'];

  RHW_E=[CRHW_lo_east' CRHW_east' CRHW_up_east'];
  RHW_S=[CRHW_lo_south' CRHW_south' CRHW_up_south'];
  RHW_W=[CRHW_lo_west' CRHW_west' CRHW_up_west'];
  RHW_I=[CRHW_lo_inter' CRHW_inter' CRHW_up_inter'];


  systemenergy=[SYSCOOL  TOT_RHE_LO TOT_RHE TOT_RHE_UP TOT_RHW_LO TOT_RHW
TOT_RHW_UP];
  roomenergy=[RHE_E RHE_S RHE_W RHE_I RHW_E RHW_S RHW_W RHW_I];
  cfm=[AHUCFM ROOMCFM];
  temp=[AHUTMP ROOMTMP];

  %For printout
  PRINTOUT=[systemenergy roomenergy cfm temp];

  %OUTPRINT is an program for printout after analysis.
  disp('This program(OUTPRINT) creates outputs.')
```

```
  dirname = 32;
  filename; % call FILENAME for output filename
  dirname = 9;
  filename;%call FILENAME for output path
  disp(' ')
  fid=fopen(hourfile,'w');
  fprintf(fid,' DATE TIME cool1 cool2 cool3 h-ele1 h-ele2 h-ele3 h-wtr1 h-wtr2 h-wtr3 hele1-e hele2-e
hele3-e hele1-s hele2-s hele3-s hele1-w hele2-w hele3-w hele1-I hele2-I hele3-I hwtr1-e hwtr2-e hwtr3-e
hwtr1-s hwtr2-s hwtr3-s hwtr1-w hwtr2-w hwtr3-w hwtr1-I hwtr2-I hwtr3-I sacfm oacfm rmcfm-e rmcfm-s
rmcfm-w rmcfm-I ma-temp clg-dat ra-temp da-temp rmtemp-e rmtemp-s rmtemp-w rmtemp-I\n');

  nDay=1;
  DATE(1)=Bdate;
  for nHR=1:24:kk/f;
    nCC = 0;
    while nCC < 24
      nCC = nCC + 1;

fprintf(fid,'%9i%5i%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%
8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%8.0f%6.0
f%6.0f%8.0f%8.0f%8.0f%8.0f%8.1f%8.1f%8.1f%8.1f%9.1f%9.1f%9.1f%9.1f\n',DATE(nDay),nCC,PRINTO
UT(nHR,:));
      nHR = nHR + 1;
    end
    DATE(nDay+1)=DATE(nDay)+1;
    nDay = nDay + 1;
  end

  Status2=fclose(fid)
  Number_of_Days=nDay-1;
cd ..
cd ..
cd programs;
end



disp('PRINTOUT run has been done!')
disp(' ')


%EAST is an Energy program for EAST-FCU
disp('This program(FEAST) analizes EAST-FCU.')
dirname = 10;
filename; % call FILENAME for setting the Bdate, Edate & time interval
format compact;

disp('EAST-FCU file names are ');
dir('\sangsoo\project\matlab\data\*reb.m')
dirname = 22;
disp(' ')
disp('EAST-FCU is being processed!!')

filename;% call data file for the eastroom
```

```
disp(' ')
east = a;
[r c]=size(east);
BeginningTime_east=[east(1,1) east(1,2)]
EndingTime_east=[east(r,1) east(r,2)]
Btime_east =east(1,1)+east(1,2);
Etime_east =east(r,1)+east(r,2);

Bdate
Edate
% Array variables.
kk=0;
for k=1:r
  if east(k,1) >= Bdate & east(k,1) <= Edate
    kk=kk+1;
    varname = 26;
    dirname = 33;
    filename; % call variables
  end
end

dirname = 22;

EAST_kk = kk;
disp('Data will be processed until ');
EAST_end_time=[date(EAST_kk) time(EAST_kk)]

%Display initial values
if fcu_dis_east(1)== -999
  FCU_DIS_east=fcu_dis_east(1)
  fcu_dis_east(1) = input('Enter an initial value for FCU-DIS of east room: ');
end
if fcu_med_east(1)== -999
  FCU_MED_east=fcu_med_east(1)
  fcu_med_east(1) = input('Enter an initial value for FCU-MED of east room: ');
end
if fcu_mix_east(1)== -999
  FCU_MIX_east=fcu_mix_east(1)
  fcu_mix_east(1) = input('Enter an initial value for FCU-MIX of east room: ');
end
if rm_temp_east(1)== -999
  RM_TEMP_east=rm_temp_east(1)
  rm_temp_east(1) = input('Enter an initial value for RM-TEMP of east room: ');
end
if vav_dat_east(1) < 0
  VAV_DAT_east  = vav_dat_east(1)
  vav_dat_east(1) = input('Enter an initial value for FCU-DAT of east room: ');
end

for i=1:kk
  if fcu_dis_east(i)== -999
    fcu_dis_east(i) = fcu_dis_east(i-1);
  end
  if fcu_med_east(i)== -999
```

```
      fcu_med_east(i) = fcu_med_east(i-1);
    end
    if fcu_mix_east(i)== -999
      fcu_mix_east(i) = fcu_mix_east(i-1);
    end
    if rm_temp_east(i)== -999
      rm_temp_east(i) = rm_temp_east(i-1);
    end
    if vav_dat_east(i) < 0
      vav_dat_east(i) = vav_dat_east(i-1);
    end
  end

  nHR=1;
  for j=1:f:kk
    nC = 0;
    while nC < f
      nC = nC+1;
      FCUDIS_east(nHR,nC) = fcu_dis_east(j);
      FCUMED_east(nHR,nC) = fcu_med_east(j);
      FCUMIX_east(nHR,nC) = fcu_mix_east(j);
      RMTEMP_east(nHR,nC) = rm_temp_east(j);
      VAVDAT_east(nHR,nC) = vav_dat_east(j);
      EN_AIR_east(nHR,nC) = fc*Ecfm*fcu_med_east(j).*(rm_temp_east(j)-vav_dat_east(j));
      if EN_AIR_east(nHR,nC) > 0
        COOL_east(nHR,nC) = EN_AIR_east(nHR,nC);
        HEAT_east(nHR,nC) = 0;
      elseif EN_AIR_east(nHR,nC) <= 0
        COOL_east(nHR,nC) = 0;
        HEAT_east(nHR,nC) = EN_AIR_east(nHR,nC);
      end

      %Uncertainty calculation
      dcfm_east(nHR,nC)=fc*fcu_med_east(j).*(rm_temp_east(j)-vav_dat_east(j));
      drmtemp_east(nHR,nC)=fc*Ecfm*fcu_med_east(j);
      dvavdat_east(nHR,nC)=-fc*Ecfm*fcu_med_east(j);
      u_east(nHR,nC)=( (dcfm_east(nHR,nC)*u_cfm).^2 + (drmtemp_east(nHR,nC)*u_rmt).^2 +
(dvavdat_east(nHR,nC)*u_dat).^2 ).^0.5;

      if dcfm_east(nHR,nC) > 0
        UCOOL_east(nHR,nC) = u_east(nHR,nC);
        UHEAT_east(nHR,nC) = 0;
      elseif dcfm_east(nHR,nC) <= 0
        UCOOL_east(nHR,nC) = 0;
        UHEAT_east(nHR,nC) = u_east(nHR,nC);
      end
      j = j+1;
    end
    nHR = nHR + 1;
  end

  nDay=1;
  for nHR=1:24:kk/f;
    nCC = 0;
```

```
    while nCC < 24
      nCC = nCC + 1;
      MFCUDIS_east(nDay,nCC) = mean(FCUDIS_east(nHR,:));
      MFCUMED_east(nDay,nCC) = mean(FCUMED_east(nHR,:));
      MFCUMIX_east(nDay,nCC) = mean(FCUMIX_east(nHR,:));
      MRMTEMP_east(nDay,nCC) = mean(RMTEMP_east(nHR,:));
      MVAVDAT_east(nDay,nCC) = mean(VAVDAT_east(nHR,:));
      MCOOL_east(nDay,nCC) = mean(COOL_east(nHR,:));
      MHEAT_east(nDay,nCC) = mean(HEAT_east(nHR,:));
      MUCOOL_east(nDay,nCC) = mean(UCOOL_east(nHR,:));
      MUHEAT_east(nDay,nCC) = mean(UHEAT_east(nHR,:));
      nHR = nHR + 1;
    end
    nDay = nDay + 1;
  end
  Number_of_Days=nDay-1;

  HR =0;
  for nHR=1:kk/f;
    HR = HR+1;
    CFCUDIS_east(HR) = mean(FCUDIS_east(nHR,:));
    CFCUMED_east(HR) = mean(FCUMED_east(nHR,:));
    CFCUMIX_east(HR) = mean(FCUMIX_east(nHR,:));
    CRMTEMP_east(HR) = mean(RMTEMP_east(nHR,:));
    CVAVDAT_east(HR) = mean(VAVDAT_east(nHR,:));
    CCOOL_east(HR) = mean(COOL_east(nHR,:));
    CHEAT_east(HR) = mean(HEAT_east(nHR,:));
    CUCOOL_east(HR) = mean(UCOOL_east(nHR,:));
    CUHEAT_east(HR) = mean(UHEAT_east(nHR,:));
  end
  disp(' ')
  disp('EAST-FCU has been processed!!')
  disp(' ')



  %FSOUTH is an Energy program for SOUTH-FCU
  disp('This program(FSOUTH) analizes SOUTH-FCU.')
  dirname = 10;
  filename; % call FILENAME for setting the Bdate, Edate & time interval
  format compact;

  disp('SOUTH-FCU file names are ');
  dir('\sangsoo\project\matlab\data\*rsb.m')
  dirname = 23;
  disp(' ')
  disp('SOUTH-FCU is being processed!!')

  filename;% call data file for the south room
  disp(' ')
  south = a;
  [r c]=size(south);
```

```
BeginningTime_south=[south(1,1) south(1,2)]
EndingTime_south=[south(r,1) south(r,2)]
Btime_south =south(1,1)+south(1,2);
Etime_south =south(r,1)+south(r,2);

Bdate
Edate

if Btime_south ~= Btime_east
  disp('There was a time difference between SOUTH-FCU and EAST-FCU !!')
end

% Array variables.
kk=0;
for k=1:r
  if south(k,1) >= Bdate & south(k,1) <= Edate
    kk=kk+1;
    varname = 27;
    dirname = 33;
    filename; % call variables
  end
end

dirname = 23;

SOUTH_kk = kk;
disp('Data will be processed until ');
SOUTH_end_time=[date(SOUTH_kk) time(SOUTH_kk)]

%Display initial values
if fcu_dis_south(1)== -999
  FCU_DIS_south=fcu_dis_south(1)
  fcu_dis_south(1) = input('Enter an initial value for FCU-DIS of south room: ');
end
if fcu_med_south(1)== -999
  FCU_MED_south=fcu_med_south(1)
  fcu_med_south(1) = input('Enter an initial value for FCU-MED of south room: ');
end
if fcu_mix_south(1)== -999
  FCU_MIX_south=fcu_mix_south(1)
  fcu_mix_south(1) = input('Enter an initial value for FCU-MIX of south room: ');
end
if rm_temp_south(1)== -999
  RM_TEMP_south=rm_temp_south(1)
  rm_temp_south(1) = input('Enter an initial value for RM-TEMP of south room: ');
end
if vav_dat_south(1) < 0
  VAV_DAT_south = vav_dat_south(1)
  vav_dat_south(1) = input('Enter an initial value for FCU-DAT of south room: ');
end

for i=1:kk
  if fcu_dis_south(i)== -999
    fcu_dis_south(i) = fcu_dis_south(i-1);
```

```
    end
    if fcu_med_south(i)== -999
      fcu_med_south(i) = fcu_med_south(i-1);
    end
    if fcu_mix_south(i)== -999
      fcu_mix_south(i) = fcu_mix_south(i-1);
    end
    if rm_temp_south(i)== -999
      rm_temp_south(i) = rm_temp_south(i-1);
    end
    if vav_dat_south(i) < 0
      vav_dat_south(i) = vav_dat_south(i-1);
    end
end

nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    FCUDIS_south(nHR,nC) = fcu_dis_south(j);
    FCUMED_south(nHR,nC) = fcu_med_south(j);
    FCUMIX_south(nHR,nC) = fcu_mix_south(j);
    RMTEMP_south(nHR,nC) = rm_temp_south(j);
    VAVDAT_south(nHR,nC) = vav_dat_south(j);
    EN_AIR_south(nHR,nC) = fc*Ecfm*fcu_med_south(j).*(rm_temp_south(j)-vav_dat_south(j));
    if EN_AIR_south(nHR,nC) > 0
      COOL_south(nHR,nC) = EN_AIR_south(nHR,nC);
      HEAT_south(nHR,nC) = 0;
    elseif EN_AIR_south(nHR,nC) <= 0
      COOL_south(nHR,nC) = 0;
      HEAT_south(nHR,nC) = EN_AIR_south(nHR,nC);
    end

    %Uncertainty calculation
    dcfm_south(nHR,nC)=fc*fcu_med_south(j).*(rm_temp_south(j)-vav_dat_south(j));
    drmtemp_south(nHR,nC)=fc*Ecfm*fcu_med_south(j);
    dvavdat_south(nHR,nC)=-fc*Ecfm*fcu_med_south(j);
    u_south(nHR,nC)=( (dcfm_south(nHR,nC)*u_cfm).^2 + (drmtemp_south(nHR,nC)*u_rmt).^2 +
(dvavdat_south(nHR,nC)*u_dat).^2 ).^0.5;

    if dcfm_south(nHR,nC) > 0
      UCOOL_south(nHR,nC) = u_south(nHR,nC);
      UHEAT_south(nHR,nC) = 0;
    elseif dcfm_south(nHR,nC) <= 0
      UCOOL_south(nHR,nC) = 0;
      UHEAT_south(nHR,nC) = u_south(nHR,nC);
    end
    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
```

```
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MFCUDIS_south(nDay,nCC) = mean(FCUDIS_south(nHR,:));
    MFCUMED_south(nDay,nCC) = mean(FCUMED_south(nHR,:));
    MFCUMIX_south(nDay,nCC) = mean(FCUMIX_south(nHR,:));
    MRMTEMP_south(nDay,nCC) = mean(RMTEMP_south(nHR,:));
    MVAVDAT_south(nDay,nCC) = mean(VAVDAT_south(nHR,:));
    MCOOL_south(nDay,nCC) = mean(COOL_south(nHR,:));
    MHEAT_south(nDay,nCC) = mean(HEAT_south(nHR,:));
    MUCOOL_south(nDay,nCC) = mean(UCOOL_south(nHR,:));
    MUHEAT_south(nDay,nCC) = mean(UHEAT_south(nHR,:));
    nHR = nHR + 1;
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CFCUDIS_south(HR) = mean(FCUDIS_south(nHR,:));
  CFCUMED_south(HR) = mean(FCUMED_south(nHR,:));
  CFCUMIX_south(HR) = mean(FCUMIX_south(nHR,:));
  CRMTEMP_south(HR) = mean(RMTEMP_south(nHR,:));
  CVAVDAT_south(HR) = mean(VAVDAT_south(nHR,:));
  CCOOL_south(HR) = mean(COOL_south(nHR,:));
  CHEAT_south(HR) = mean(HEAT_south(nHR,:));
  CUCOOL_south(HR) = mean(UCOOL_south(nHR,:));
  CUHEAT_south(HR) = mean(UHEAT_south(nHR,:));
end
disp(' ')
disp('SOUTH-FCU has been processed!!')
disp(' ')


%FWEST is an Energy program for WEST-FCU
disp('This program(FWEST) analizes WEST-FCU.')
dirname = 10;
filename; % call FILENAME for setting the Bdate, Edate & time interval
format compact;

disp('WEST-FCU file names are ');
dir('\sangsoo\project\matlab\data\*rwb.m')
dirname = 24;
disp(' ')
disp('WEST-FCU is being processed!!')

filename;% call data file for the west room
disp(' ')
west = a;
[r c]=size(west);
BeginningTime_west=[west(1,1) west(1,2)]
```

```
EndingTime_west=[west(r,1) west(r,2)]
Btime_west =west(1,1)+west(1,2);
Etime_west =west(r,1)+west(r,2);

Bdate
Edate

if Btime_west ~= Btime_east
  disp('There was a time difference between WEST-FCU and EAST-FCU !!')
end

% Array variables.
kk=0;
for k=1:r
  if west(k,1) >= Bdate & west(k,1) <= Edate
    kk=kk+1;
    varname = 28;
    dirname = 33;
    filename; % call variables
  end
end

dirname = 24;

WEST_kk = kk;
disp('Data will be processed until ');
WEST_end_time=[date(WEST_kk) time(WEST_kk)]

%Display initial values
if fcu_dis_west(1)== -999
  FCU_DIS_west=fcu_dis_west(1)
  fcu_dis_west(1) = input('Enter an initial value for FCU-DIS of west room: ');
end
if fcu_med_west(1)== -999
  FCU_MED_west=fcu_med_west(1)
  fcu_med_west(1) = input('Enter an initial value for FCU-MED of west room: ');
end
if fcu_mix_west(1)== -999
  FCU_MIX_west=fcu_mix_west(1)
  fcu_mix_west(1) = input('Enter an initial value for FCU-MIX of west room: ');
end
if rm_temp_west(1)== -999
  RM_TEMP_west=rm_temp_west(1)
  rm_temp_west(1) = input('Enter an initial value for RM-TEMP of west room: ');
end
if vav_dat_west(1) < 0
  VAV_DAT_west = vav_dat_west(1)
  vav_dat_west(1) = input('Enter an initial value for FCU-DAT of west room: ');
end

for i=1:kk
  if fcu_dis_west(i)== -999
    fcu_dis_west(i) = fcu_dis_west(i-1);
  end
```

```
  if fcu_med_west(i)== -999
    fcu_med_west(i) = fcu_med_west(i-1);
  end
  if fcu_mix_west(i)== -999
    fcu_mix_west(i) = fcu_mix_west(i-1);
  end
  if rm_temp_west(i)== -999
    rm_temp_west(i) = rm_temp_west(i-1);
  end
  if vav_dat_west(i) < 0
    vav_dat_west(i) = vav_dat_west(i-1);
  end
end

nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    FCUDIS_west(nHR,nC) = fcu_dis_west(j);
    FCUMED_west(nHR,nC) = fcu_med_west(j);
    FCUMIX_west(nHR,nC) = fcu_mix_west(j);
    RMTEMP_west(nHR,nC) = rm_temp_west(j);
    VAVDAT_west(nHR,nC) = vav_dat_west(j);
    EN_AIR_west(nHR,nC) = fc*Ecfm*fcu_med_west(j).*(rm_temp_west(j)-vav_dat_west(j));
    if EN_AIR_west(nHR,nC) > 0
      COOL_west(nHR,nC) = EN_AIR_west(nHR,nC);
      HEAT_west(nHR,nC) = 0;
    elseif EN_AIR_west(nHR,nC) <= 0
      COOL_west(nHR,nC) = 0;
      HEAT_west(nHR,nC) = EN_AIR_west(nHR,nC);
    end

    %Uncertainty calculation
    dcfm_west(nHR,nC)=fc*fcu_med_west(j).*(rm_temp_west(j)-vav_dat_west(j));
    drmtemp_west(nHR,nC)=fc*Ecfm*fcu_med_west(j);
    dvavdat_west(nHR,nC)=-fc*Ecfm*fcu_med_west(j);
    u_west(nHR,nC)=( (dcfm_west(nHR,nC)*u_cfm).^2 + (drmtemp_west(nHR,nC)*u_rmt).^2 +
(dvavdat_west(nHR,nC)*u_dat).^2 ).^0.5;

    if dcfm_west(nHR,nC) > 0
      UCOOL_west(nHR,nC) = u_west(nHR,nC);
      UHEAT_west(nHR,nC) = 0;
    elseif dcfm_west(nHR,nC) <= 0
      UCOOL_west(nHR,nC) = 0;
      UHEAT_west(nHR,nC) = u_west(nHR,nC);
    end
    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
```

```
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MFCUDIS_west(nDay,nCC) = mean(FCUDIS_west(nHR,:));
    MFCUMED_west(nDay,nCC) = mean(FCUMED_west(nHR,:));
    MFCUMIX_west(nDay,nCC) = mean(FCUMIX_west(nHR,:));
    MRMTEMP_west(nDay,nCC) = mean(RMTEMP_west(nHR,:));
    MVAVDAT_west(nDay,nCC) = mean(VAVDAT_west(nHR,:));
    MCOOL_west(nDay,nCC) = mean(COOL_west(nHR,:));
    MHEAT_west(nDay,nCC) = mean(HEAT_west(nHR,:));
    MUCOOL_west(nDay,nCC) = mean(UCOOL_west(nHR,:));
    MUHEAT_west(nDay,nCC) = mean(UHEAT_west(nHR,:));
    nHR = nHR + 1;
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CFCUDIS_west(HR) = mean(FCUDIS_west(nHR,:));
  CFCUMED_west(HR) = mean(FCUMED_west(nHR,:));
  CFCUMIX_west(HR) = mean(FCUMIX_west(nHR,:));
  CRMTEMP_west(HR) = mean(RMTEMP_west(nHR,:));
  CVAVDAT_west(HR) = mean(VAVDAT_west(nHR,:));
  CCOOL_west(HR) = mean(COOL_west(nHR,:));
  CHEAT_west(HR) = mean(HEAT_west(nHR,:));
  CUCOOL_west(HR) = mean(UCOOL_west(nHR,:));
  CUHEAT_west(HR) = mean(UHEAT_west(nHR,:));
end
disp(' ')
disp('WEST-FCU has been processed!!')
disp(' ')


%FINTER is an Energy program for INTER-FCU
disp('This program(FINTER) analizes INTER-FCU.')
dirname = 10;
filename; % call FILENAME for setting the Bdate, Edate & time interval
format compact;

disp('INTER-FCU file names are ');
dir('\sangsoo\project\matlab\data\*rib.m')
dirname = 25;
disp(' ')
disp('INTER-FCU is being processed!!')

filename;% call data file for the inter room
disp(' ')
inter = a;
[r c]=size(inter);
BeginningTime_inter=[inter(1,1) inter(1,2)]
EndingTime_inter=[inter(r,1) inter(r,2)]
```

```
Btime_inter =inter(1,1)+inter(1,2);
Etime_inter =inter(r,1)+inter(r,2);

Bdate
Edate

if Btime_inter ~= Btime_east
  disp('There was a time difference between INTER-FCU and EAST-FCU !!')
end

% Array variables.
kk=0;
for k=1:r
  if inter(k,1) >= Bdate & inter(k,1) <= Edate
    kk=kk+1;
    varname = 29;
    dirname = 33;
    filename; % call variables
  end
end

dirname = 25;

INTER_kk = kk;
disp('Data will be processed until ');
INTER_end_time=[date(INTER_kk) time(INTER_kk)]

%Display initial values
if fcu_dis_inter(1)== -999
  FCU_DIS_inter=fcu_dis_inter(1)
  fcu_dis_inter(1) = input('Enter an initial value for FCU-DIS of inter room: ');
end
if fcu_med_inter(1)== -999
  FCU_MED_inter=fcu_med_inter(1)
  fcu_med_inter(1) = input('Enter an initial value for FCU-MED of inter room: ');
end
if fcu_mix_inter(1)== -999
  FCU_MIX_inter=fcu_mix_inter(1)
  fcu_mix_inter(1) = input('Enter an initial value for FCU-MIX of inter room: ');
end
if rm_temp_inter(1)== -999
  RM_TEMP_inter=rm_temp_inter(1)
  rm_temp_inter(1) = input('Enter an initial value for RM-TEMP of inter room: ');
end
if vav_dat_inter(1) < 0
  VAV_DAT_inter = vav_dat_inter(1)
  vav_dat_inter(1) = input('Enter an initial value for FCU-DAT of inter room: ');
end

for i=1:kk
  if fcu_dis_inter(i)== -999
    fcu_dis_inter(i) = fcu_dis_inter(i-1);
  end
  if fcu_med_inter(i)== -999
```

```
    fcu_med_inter(i) = fcu_med_inter(i-1);
  end
  if fcu_mix_inter(i)== -999
    fcu_mix_inter(i) = fcu_mix_inter(i-1);
  end
  if rm_temp_inter(i)== -999
    rm_temp_inter(i) = rm_temp_inter(i-1);
  end
  if vav_dat_inter(i) < 0
    vav_dat_inter(i) = vav_dat_inter(i-1);
  end
end

nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    FCUDIS_inter(nHR,nC) = fcu_dis_inter(j);
    FCUMED_inter(nHR,nC) = fcu_med_inter(j);
    FCUMIX_inter(nHR,nC) = fcu_mix_inter(j);
    RMTEMP_inter(nHR,nC) = rm_temp_inter(j);
    VAVDAT_inter(nHR,nC) = vav_dat_inter(j);
    EN_AIR_inter(nHR,nC) = fc*Icfm*fcu_med_inter(j).*(rm_temp_inter(j)-vav_dat_inter(j));
    if EN_AIR_inter(nHR,nC) > 0
      COOL_inter(nHR,nC) = EN_AIR_inter(nHR,nC);
      HEAT_inter(nHR,nC) = 0;
    elseif EN_AIR_inter(nHR,nC) <= 0
      COOL_inter(nHR,nC) = 0;
      HEAT_inter(nHR,nC) = EN_AIR_inter(nHR,nC);
    end

    %Uncertainty calculation
    dcfm_inter(nHR,nC)=fc*fcu_med_inter(j).*(rm_temp_inter(j)-vav_dat_inter(j));
    drmtemp_inter(nHR,nC)=fc*Ecfm*fcu_med_inter(j);
    dvavdat_inter(nHR,nC)=-fc*Ecfm*fcu_med_inter(j);
    u_inter(nHR,nC)=( (dcfm_inter(nHR,nC)*u_cfm).^2 + (drmtemp_inter(nHR,nC)*u_rmt).^2 +
(dvavdat_inter(nHR,nC)*u_dat).^2 ).^0.5;

    if dcfm_inter(nHR,nC) > 0
      UCOOL_inter(nHR,nC) = u_inter(nHR,nC);
      UHEAT_inter(nHR,nC) = 0;
    elseif dcfm_inter(nHR,nC) <= 0
      UCOOL_inter(nHR,nC) = 0;
      UHEAT_inter(nHR,nC) = u_inter(nHR,nC);
    end
    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
```

```
    while nCC < 24
      nCC = nCC + 1;
      MFCUDIS_inter(nDay,nCC) = mean(FCUDIS_inter(nHR,:));
      MFCUMED_inter(nDay,nCC) = mean(FCUMED_inter(nHR,:));
      MFCUMIX_inter(nDay,nCC) = mean(FCUMIX_inter(nHR,:));
      MRMTEMP_inter(nDay,nCC) = mean(RMTEMP_inter(nHR,:));
      MVAVDAT_inter(nDay,nCC) = mean(VAVDAT_inter(nHR,:));
      MCOOL_inter(nDay,nCC) = mean(COOL_inter(nHR,:));
      MHEAT_inter(nDay,nCC) = mean(HEAT_inter(nHR,:));
      MUCOOL_inter(nDay,nCC) = mean(UCOOL_inter(nHR,:));
      MUHEAT_inter(nDay,nCC) = mean(UHEAT_inter(nHR,:));
      nHR = nHR + 1;
    end
    nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
    HR = HR+1;
    CFCUDIS_inter(HR) = mean(FCUDIS_inter(nHR,:));
    CFCUMED_inter(HR) = mean(FCUMED_inter(nHR,:));
    CFCUMIX_inter(HR) = mean(FCUMIX_inter(nHR,:));
    CRMTEMP_inter(HR) = mean(RMTEMP_inter(nHR,:));
    CVAVDAT_inter(HR) = mean(VAVDAT_inter(nHR,:));
    CCOOL_inter(HR) = mean(COOL_inter(nHR,:));
    CHEAT_inter(HR) = mean(HEAT_inter(nHR,:));
    CUCOOL_inter(HR) = mean(UCOOL_inter(nHR,:));
    CUHEAT_inter(HR) = mean(UHEAT_inter(nHR,:));
end
disp(' ')
disp('INTER-FCU has been processed!!')
disp(' ')


%FCLG is an Energy program for CLG-WTR
disp('This program(FCLG) analizes COOLING WATER.')
dirname = 10;
filename; % call FILENAME for setting the Bdate, Edate & time
format compact;

disp('CLG file names are ');
dir('\sangsoo\project\matlab\data\*clg.m')
dirname = 26;
disp(' ')
disp('CLG is being processed!!')

filename;% call data file for the clg
disp(' ')
clg = a;
[r c]=size(clg);
BeginningTime_clg=[clg(1,1) clg(1,2)]
EndingTime_clg=[clg(r,1) clg(r,2)]
Btime_clg =clg(1,1)+clg(1,2);
```

```
Etime_clg =clg(r,1)+clg(r,2);

Bdate
Edate

if Btime_clg ~= Btime_east
  disp('There was a time difference between CLG and EAST-FCU !!')
end

% Array variables.
kk=0;
for k=1:r
  if clg(k,1) >= Bdate & clg(k,1) <= Edate
    kk=kk+1;
    varname = 30;
    dirname = 33;
    filename; % call variables
  end
end

dirname = 26;

CLG_kk = kk;
disp('Data will be processed until ');
CLG_end_time=[date(CLG_kk) time(CLG_kk)]

%Display initial values
if cw_flowc_clg(1)== -999
  cw_flowc_clg(1) = input('Enter an initial value for CLG-FLOW RATE in loop-c: ');
end
if cwr_tmpc_clg(1)== -999
  cwr_tmpc_clg(1) = input('Enter an initial value for CLG-CWR-TEMP in loop-c: ');
end
if cws_tmpc_clg(1)== -999
  cws_tmpc_clg(1) = input('Enter an initial value for CLG-CWS-TEMP in loop-c: ');
end
for i=1:kk
  if cw_flowc_clg(i)== -999
    cw_flowc_clg(i) = cw_flowc_clg(i-1);
  end
  if cwr_tmpc_clg(i)== -999
    cwr_tmpc_clg(i) = cwr_tmpc_clg(i-1);
  end
  if cws_tmpc_clg(i)== -999
    cws_tmpc_clg(i) = cws_tmpc_clg(i-1);
  end
end

FCDS=497;%factor
nHR=1;
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
```

```
    CWFLOWC_clg(nHR,nC) = cw_flowc_clg(j);
    CWRTMPC_clg(nHR,nC) = cwr_tmpc_clg(j);
    CWSTMPC_clg(nHR,nC) = cws_tmpc_clg(j);
    EN_WTR_clg(nHR,nC) = FCDS*cw_flowc_clg(j).*(cwr_tmpc_clg(j)-cws_tmpc_clg(j));
    if EN_WTR_clg(nHR,nC) <= 0
      EN_WTR_clg(nHR,nC) = 0;
    end
    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MCWFLOWC_clg(nDay,nCC)=mean(CWFLOWC_clg(nHR,:));
    MCWRTMPC_clg(nDay,nCC)=mean(CWRTMPC_clg(nHR,:));
    MCWSTMPC_clg(nDay,nCC)=mean(CWSTMPC_clg(nHR,:));
    MEN_WTR_clg(nDay,nCC)=mean(EN_WTR_clg(nHR,:));
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CCWFLOWC_clg(HR)=mean(CWFLOWC_clg(nHR,:));
  CCWRTMPC_clg(HR)=mean(CWRTMPC_clg(nHR,:));
  CCWSTMPC_clg(HR)=mean(CWSTMPC_clg(nHR,:));
  CEN_WTR_clg(HR)=mean(EN_WTR_clg(nHR,:));
end
disp(' ')
disp('CLG has been processed!!')
disp(' ')


%FHTG is an Energy program for HTG-WTR
disp('This program(FHTG) analizes HEATING WATER.')
dirname = 10;
filename; % call FILENAME for setting the Bdate, Edate & time
format compact;

disp('HTG file names are ');
dir('\sangsoo\project\matlab\data\*htg.m')
dirname = 27;
disp(' ')
disp('HTG is being processed!!')

filename;% call data file for the htg
disp(' ')
htg = a;
```

```
[r c]=size(htg);
BeginningTime_htg=[htg(1,1) htg(1,2)]
EndingTime_htg=[htg(r,1) htg(r,2)]
Btime_htg =htg(1,1)+htg(1,2);
Etime_htg =htg(r,1)+htg(r,2);

Bdate
Edate

if Btime_htg ~= Btime_east
  disp('There was a time difference between HTG and EAST-FCU !!')
end

% Array variables.
kk=0;
for k=1:r
  if htg(k,1) >= Bdate & htg(k,1) <= Edate
    kk=kk+1;
    varname = 31;
    dirname = 33;
    filename; % call variables
  end
end

dirname = 27;

HTG_kk = kk;
disp('Data will be processed until ');
HTG_end_time=[date(HTG_kk) time(HTG_kk)]

%Display initial values
if hw_flowb_htg(1)== -999
  hw_flowb_htg(1) = input('Enter an initial value for HTG-FLOW RATE in loop-c: ');
end
if hwr_tmpb_htg(1)== -999
  hwr_tmpb_htg(1) = input('Enter an initial value for HTG-HWR-TEMP in loop-c: ');
end
if hws_tmpb_htg(1)== -999
  hws_tmpb_htg(1) = input('Enter an initial value for HTG-HWS-TEMP in loop-c: ');
end
for i=1:kk
  if hw_flowb_htg(i)== -999
    hw_flowb_htg(i) = hw_flowb_htg(i-1);
  end
  if hwr_tmpb_htg(i)== -999
    hwr_tmpb_htg(i) = hwr_tmpb_htg(i-1);
  end
  if hws_tmpb_htg(i)== -999
    hws_tmpb_htg(i) = hws_tmpb_htg(i-1);
  end
end

FHDS=494;%factor
nHR=1;
```

```
for j=1:f:kk
  nC = 0;
  while nC < f
    nC = nC+1;
    HWFLOWB_htg(nHR,nC) = hw_flowb_htg(j);
    HWRTMPB_htg(nHR,nC) = hwr_tmpb_htg(j);
    HWSTMPB_htg(nHR,nC) = hws_tmpb_htg(j);
    EN_WTR_htg(nHR,nC) = FHDS*hw_flowb_htg(j).*(hwr_tmpb_htg(j)-hws_tmpb_htg(j));
    if EN_WTR_htg(nHR,nC) >= 0
      EN_WTR_htg(nHR,nC) = 0;
    end
    j = j+1;
  end
  nHR = nHR + 1;
end

nDay=1;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;
    MHWFLOWB_htg(nDay,nCC)=mean(HWFLOWB_htg(nHR,:));
    MHWRTMPB_htg(nDay,nCC)=mean(HWRTMPB_htg(nHR,:));
    MHWSTMPB_htg(nDay,nCC)=mean(HWSTMPB_htg(nHR,:));
    MEN_WTR_htg(nDay,nCC)=mean(EN_WTR_htg(nHR,:));
  end
  nDay = nDay + 1;
end
Number_of_Days=nDay-1;

HR =0;
for nHR=1:kk/f;
  HR = HR+1;
  CHWFLOWB_htg(HR)=mean(HWFLOWB_htg(nHR,:));
  CHWRTMPB_htg(HR)=mean(HWRTMPB_htg(nHR,:));
  CHWSTMPB_htg(HR)=mean(HWSTMPB_htg(nHR,:));
  CEN_WTR_htg(HR)=mean(EN_WTR_htg(nHR,:));
end
disp(' ')
disp('HTG has been processed!!')
disp(' ')



%Go to the directory to save psfiles
cd ..
  cd ..
  cd matlab\psfiles\fcu;

%Array of figures
ztemp=[CRMTEMP_east' CRMTEMP_south' CRMTEMP_west' CRMTEMP_inter'];
zcool=[CCOOL_east' CCOOL_south' CCOOL_west' CCOOL_inter'];
zheat=[CHEAT_east' CHEAT_south' CHEAT_west' CHEAT_inter'];
zcfm=[Ecfm*CFCUMED_east' Ecfm*CFCUMED_south' Ecfm*CFCUMED_west' Icfm*CFCUMED_inter'];
```

```
COOL= CCOOL_east' + CCOOL_south' + CCOOL_west' + CCOOL_inter';
HEAT=CHEAT_east' + CHEAT_south' + CHEAT_west' + CHEAT_inter';
tcfm=(CFCUMED_east' + CFCUMED_south' + CFCUMED_west')*Ecfm +CFCUMED_inter'*Icfm;

rmtemp_e=[CRMTEMP_east' CFCUDIS_east' CFCUMIX_east' CVAVDAT_east'];
rmtemp_s=[CRMTEMP_south' CFCUDIS_south' CFCUMIX_south' CVAVDAT_south'];
rmtemp_w=[CRMTEMP_west' CFCUDIS_west' CFCUMIX_west' CVAVDAT_west'];
rmtemp_I=[CRMTEMP_inter' CFCUDIS_inter' CFCUMIX_inter' CVAVDAT_inter'];

%check energy balance between air side and water side
wtrtemp=[CCWRTMPC_clg' CCWSTMPC_clg' CHWRTMPB_htg' CHWSTMPB_htg'];
wtrflow=[CCWFLOWC_clg' CHWFLOWB_htg'];
delclg=(CEN_WTR_clg'-COOL);
delhtg=(CEN_WTR_htg'-HEAT);
clgbtu=[delclg CEN_WTR_clg' COOL];
htgbtu=[-delhtg -CEN_WTR_htg' -HEAT];
clgbar=sum(clgbtu);
htgbar=sum(htgbtu);


figure
plot(ztemp),title('Room Temperatures'),legend('east','south','west','inter',0), grid,
xlabel('Hour'),ylabel('F');
print -dpsc fcu1

figure
plot(zcool),title('Room Cooling Energy Rate'),legend('east','south','west','inter',0), grid,
xlabel('Hour'),ylabel('Btu/Hr');
print -dpsc fcu2

figure
plot(-zheat),title('Room Heating Energy Rate'),legend('east','south','west','inter',0), grid,
xlabel('Hour'),ylabel('Btu/Hr');
print -dpsc fcu3

figure
plot(COOL),title('Total Cooling Energy Rate'), grid,
xlabel('Hour'),ylabel('Btu/Hr');
print -dpsc fcu4

figure
plot(-HEAT),title('Total Heating Energy Rate'), grid,
xlabel('Hour'),ylabel('Btu/Hr');
print -dpsc fcu5

figure
plot(zcfm),title('Room Air Flow'),legend('east','south','west','inter',0), grid,
xlabel('Hour'),ylabel('CFM');
print -dpsc fcu6

figure
plot(tcfm),title('Sum of Rooms Air Flow'), grid,
xlabel('Hour'),ylabel('CFM');
print -dpsc fcu7
```

```
x=kk/f;
figure
plot(rmtemp_e),title('East Room Temperatures'),legend('room','fcu-dis','fcu-mix','vav-dat',0), grid,
xlabel('Hour'),ylabel('F');axis([ 1 x 50 85]);
print -dpsc fcu8

figure
plot(rmtemp_s),title('South Room Temperatures'),legend('room','fcu-dis','fcu-mix','vav-dat',0), grid,
xlabel('Hour'),ylabel('F');axis([ 1 x 50 85]);
print -dpsc fcu9

figure
plot(rmtemp_w),title('West Room Temperatures'),legend('room','fcu-dis','fcu-mix','vav-dat',0), grid,
xlabel('Hour'),ylabel('F');axis([ 1 x 50 85]);
print -dpsc fcu10

figure
plot(rmtemp_I),title('Interior Room Temperatures'),legend('room','fcu-dis','fcu-mix','vav-dat',0), grid,
xlabel('Hour'),ylabel('F');axis([ 1 x 50 85]);
print -dpsc fcu11

figure
plot(wtrtemp),title('Water temperatures'),legend('cwr','cws','hwr','hws',0), grid,
xlabel('Hour'),ylabel('F');axis([ 1 x 40 130]);
print -dpsc fcu12

figure
plot(wtrflow),title('Water Flow'),legend('chw','hw',0), grid,
xlabel('Hour'),ylabel('gpm');axis([ 1 x 0 3]);
print -dpsc fcu13

figure
plot(clgbtu),title('Cooling Energy Rate'),legend('difference','water side','air side',0), grid,
xlabel('Hour'),ylabel('Btu/Hr');
print -dpsc fcu14

figure
plot(htgbtu),title('Heating Energy Rate'),legend('difference','water side','air side',0), grid,
xlabel('Hour'),ylabel('Btu/Hr');
print -dpsc fcu15

figure
bar(clgbar,0.25), grid,title('Total Cooling Btu'),legend('1=diff','2=water-side','3=air-side',0),
print -dpsc fcu16

figure
bar(htgbar,0.25), grid,title('Total Heating Btu'),legend('1=diff','2=water-side','3=air-side',0);
print -dpsc fcu17

%go back to the program directory
cd ..
  cd ..
  cd ..
```

```
cd matlab2\programs;


%Array of Calculated data for Thesis Out

COOL= CCOOL_east' + CCOOL_south' + CCOOL_west' + CCOOL_inter';
HEAT=CHEAT_east' + CHEAT_south' + CHEAT_west' + CHEAT_inter';
zheat=[CHEAT_east' CHEAT_south' CHEAT_west' CHEAT_inter'];
tcfm=(CFCUMED_east' + CFCUMED_south' + CFCUMED_west')*Ecfm +CFCUMED_inter'*Icfm;
zcool=[CCOOL_east' CCOOL_south' CCOOL_west' CCOOL_inter'];
ztemp=[CRMTEMP_east' CRMTEMP_south' CRMTEMP_west' CRMTEMP_inter'];
UCQ=CUCOOL_east' + CUCOOL_south' + CUCOOL_west' + CUCOOL_inter';
UHQ=CUHEAT_east' + CUHEAT_south' + CUHEAT_west' + CUHEAT_inter';

%data summary report
syscool=[max(COOL) mean(COOL) min(COOL) max(UCQ) mean(UCQ) min(UCQ)];
sysheat=[-min(HEAT) -mean(HEAT) -max(HEAT) max(UHQ) mean(UHQ) min(UHQ)];
heast=[-min(CHEAT_east') -mean(CHEAT_east') -max(CHEAT_east') max(CUHEAT_east)
mean(CUHEAT_east) min(CUHEAT_east)];
hsouth=[-min(CHEAT_south') -mean(CHEAT_south') -max(CHEAT_south') max(CUHEAT_south)
mean(CUHEAT_south) min(CUHEAT_south)];
hwest=[-min(CHEAT_west') -mean(CHEAT_west') -max(CHEAT_west') max(CUHEAT_west)
mean(CUHEAT_west) min(CUHEAT_west)];
hinter=[-min(CHEAT_inter') -mean(CHEAT_inter') -max(CHEAT_inter') max(CUHEAT_inter)
mean(CUHEAT_inter) min(CUHEAT_inter)];

ceast=[max(CCOOL_east') mean(CCOOL_east') min(CCOOL_east') max(CUCOOL_east)
mean(CUCOOL_east) min(CUCOOL_east)];
csouth=[max(CCOOL_south') mean(CCOOL_south') min(CCOOL_south') max(CUCOOL_south)
mean(CUCOOL_south) min(CUCOOL_south)];
cwest=[max(CCOOL_west') mean(CCOOL_west') min(CCOOL_west') max(CUCOOL_west)
mean(CUCOOL_west) min(CUCOOL_west)];
cinter=[max(CCOOL_inter') mean(CCOOL_inter') min(CCOOL_inter') max(CUCOOL_inter)
mean(CUCOOL_inter) min(CUCOOL_inter)];

%Prepare hourly output table
A=[COOL HEAT zheat tcfm];
B=[zcool ztemp];
wtrE=[CEN_WTR_clg' CEN_WTR_htg' delclg delhtg];

disp('This program(FCUPRINT) creates outputs.')
dirname = 34;
filename;% call output filename for data summary
dirname = 35;
filename;%call hourly filename for hourly report
pwd
cd ..
cd thesisout\compact;

disp(' ')
fid=fopen(datfile,'w');
fprintf(fid,'ENERGY     MAX  MEAN   MIN  UMAX  UMEAN  UMIN\n');
fprintf(fid,'SYSCOOL  %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',syscool);
fprintf(fid,'SYSHEAT  %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',sysheat);
```

```
fprintf(fid,'HEAST    %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',heast);
fprintf(fid,'HSOUTH   %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',hsouth);
fprintf(fid,'HWEST    %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',hwest);
fprintf(fid,'HINTER   %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',hinter);
fprintf(fid,'CEAST    %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',ceast);
fprintf(fid,'CSOUTH   %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',csouth);
fprintf(fid,'CWEST    %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',cwest);
fprintf(fid,'CINTER   %7.0f%7.0f%7.0f%7.0f%7.0f%7.0f\n',cinter);
fclose(fid)

disp(' ')
fid=fopen(hourfile,'w');
fprintf(fid,' DATE  TIME   clg   htg   dclg   dhtg   cool  h-ele hele-e hele-s hele-w hele-I  sacfm  oacfm rcool-
e rcool-s rcool-w rcool-I rmtemp-e rmtemp-s rmtemp-w rmtemp-I\n');
nDay=1;
DATE(1)=Bdate;
for nHR=1:24:kk/f;
  nCC = 0;
  while nCC < 24
    nCC = nCC + 1;

fprintf(fid,'%9i%5i%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%7.0f%8.0f%8.0f%8.0f%
8.0f%9.1f%9.1f%9.1f%9.1f\n',DATE(nDay),nCC,wtrE(nHR,:),A(nHR,:),0,B(nHR,:));
    nHR = nHR + 1;
  end
  DATE(nDay+1)=DATE(nDay)+1;
  nDay = nDay + 1;
end

Status2=fclose(fid)
Number_of_Days=nDay-1;


cd ..
  cd ..
  cd programs;

disp('FCUPRINT run has been done!')
disp(' ')
```

```
%FILENAME program shows file names that will be processed in the program
if dirname == 9
  cd ..
    if programselect == 1
    cd ieaout;
  else
```

```
    if outputselect==1
      cd thesisout\compact;
    else
      cd thesisout\extended;
    end
  end
elseif dirname == 10
  Bdate = 990316
  Edate = 990318
  timeinterval = 1
  f = 60/timeinterval;

  rho_cold_wtr=1/0.016021; %T=44F
  cp_cold_wtr=1.004;      %T=44F
  rho_cold_air=1/12.995;  %T=56F
  cp_cold_air=0.2404;     %T=56F

  rho_hot_wtr=1/0.016130;  %T=95F
  cp_hot_wtr=0.998;        %T=95F
  rho_hot_air=1/13.14;     %T=60F
  cp_hot_air=0.2404;       %T=75F

  if Bdate < 980101
    stg1=0.965;
    stg2=0.965;
    stg3=0;
    stgi1=0.965; %interior room
    stgi2=0.965;

    % define uncertainty values
    u_gpm=0.09;
    u_mwt=0.5;
    u_ewt=0.5;
    u_hgpm=0;
    u_hlwt=0;
    u_hewt=0;
    u_stg1=0.007;
    u_stg2=0.007;
    u_stg3=0;
    u_stgi1=0.007;
    u_stgi2=0.007;

  else
    stg1=1.635;
    stg2=1.682;
    stg3=1.533;
    stgi1=0.965; %interior room
    stgi2=0.965;

    % define uncertainty values
    u_gpm=0.09;
    u_mwt=0.5;
    u_ewt=0.5;
    u_hgpm=0.04;
```

```
      u_hlwt=0.5;
      u_hewt=0.5;
      u_stg1=0.0339;
      u_stg2=0.0584;
      u_stg3=0.0516;
      u_stgi1=0.007;
      u_stgi2=0.007;
      % define uncertainty values for FCU
      u_cfm=10;
      u_dat=0.5;
      u_rmt=0.5;
      den_spec=1.08;
      fc=den_spec;
      Ecfm=580; %exterior FCU at med
      Icfm=370; %interior FCU at med
   end
elseif dirname == 11
   m990316aha;
elseif dirname == 12
   m990316rea;
elseif dirname == 13
   m990316rsa;
elseif dirname == 14
   m990316rwa;
elseif dirname == 15
   m990316ria;
elseif dirname == 21
   m990316ahb;
elseif dirname == 22
   m990316reb;
elseif dirname == 23
   m990316rsb;
elseif dirname == 24
   m990316rwb;
elseif dirname == 25
   m990316rib;
elseif dirname == 26
   m990316clg;
elseif dirname == 27
   m990316htg;
elseif dirname == 31
   if systemselect == 1
      datfile = 'TC990316A.dat';
   else
      datfile='TC990316B.dat';
   end
elseif dirname == 32
   if programselect == 1
      if systemselect == 1
         hourfile = 'S990316a.out';
      else
         hourfile = 'S990316b.out';
      end
   else
```

```
    if systemselect == 1
      if outputselect==1
        hourfile = 'TC990316A.out';
      else
        hourfile = 'TE990316A.out';
      end
    elseif systemselect == 2
      if outputselect==1
        hourfile = 'TC990316B.out';
      else
        hourfile = 'TE990316B.out';
      end
    end
  end
elseif dirname == 33
  var990316;
elseif dirname == 34
  datfile = 'FCU990316.dat';
elseif dirname == 35
  hourfile = 'FCU990316.out';
end


%CALLVAR arrays variable names for systems and testrooms for Master Program
if varname == 11 %for AHU-A
  date(kk)=sys(k,1);
  time(kk)=sys(k,2);
  chw_flow(kk)=sys(k,4);
  clg_dat(kk)=sys(k,6);
  clg_ewt(kk)=sys(k,7);
  clg_lwt(kk)=sys(k,8);
  clg_mwt(kk)=sys(k,9);
  da_temp(kk)=sys(k,14);
  ma_temp(kk)=sys(k,28);
  oa_flow(kk)=sys(k,37);
  ra_temp(kk)=sys(k,44);
  sa_flow(kk)=sys(k,53);
  sup_spt(kk)=sys(k,58);
  airT(kk,:)=[clg_dat(kk) da_temp(kk) ma_temp(kk) ra_temp(kk) sup_spt(kk)];
  chwT(kk,:)=[clg_ewt(kk) clg_lwt(kk) clg_mwt(kk)];
  airF(kk,:)=[oa_flow(kk) sa_flow(kk)];
  chwF(kk)=chw_flow(kk);

elseif varname == 12 % for EASTROOM-A
  date(kk)=east(k,1);
  time(kk)=east(k,2);
  pln_temp_east(kk)=east(k,11);
  rm_temp_east(kk)=east(k,15);
  rmclgspt_east(kk)=east(k,12);
  rmhtgspt_east(kk)=east(k,13);
  vav_dat_east(kk)=east(k,21);
  vav_eat_east(kk)=east(k,23);
  vav_dat_east(kk)=(vav_dat_east(kk)+vav_eat_east(kk))/2;
  vav_htg1_east(kk)=east(k,30);
```

```
  vav_htg2_east(kk)=east(k,31);
  vav_htg3_east(kk)=east(k,32);
  vavcfmvt_east(kk)=east(k,18);%for vavcfmdp
  vavhcewt_east(kk)=east(k,27);
  vavhcgpm_east(kk)=east(k,28);
  vavhclwt_east(kk)=east(k,29);
  airT_east(kk,:)=[rm_temp_east(kk) rmclgspt_east(kk) rmhtgspt_east(kk) vav_dat_east(kk)];
  hwT_east(kk,:)=[vavhcewt_east(kk) vavhclwt_east(kk)];
  hwF_east(kk)=vavhcgpm_east(kk);
  airF_east(kk)=vavcfmvt_east(kk);

elseif varname == 13 % for SOUTHROOM-A
  date(kk)=south(k,1);
  time(kk)=south(k,2);
  pln_temp_south(kk)=south(k,11);
  rm_temp_south(kk)=south(k,15);
  rmclgspt_south(kk)=south(k,12);
  rmhtgspt_south(kk)=south(k,13);
  vav_dat_south(kk)=south(k,21);
  vav_eat_south(kk)=south(k,23);
  vav_dat_south(kk)=(vav_dat_south(kk)+vav_eat_south(kk))/2;
  vav_htg1_south(kk)=south(k,30);
  vav_htg2_south(kk)=south(k,31);
  vav_htg3_south(kk)=south(k,32);
  vavcfmvt_south(kk)=south(k,18);%for vavcfmdp
  vavhcewt_south(kk)=south(k,27);
  vavhcgpm_south(kk)=south(k,28);
  vavhclwt_south(kk)=south(k,29);
  airT_south(kk,:)=[rm_temp_south(kk) rmclgspt_south(kk) rmhtgspt_south(kk) vav_dat_south(kk)];
  hwT_south(kk,:)=[vavhcewt_south(kk) vavhclwt_south(kk)];
  hwF_south(kk)=vavhcgpm_south(kk);
  airF_south(kk)=vavcfmvt_south(kk);

elseif varname == 14 %for WEATROOM-A
  date(kk)=west(k,1);
  time(kk)=west(k,2);
  pln_temp_west(kk)=west(k,11);
  rm_temp_west(kk)=west(k,15);
  rmclgspt_west(kk)=west(k,12);
  rmhtgspt_west(kk)=west(k,13);
  vav_dat_west(kk)=west(k,21);
  vav_eat_west(kk)=west(k,23);
  vav_dat_west(kk)=(vav_dat_west(kk)+vav_eat_west(kk))/2;
  vav_htg1_west(kk)=west(k,30);
  vav_htg2_west(kk)=west(k,31);
  vav_htg3_west(kk)=west(k,32);
  vavcfmvt_west(kk)=west(k,18);%for vavcfmdp
  vavhcewt_west(kk)=west(k,27);
  vavhcgpm_west(kk)=west(k,28);
  vavhclwt_west(kk)=west(k,29);
  vavhclwt_west(kk)=west(k,34);
  airT_west(kk,:)=[rm_temp_west(kk) rmclgspt_west(kk) rmhtgspt_west(kk) vav_dat_west(kk)];
  hwT_west(kk,:)=[vavhcewt_west(kk) vavhclwt_west(kk)];
  hwF_west(kk)=vavhcgpm_west(kk);
```

```
  airF_west(kk)=vavcfmvt_west(kk);

elseif varname == 15 %for INTERIOR ROOM-A
  date(kk)=inter(k,1);
  time(kk)=inter(k,2);
  pln_temp_inter(kk)=inter(k,11);
  rm_temp_inter(kk)=inter(k,15);
  rmclgspt_inter(kk)=inter(k,12);
  rmhtgspt_inter(kk)=inter(k,13);
  vav_dat_inter(kk)=inter(k,21);
  vav_eat_inter(kk)=inter(k,23);
  vav_dat_inter(kk)=(vav_dat_inter(kk)+vav_eat_inter(kk))/2;
  vav_htg1_inter(kk)=inter(k,30);
  vav_htg2_inter(kk)=inter(k,31);
  vavcfmvt_inter(kk)=inter(k,18);%for vavcfmdp
  vavhcewt_inter(kk)=inter(k,27);
  vavhcgpm_inter(kk)=inter(k,28);
  vavhclwt_inter(kk)=inter(k,29);
  airT_inter(kk,:)=[rm_temp_inter(kk) rmclgspt_inter(kk) rmhtgspt_inter(kk) vav_dat_inter(kk)];
  hwT_inter(kk,:)=[vavhcewt_inter(kk) vavhclwt_inter(kk)];
  hwF_inter(kk)=vavhcgpm_inter(kk);
  airF_inter(kk)=vavcfmvt_inter(kk);

elseif varname == 21 %for AHU-B
  date(kk)=sys(k,1);
  time(kk)=sys(k,2);
  chw_flow(kk)=sys(k,4);
  clg_dat(kk)=sys(k,6);
  clg_ewt(kk)=sys(k,7);
  clg_lwt(kk)=sys(k,8);
  clg_mwt(kk)=sys(k,9);
  da_temp(kk)=sys(k,14);
  ma_temp(kk)=sys(k,28);
  oa_flow(kk)=sys(k,37);
  ra_temp(kk)=sys(k,44);
  sa_flow(kk)=sys(k,53);
  sup_spt(kk)=sys(k,58);
  airT(kk,:)=[clg_dat(kk) da_temp(kk) ma_temp(kk) ra_temp(kk) sup_spt(kk)];
  chwT(kk,:)=[clg_ewt(kk) clg_lwt(kk) clg_mwt(kk)];
  airF(kk,:)=[oa_flow(kk) sa_flow(kk)];
  chwF(kk)=chw_flow(kk);

elseif varname == 22 %for EASTROOM-B
  date(kk)=east(k,1);
  time(kk)=east(k,2);
  pln_temp_east(kk)=east(k,20);
  rm_temp_east(kk)=east(k,24);
  rmclgspt_east(kk)=east(k,21);
  rmhtgspt_east(kk)=east(k,22);
  vav_dat_east(kk)=east(k,31);
  vav_eat_east(kk)=east(k,33);
  vav_dat_east(kk)=(vav_dat_east(kk)+vav_eat_east(kk))/2;
  vav_htg1_east(kk)=east(k,40);
  vav_htg2_east(kk)=east(k,41);
```

```
  vav_htg3_east(kk)=east(k,42);
  vavcfmvt_east(kk)=east(k,28);%for vavcfmdp
  vavhcewt_east(kk)=east(k,37);
  vavhcgpm_east(kk)=east(k,38);
  vavhclwt_east(kk)=east(k,39);
  airT_east(kk,:)=[rm_temp_east(kk) rmclgspt_east(kk) rmhtgspt_east(kk) vav_dat_east(kk)];
  hwT_east(kk,:)=[vavhcewt_east(kk) vavhclwt_east(kk)];
  hwF_east(kk)=vavhcgpm_east(kk);
  airF_east(kk)=vavcfmvt_east(kk);

elseif varname == 23 %for SOUTHROOM-B
  date(kk)=south(k,1);
  time(kk)=south(k,2);
  pln_temp_south(kk)=south(k,20);
  rm_temp_south(kk)=south(k,24);
  rmclgspt_south(kk)=south(k,21);
  rmhtgspt_south(kk)=south(k,22);
  vav_dat_south(kk)=south(k,31);
  vav_eat_south(kk)=south(k,33);
  vav_dat_south(kk)=(vav_dat_south(kk)+vav_eat_south(kk))/2;
  vav_htg1_south(kk)=south(k,40);
  vav_htg2_south(kk)=south(k,41);
  vav_htg3_south(kk)=south(k,42);
  vavcfmvt_south(kk)=south(k,28);%for vavcfmdp
  vavhcewt_south(kk)=south(k,37);
  vavhcgpm_south(kk)=south(k,38);
  vavhclwt_south(kk)=south(k,39);
  airT_south(kk,:)=[rm_temp_south(kk) rmclgspt_south(kk) rmhtgspt_south(kk) vav_dat_south(kk)];
  hwT_south(kk,:)=[vavhcewt_south(kk) vavhclwt_south(kk)];
  hwF_south(kk)=vavhcgpm_south(kk);
  airF_south(kk)=vavcfmvt_south(kk);

elseif varname == 24 %for WESTROOM-B
  date(kk)=west(k,1);
  time(kk)=west(k,2);
  pln_temp_west(kk)=west(k,20);
  rm_temp_west(kk)=west(k,24);
  rmclgspt_west(kk)=west(k,21);
  rmhtgspt_west(kk)=west(k,22);
  vav_dat_west(kk)=west(k,31);
  vav_eat_west(kk)=west(k,33);
  vav_dat_west(kk)=(vav_dat_west(kk)+vav_eat_west(kk))/2;
  vav_htg1_west(kk)=west(k,40);
  vav_htg2_west(kk)=west(k,41);
  vav_htg3_west(kk)=west(k,42);
  vavhcewt_west(kk)=west(k,37);
  vavhcgpm_west(kk)=west(k,38);
  vavhclwt_west(kk)=west(k,39);
  airT_west(kk,:)=[rm_temp_west(kk) rmclgspt_west(kk) rmhtgspt_west(kk) vav_dat_west(kk)];
  hwT_west(kk,:)=[vavhcewt_west(kk) vavhclwt_west(kk)];
  hwF_west(kk)=vavhcgpm_west(kk);
  airF_west(kk)=vavcfmvt_west(kk);

elseif varname == 25 %for INTERIOR ROOM-B
```

```
    date(kk)=inter(k,1);
    time(kk)=inter(k,2);
    pln_temp_inter(kk)=inter(k,20);
    rm_temp_inter(kk)=inter(k,24);
    rmclgspt_inter(kk)=inter(k,21);
    rmhtgspt_inter(kk)=inter(k,22);
    vav_dat_inter(kk)=inter(k,31);
    vav_eat_inter(kk)=inter(k,33);
    vav_dat_inter(kk)=(vav_dat_inter(kk)+vav_eat_inter(kk))/2;
    vav_htg1_inter(kk)=inter(k,40);
    vav_htg2_inter(kk)=inter(k,41);
    vavcfmvt_inter(kk)=inter(k,28);%for vavcfmdp
    vavhcewt_inter(kk)=inter(k,37);
    vavhcgpm_inter(kk)=inter(k,38);
    vavhclwt_inter(kk)=inter(k,39);
    airT_inter(kk,:)=[rm_temp_inter(kk) rmclgspt_inter(kk) rmhtgspt_inter(kk) vav_dat_inter(kk)];
    hwT_inter(kk,:)=[vavhcewt_inter(kk) vavhclwt_inter(kk)];
    hwF_inter(kk)=vavhcgpm_inter(kk);
    airF_inter(kk)=vavcfmvt_inter(kk);

 elseif varname == 26 %for EAST-FCU
    date(kk)=east(k,1);
    time(kk)=east(k,2);
    fcu_dis_east(kk)=east(k,9);
    fcu_med_east(kk)=east(k,14);
    fcu_mix_east(kk)=east(k,15);
    rm_temp_east(kk)=east(k,24);
    rmclgspt_east(kk)=east(k,21);
    rmhtgspt_east(kk)=east(k,22);
    vav_dat_east(kk)=east(k,31);
    vav_eat_east(kk)=east(k,33);
    vav_dat_east(kk)=(vav_dat_east(kk)+vav_eat_east(kk))/2;
    airT_east(kk,:)=[rm_temp_east(kk) rmclgspt_east(kk) rmhtgspt_east(kk) vav_dat_east(kk) fcu_dis_east(kk)
 fcu_mix_east(kk) ];

 elseif varname == 27 %for SOUTH-FCU
    date(kk)=south(k,1);
    time(kk)=south(k,2);
    fcu_dis_south(kk)=south(k,9);
    fcu_med_south(kk)=south(k,14);
    fcu_mix_south(kk)=south(k,15);
    rm_temp_south(kk)=south(k,24);
    rmclgspt_south(kk)=south(k,21);
    rmhtgspt_south(kk)=south(k,22);
    vav_dat_south(kk)=south(k,31);
    vav_eat_south(kk)=south(k,33);
    vav_dat_south(kk)=(vav_dat_south(kk)+vav_eat_south(kk))/2;
    airT_south(kk,:)=[rm_temp_south(kk) rmclgspt_south(kk) rmhtgspt_south(kk) vav_dat_south(kk)
 fcu_dis_south(kk) fcu_mix_south(kk) ];
 elseif varname == 28 %for WEST-FCU
    date(kk)=west(k,1);
    time(kk)=west(k,2);
    fcu_dis_west(kk)=west(k,9);
    fcu_med_west(kk)=west(k,14);
```

```
  fcu_mix_west(kk)=west(k,15);
  rm_temp_west(kk)=west(k,24);
  rmclgspt_west(kk)=west(k,21);
  rmhtgspt_west(kk)=west(k,22);
  vav_dat_west(kk)=west(k,31);
  vav_eat_west(kk)=west(k,33);
  %vav_dat_west(kk)=(vav_dat_west(kk)+vav_eat_west(kk))/2;
  airT_west(kk,:)=[rm_temp_west(kk) rmclgspt_west(kk) rmhtgspt_west(kk) vav_dat_west(kk)
fcu_dis_west(kk) fcu_mix_west(kk) ];
elseif varname == 29 %for INTERIOR-FCU
  date(kk)=inter(k,1);
  time(kk)=inter(k,2);
  fcu_dis_inter(kk)=inter(k,9);
  fcu_med_inter(kk)=inter(k,14);
  fcu_mix_inter(kk)=inter(k,15);
  rm_temp_inter(kk)=inter(k,24);
  rmclgspt_inter(kk)=inter(k,21);
  rmhtgspt_inter(kk)=inter(k,22);
  vav_dat_inter(kk)=inter(k,31);
  vav_eat_inter(kk)=inter(k,33);
  vav_dat_inter(kk)=(vav_dat_inter(kk)+vav_eat_inter(kk))/2;
  airT_inter(kk,:)=[rm_temp_inter(kk) rmclgspt_inter(kk) rmhtgspt_inter(kk) vav_dat_inter(kk)
fcu_dis_inter(kk) fcu_mix_inter(kk) ];
elseif varname == 30 %for CLG
  date(kk)=clg(k,1);
  time(kk)=clg(k,2);
  cw_flowc_clg(kk)=clg(k,8);
  cwr_tmpc_clg(kk)=clg(k,9);
  cws_tmpc_clg(kk)=clg(k,11);
elseif varname == 31 %for HTG
  date(kk)=htg(k,1);
  time(kk)=htg(k,2);
  hw_flowb_htg(kk)=htg(k,6);
  hwr_tmpb_htg(kk)=htg(k,18);
  hws_tmpb_htg(kk)=htg(k,22);
end
```

APPENDIX I LISTINGS OF MATLAB PROGRAMS FOR STATISTICAL SUMMARY BEWTEEN EXPERIMENTAL DATA AND SIMULATION RESULTS

%[ANALYSIS PROGRAM]

```
%ANALYSIS program calculates statistical summary between experimental data and simulation
% results, and creates plots for the thesis.
% This program has total 11 subprograms
clear all;
close all;
path(path,'\sangsoo\project\matlab3\Data');
option=menu('Choose an Option','STATISTICS OLNY','PLOTS OLNY','BOTH');
ERS;
DOE;
HAP;
TRACE;
WEATHER;
if option == 1
  OUTPRINT;
elseif option == 2
  select=menu('Choose one','COLOR','BLACK and WHITE');
  if select == 1
    COLORPLOT;
  else
    shape=menu('Choose one','PORTRAIT','LANDSCAPE');
    if shape==1
      PORTPLOT;
    else
      LANDPLOT;
    end
  end
elseif option==3
  OUTPRINT;
  COLORPLOT;
end

disp('All program runs were performed successfully!!')
disp('Current PWD is :')
  pwd
```

```
%ERS processes actual data.
disp('This program(ERS) processes actual data.')

dirname = 10;
filename; % call FILENAME for setting the Bdate, Edate & time interval
format compact;
disp('ERS Data file names are: ')
dir('\sangsoo\project\matlab3\data\*ers.m')

dirname = 11;
disp('ERS data is being processed!!')
filename; %call data file for ERS data

disp(' ')
```

```
ers = a;
[r c]=size(ers);
BeginningTime=[ers(1,1) ers(1,2)]
EndingTime=[ers(r,1) ers(r,2)]
Btime = ers(1,1)+ers(1,2);
Etime = ers(r,1)+ers(r,2);
disp(' ')
Bdate
Edate

% Array variables
j=0;
for i=1:r
  if ers(i,1) >= Bdate & ers(i,1) <= Edate
    j=j+1;
    varname = 11;
    dirname = 33;
    filename; % call variable
  end
end
dirname=11;

y=j;
while y > -1
  y=y-24;
end
if y ~= -24
  disp('');
  disp('Check the time of the ERS data');
  SART_TIME=[date_ers(1) time_ers(1)]
  END_TIME=[date_ers(j) time_ers(j)]
  error('Error!!!! ---->> Check the starting & ending time of the ERS data!!!');
end

ERS_j = j;
ERS_end_time=[time_ers(ERS_j)];

if dirname == 11
  disp('ERS data has been processed!!')
end
disp(' ')


%DOE processes data from DOE2 program.
disp('This program(DOE) processes DOE2 OUTPUT.')
disp('DOE2 Data file names are: ')
dir('\sangsoo\project\matlab3\data\*doe.m')
dirname = 12;
disp('')
disp('DOE2 data is being processed!!')
filename;% call data file for DOE2

disp(' ')
doe = a;
```

```
[r c]=size(doe);
BeginningTime_doe=[doe(1,1) doe(1,2)];
EndingTime_doe=[doe(r,1) doe(r,2)];
Btime_doe =doe(1,1)+doe(1,2);
Etime_doe =doe(r,1)+doe(r,2);

if (Btime_doe ~= Btime) | (Etime_doe ~= Etime)
  disp('There was a time difference between DOE and ERS !!')
end

% Array variables
j=0;
for i=1:r
  if doe(i,1) >= Bdate & doe(i,1) <= Edate
    j=j+1;
    varname = 12;
    dirname = 33;
    filename; % call variable
  end
end

dirname=12;
DOE_j = j;
DOE_end_time=[date_doe(DOE_j) time_doe(DOE_j)];
if ERS_j ~= DOE_j
  disp('')
  disp('You need to look at the date and time in DOE data.')
  ERS_end_time=[date_ers(ERS_j) time_ers(ERS_j)]
  DOE_end_time=[date_doe(DOE_j) time_doe(DOE_j)]
  error('Error!! ---> Number of rows is different between ERS and DOE')
end

disp('DOE data has been processed!!')
disp(' ')


%HAP processes data from HAP program.
disp('This program(HAP) processes HAP OUTPUT.')
disp('HAP Data file names are: ')
dir('\sangsoo\project\matlab3\data\*hap.m')
dirname = 13;
disp('')
disp('HAP data is being processed!!')
filename;% call data file for HAP

disp(' ')
hap = a;
[r c]=size(hap);
BeginningTime_hap=[hap(1,1) hap(1,2)];
EndingTime_hap=[hap(r,1) hap(r,2)];
Btime_hap =hap(1,1)+hap(1,2);
Etime_hap =hap(r,1)+hap(r,2);

if (Btime_hap ~= Btime) | (Etime_hap ~= Etime)
```

```
  disp('There was a time difference between HAP and ERS !!')
end

% Array variables
j=0;
for i=1:r
  if hap(i,1) >= Bdate & hap(i,1) <= Edate
    j=j+1;
    varname = 13;
    dirname = 33;
    filename; % call variable
  end
end

dirname=13;
HAP_j = j;
HAP_end_time=[date_hap(HAP_j) time_hap(HAP_j)];
if ERS_j ~= HAP_j
  disp('')
  disp('You need to look at the date and time in HAP data.')
  ERS_end_time=[date_ers(ERS_j) time_ers(ERS_j)]
  HAP_end_time=[date_hap(HAP_j) time_hap(HAP_j)]
  error('Error!! ---> Number of rows is different between ERS and HAP')
end

disp('HAP data has been processed!!')
disp(' ')


%TRACE processes data from TRACE program.
disp('This program(TRACE) processes TRACE OUTPUT.')
disp('TRACE Data file names are: ')
dir('\sangsoo\project\matlab3\data\*trace.m')
dirname = 14;
disp('')
disp('TRACE data is being processed!!')
filename;% call data file for TRACE

disp(' ')
trace = a;
[r c]=size(trace);
BeginningTime_trace=[trace(1,1) trace(1,2)];
EndingTime_trace=[trace(r,1) trace(r,2)];
Btime_trace =trace(1,1)+trace(1,2);
Etime_trace =trace(r,1)+trace(r,2);

if (Btime_trace ~= Btime) | (Etime_trace ~= Etime)
  disp('There was a time difference between TRACE and ERS !!')
end

% Array variables
j=0;
for i=1:r
  if trace(i,1) >= Bdate & trace(i,1) <= Edate
```

```
    j=j+1;
    varname = 14;
    dirname = 33;
    filename; % call variable
  end
end

dirname=14;
TRACE_j = j;
TRACE_end_time=[date_trace(TRACE_j) time_trace(TRACE_j)];
if ERS_j ~= TRACE_j
  disp('')
  disp('You need to look at the date and time in TRACE data.')
  ERS_end_time=[date_ers(ERS_j) time_ers(ERS_j)]
  TRACE_end_time=[date_trace(TRACE_j) time_trace(TRACE_j)]
  error('Error!! ---> Number of rows is different between ERS and TRACE')
end

disp('TRACE data has been processed!!')
disp(' ')


%WEATHER processes data from WEATHER program.
disp('This program(WEATHER) processes WEATHER OUTPUT.')
disp('WEATHER Data file names are: ')
dir('\sangsoo\project\matlab3\data\*wtr.m')
dirname = 15;
disp('')
disp('WEATHER data is being processed!!')
filename;% call data file for WEATHER

disp(' ')
wtr = a;
[r c]=size(wtr);
BeginningTime_wtr=[wtr(1,1) wtr(1,2)];
EndingTime_wtr=[wtr(r,1) wtr(r,2)];
Btime_wtr =wtr(1,1)+wtr(1,2);
Etime_wtr =wtr(r,1)+wtr(r,2);

if (Btime_wtr ~= Btime) | (Etime_wtr ~= Etime)
  disp('There was a time difference between WEATHER and ERS !!')
end

% Array variables
j=0;
for i=1:r
  if wtr(i,1) >= Bdate & wtr(i,1) <= Edate
    j=j+1;
    varname = 15;
    dirname = 33;
    filename; % call variable
  end
end
```

```
dirname=15;
WEATHER_j = j;
WEATHER_end_time=[date_wtr(WEATHER_j) time_wtr(WEATHER_j)];
if ERS_j ~= WEATHER_j
  disp('')
  disp('You need to look at the date and time in WEATHER data.')
  ERS_end_time=[date_ers(ERS_j) time_ers(ERS_j)]
  WEATHER_end_time=[date_wtr(WEATHER_j) time_wtr(WEATHER_j)]
  error('Error!! ---> Number of rows is different between ERS and WEATHER')
end

disp('WEATHER data has been processed!!')
disp(' ')



  %Calculation of statistical summary
  %(1)Difference between ERS and DOE2
  dt_cool_doe=cool2_ers - cool_doe;
  dt_hen_doe=h_ele2_ers - hen_doe;
  dt_hen_e_doe=hele2_e_ers - hen_e_doe;
  dt_hen_s_doe=hele2_s_ers - hen_s_doe;
  dt_hen_w_doe=hele2_w_ers - hen_w_doe;
  dt_hen_I_doe=hele2_I_ers - hen_I_doe;
  dt_sacfm_doe=sacfm_ers - sacfm_doe;
  dt_oacfm_doe=oacfm_ers - oacfm_doe;
  dt_rmcfm_e_doe=rmcfm_e_ers - rmcfm_e_doe;
  dt_rmcfm_s_doe=rmcfm_s_ers - rmcfm_s_doe;
  dt_rmcfm_w_doe=rmcfm_w_ers - rmcfm_w_doe;
  dt_rmcfm_I_doe=rmcfm_I_ers - rmcfm_I_doe;
  dt_rmtemp_e_doe=rmtemp_e_ers - rmtemp_e_doe;
  dt_rmtemp_s_doe=rmtemp_s_ers - rmtemp_s_doe;
  dt_rmtemp_w_doe=rmtemp_w_ers - rmtemp_w_doe;
  dt_rmtemp_I_doe=rmtemp_I_ers - rmtemp_I_doe;
  %(2)Difference between ERS and HAP
  dt_cool_hap=cool2_ers - cool_hap;
  dt_hen_hap=h_ele2_ers - hen_hap;
  dt_hen_e_hap=hele2_e_ers - hen_e_hap;
  dt_hen_s_hap=hele2_s_ers - hen_s_hap;
  dt_hen_w_hap=hele2_w_ers - hen_w_hap;
  dt_hen_I_hap=hele2_I_ers - hen_I_hap;
  dt_sacfm_hap=sacfm_ers - sacfm_hap;
  dt_oacfm_hap=oacfm_ers - oacfm_hap;
  dt_rmcfm_e_hap=rmcfm_e_ers - rmcfm_e_hap;
  dt_rmcfm_s_hap=rmcfm_s_ers - rmcfm_s_hap;
  dt_rmcfm_w_hap=rmcfm_w_ers - rmcfm_w_hap;
  dt_rmcfm_I_hap=rmcfm_I_ers - rmcfm_I_hap;
  dt_rmtemp_e_hap=rmtemp_e_ers - rmtemp_e_hap;
  dt_rmtemp_s_hap=rmtemp_s_ers - rmtemp_s_hap;
  dt_rmtemp_w_hap=rmtemp_w_ers - rmtemp_w_hap;
  dt_rmtemp_I_hap=rmtemp_I_ers - rmtemp_I_hap;
  %(3)Difference between ERS and TRACE
  dt_cool_trace=cool2_ers - cool_trace;
  dt_hen_trace=h_ele2_ers - hen_trace;
```

```
dt_sacfm_trace=sacfm_ers - sacfm_trace;
dt_oacfm_trace=oacfm_ers - oacfm_trace;

%Mean Value Calculation
%(4) ERS
av_cool_ers=mean(cool2_ers);
av_hen_ers=mean(h_ele2_ers);
av_hen_e_ers=mean(hele2_e_ers);
av_hen_s_ers=mean(hele2_s_ers);
av_hen_w_ers=mean(hele2_w_ers);
av_hen_I_ers=mean(hele2_I_ers);
av_sacfm_ers=mean(sacfm_ers);
av_oacfm_ers=mean(oacfm_ers);
av_rmcfm_e_ers=mean(rmcfm_e_ers);
av_rmcfm_s_ers=mean(rmcfm_s_ers);
av_rmcfm_w_ers=mean(rmcfm_w_ers);
av_rmcfm_I_ers=mean(rmcfm_I_ers);
av_rmtemp_e_ers=mean(rmtemp_e_ers);
av_rmtemp_s_ers=mean(rmtemp_s_ers);
av_rmtemp_w_ers=mean(rmtemp_w_ers);
av_rmtemp_I_ers=mean(rmtemp_I_ers);
%(5) DOE2
av_cool_doe=mean(cool_doe);
av_hen_doe=mean(hen_doe);
av_hen_e_doe=mean(hen_e_doe);
av_hen_s_doe=mean(hen_s_doe);
av_hen_w_doe=mean(hen_w_doe);
av_hen_I_doe=mean(hen_I_doe);
av_sacfm_doe=mean(sacfm_doe);
av_oacfm_doe=mean(oacfm_doe);
av_rmcfm_e_doe=mean(rmcfm_e_doe);
av_rmcfm_s_doe=mean(rmcfm_s_doe);
av_rmcfm_w_doe=mean(rmcfm_w_doe);
av_rmcfm_I_doe=mean(rmcfm_I_doe);
av_rmtemp_e_doe=mean(rmtemp_e_doe);
av_rmtemp_s_doe=mean(rmtemp_s_doe);
av_rmtemp_w_doe=mean(rmtemp_w_doe);
av_rmtemp_I_doe=mean(rmtemp_I_doe);
%(6) HAP
av_cool_hap=mean(cool_hap);
av_hen_hap=mean(hen_hap);
av_hen_e_hap=mean(hen_e_hap);
av_hen_s_hap=mean(hen_s_hap);
av_hen_w_hap=mean(hen_w_hap);
av_hen_I_hap=mean(hen_I_hap);
av_sacfm_hap=mean(sacfm_hap);
av_oacfm_hap=mean(oacfm_hap);
av_rmcfm_e_hap=mean(rmcfm_e_hap);
av_rmcfm_s_hap=mean(rmcfm_s_hap);
av_rmcfm_w_hap=mean(rmcfm_w_hap);
av_rmcfm_I_hap=mean(rmcfm_I_hap);
av_rmtemp_e_hap=mean(rmtemp_e_hap);
av_rmtemp_s_hap=mean(rmtemp_s_hap);
av_rmtemp_w_hap=mean(rmtemp_w_hap);
```

```
av_rmtemp_I_hap=mean(rmtemp_I_hap);
%(7) TRACE
av_cool_trace=mean(cool_trace);
av_hen_trace=mean(hen_trace);
av_sacfm_trace=mean(sacfm_trace);
av_oacfm_trace=mean(oacfm_trace);

%MAX Value Calculation
%(8) ERS
max_cool_ers=max(cool2_ers);
max_hen_ers=max(h_ele2_ers);
max_hen_e_ers=max(hele2_e_ers);
max_hen_s_ers=max(hele2_s_ers);
max_hen_w_ers=max(hele2_w_ers);
max_hen_I_ers=max(hele2_I_ers);
max_sacfm_ers=max(sacfm_ers);
max_oacfm_ers=max(oacfm_ers);
max_rmcfm_e_ers=max(rmcfm_e_ers);
max_rmcfm_s_ers=max(rmcfm_s_ers);
max_rmcfm_w_ers=max(rmcfm_w_ers);
max_rmcfm_I_ers=max(rmcfm_I_ers);
max_rmtemp_e_ers=max(rmtemp_e_ers);
max_rmtemp_s_ers=max(rmtemp_s_ers);
max_rmtemp_w_ers=max(rmtemp_w_ers);
max_rmtemp_I_ers=max(rmtemp_I_ers);
%(9) DOE2
max_cool_doe=max(cool_doe);
max_hen_doe=max(hen_doe);
max_hen_e_doe=max(hen_e_doe);
max_hen_s_doe=max(hen_s_doe);
max_hen_w_doe=max(hen_w_doe);
max_hen_I_doe=max(hen_I_doe);
max_sacfm_doe=max(sacfm_doe);
max_oacfm_doe=max(oacfm_doe);
max_rmcfm_e_doe=max(rmcfm_e_doe);
max_rmcfm_s_doe=max(rmcfm_s_doe);
max_rmcfm_w_doe=max(rmcfm_w_doe);
max_rmcfm_I_doe=max(rmcfm_I_doe);
max_rmtemp_e_doe=max(rmtemp_e_doe);
max_rmtemp_s_doe=max(rmtemp_s_doe);
max_rmtemp_w_doe=max(rmtemp_w_doe);
max_rmtemp_I_doe=max(rmtemp_I_doe);
%(10) HAP
max_cool_hap=max(cool_hap);
max_hen_hap=max(hen_hap);
max_hen_e_hap=max(hen_e_hap);
max_hen_s_hap=max(hen_s_hap);
max_hen_w_hap=max(hen_w_hap);
max_hen_I_hap=max(hen_I_hap);
max_sacfm_hap=max(sacfm_hap);
max_oacfm_hap=max(oacfm_hap);
max_rmcfm_e_hap=max(rmcfm_e_hap);
max_rmcfm_s_hap=max(rmcfm_s_hap);
max_rmcfm_w_hap=max(rmcfm_w_hap);
```

```
max_rmcfm_I_hap=max(rmcfm_I_hap);
max_rmtemp_e_hap=max(rmtemp_e_hap);
max_rmtemp_s_hap=max(rmtemp_s_hap);
max_rmtemp_w_hap=max(rmtemp_w_hap);
max_rmtemp_I_hap=max(rmtemp_I_hap);
%(11) TRACE
max_cool_trace=max(cool_trace);
max_hen_trace=max(hen_trace);
max_sacfm_trace=max(sacfm_trace);
max_oacfm_trace=max(oacfm_trace);

%MIN Value Calculation
%(12) ERS
min_cool_ers=min(cool2_ers);
min_hen_ers=min(h_ele2_ers);
min_hen_e_ers=min(hele2_e_ers);
min_hen_s_ers=min(hele2_s_ers);
min_hen_w_ers=min(hele2_w_ers);
min_hen_I_ers=min(hele2_I_ers);
min_sacfm_ers=min(sacfm_ers);
min_oacfm_ers=min(oacfm_ers);
min_rmcfm_e_ers=min(rmcfm_e_ers);
min_rmcfm_s_ers=min(rmcfm_s_ers);
min_rmcfm_w_ers=min(rmcfm_w_ers);
min_rmcfm_I_ers=min(rmcfm_I_ers);
min_rmtemp_e_ers=min(rmtemp_e_ers);
min_rmtemp_s_ers=min(rmtemp_s_ers);
min_rmtemp_w_ers=min(rmtemp_w_ers);
min_rmtemp_I_ers=min(rmtemp_I_ers);
%(13) DOE2
min_cool_doe=min(cool_doe);
min_hen_doe=min(hen_doe);
min_hen_e_doe=min(hen_e_doe);
min_hen_s_doe=min(hen_s_doe);
min_hen_w_doe=min(hen_w_doe);
min_hen_I_doe=min(hen_I_doe);
min_sacfm_doe=min(sacfm_doe);
min_oacfm_doe=min(oacfm_doe);
min_rmcfm_e_doe=min(rmcfm_e_doe);
min_rmcfm_s_doe=min(rmcfm_s_doe);
min_rmcfm_w_doe=min(rmcfm_w_doe);
min_rmcfm_I_doe=min(rmcfm_I_doe);
min_rmtemp_e_doe=min(rmtemp_e_doe);
min_rmtemp_s_doe=min(rmtemp_s_doe);
min_rmtemp_w_doe=min(rmtemp_w_doe);
min_rmtemp_I_doe=min(rmtemp_I_doe);
%(14) HAP
min_cool_hap=min(cool_hap);
min_hen_hap=min(hen_hap);
min_hen_e_hap=min(hen_e_hap);
min_hen_s_hap=min(hen_s_hap);
min_hen_w_hap=min(hen_w_hap);
min_hen_I_hap=min(hen_I_hap);
min_sacfm_hap=min(sacfm_hap);
```

```
min_oacfm_hap=min(oacfm_hap);
min_rmcfm_e_hap=min(rmcfm_e_hap);
min_rmcfm_s_hap=min(rmcfm_s_hap);
min_rmcfm_w_hap=min(rmcfm_w_hap);
min_rmcfm_I_hap=min(rmcfm_I_hap);
min_rmtemp_e_hap=min(rmtemp_e_hap);
min_rmtemp_s_hap=min(rmtemp_s_hap);
min_rmtemp_w_hap=min(rmtemp_w_hap);
min_rmtemp_I_hap=min(rmtemp_I_hap);
%(15) TRACE
min_cool_trace=min(cool_trace);
min_hen_trace=min(hen_trace);
min_sacfm_trace=min(sacfm_trace);
min_oacfm_trace=min(oacfm_trace);

%Largest, Smallest Mean differences between ERS and PROGRAMS
%(16) DOE smallest
dtmin_cool_doe=min(dt_cool_doe);
dtmin_hen_doe=min(dt_hen_doe);
dtmin_hen_e_doe=min(dt_hen_e_doe);
dtmin_hen_s_doe=min(dt_hen_s_doe);
dtmin_hen_w_doe=min(dt_hen_w_doe);
dtmin_hen_I_doe=min(dt_hen_I_doe);
dtmin_sacfm_doe=min(dt_sacfm_doe);
dtmin_oacfm_doe=min(dt_oacfm_doe);
dtmin_rmcfm_e_doe=min(dt_rmcfm_e_doe);
dtmin_rmcfm_s_doe=min(dt_rmcfm_s_doe);
dtmin_rmcfm_w_doe=min(dt_rmcfm_w_doe);
dtmin_rmcfm_I_doe=min(dt_rmcfm_I_doe);
dtmin_rmtemp_e_doe=min(dt_rmtemp_e_doe);
dtmin_rmtemp_s_doe=min(dt_rmtemp_s_doe);
dtmin_rmtemp_w_doe=min(dt_rmtemp_w_doe);
dtmin_rmtemp_I_doe=min(dt_rmtemp_I_doe);
%(17) DOE Largest
dtmax_cool_doe=max(dt_cool_doe);
dtmax_hen_doe=max(dt_hen_doe);
dtmax_hen_e_doe=max(dt_hen_e_doe);
dtmax_hen_s_doe=max(dt_hen_s_doe);
dtmax_hen_w_doe=max(dt_hen_w_doe);
dtmax_hen_I_doe=max(dt_hen_I_doe);
dtmax_sacfm_doe=max(dt_sacfm_doe);
dtmax_oacfm_doe=max(dt_oacfm_doe);
dtmax_rmcfm_e_doe=max(dt_rmcfm_e_doe);
dtmax_rmcfm_s_doe=max(dt_rmcfm_s_doe);
dtmax_rmcfm_w_doe=max(dt_rmcfm_w_doe);
dtmax_rmcfm_I_doe=max(dt_rmcfm_I_doe);
dtmax_rmtemp_e_doe=max(dt_rmtemp_e_doe);
dtmax_rmtemp_s_doe=max(dt_rmtemp_s_doe);
dtmax_rmtemp_w_doe=max(dt_rmtemp_w_doe);
dtmax_rmtemp_I_doe=max(dt_rmtemp_I_doe);
%(18) DOE mean difference
dtmean_cool_doe=mean(dt_cool_doe);
dtmean_hen_doe=mean(dt_hen_doe);
dtmean_hen_e_doe=mean(dt_hen_e_doe);
```

```
dtmean_hen_s_doe=mean(dt_hen_s_doe);
dtmean_hen_w_doe=mean(dt_hen_w_doe);
dtmean_hen_I_doe=mean(dt_hen_I_doe);
dtmean_sacfm_doe=mean(dt_sacfm_doe);
dtmean_oacfm_doe=mean(dt_oacfm_doe);
dtmean_rmcfm_e_doe=mean(dt_rmcfm_e_doe);
dtmean_rmcfm_s_doe=mean(dt_rmcfm_s_doe);
dtmean_rmcfm_w_doe=mean(dt_rmcfm_w_doe);
dtmean_rmcfm_I_doe=mean(dt_rmcfm_I_doe);
dtmean_rmtemp_e_doe=mean(dt_rmtemp_e_doe);
dtmean_rmtemp_s_doe=mean(dt_rmtemp_s_doe);
dtmean_rmtemp_w_doe=mean(dt_rmtemp_w_doe);
dtmean_rmtemp_I_doe=mean(dt_rmtemp_I_doe);

%(19) HAP smallest
dtmin_cool_hap=min(dt_cool_hap);
dtmin_hen_hap=min(dt_hen_hap);
dtmin_hen_e_hap=min(dt_hen_e_hap);
dtmin_hen_s_hap=min(dt_hen_s_hap);
dtmin_hen_w_hap=min(dt_hen_w_hap);
dtmin_hen_I_hap=min(dt_hen_I_hap);
dtmin_sacfm_hap=min(dt_sacfm_hap);
dtmin_oacfm_hap=min(dt_oacfm_hap);
dtmin_rmcfm_e_hap=min(dt_rmcfm_e_hap);
dtmin_rmcfm_s_hap=min(dt_rmcfm_s_hap);
dtmin_rmcfm_w_hap=min(dt_rmcfm_w_hap);
dtmin_rmcfm_I_hap=min(dt_rmcfm_I_hap);
dtmin_rmtemp_e_hap=min(dt_rmtemp_e_hap);
dtmin_rmtemp_s_hap=min(dt_rmtemp_s_hap);
dtmin_rmtemp_w_hap=min(dt_rmtemp_w_hap);
dtmin_rmtemp_I_hap=min(dt_rmtemp_I_hap);
%(20) HAP largest
dtmax_cool_hap=max(dt_cool_hap);
dtmax_hen_hap=max(dt_hen_hap);
dtmax_hen_e_hap=max(dt_hen_e_hap);
dtmax_hen_s_hap=max(dt_hen_s_hap);
dtmax_hen_w_hap=max(dt_hen_w_hap);
dtmax_hen_I_hap=max(dt_hen_I_hap);
dtmax_sacfm_hap=max(dt_sacfm_hap);
dtmax_oacfm_hap=max(dt_oacfm_hap);
dtmax_rmcfm_e_hap=max(dt_rmcfm_e_hap);
dtmax_rmcfm_s_hap=max(dt_rmcfm_s_hap);
dtmax_rmcfm_w_hap=max(dt_rmcfm_w_hap);
dtmax_rmcfm_I_hap=max(dt_rmcfm_I_hap);
dtmax_rmtemp_e_hap=max(dt_rmtemp_e_hap);
dtmax_rmtemp_s_hap=max(dt_rmtemp_s_hap);
dtmax_rmtemp_w_hap=max(dt_rmtemp_w_hap);
dtmax_rmtemp_I_hap=max(dt_rmtemp_I_hap);
%(21) HAP mean difference
dtmean_cool_hap=mean(dt_cool_hap);
dtmean_hen_hap=mean(dt_hen_hap);
dtmean_hen_e_hap=mean(dt_hen_e_hap);
dtmean_hen_s_hap=mean(dt_hen_s_hap);
dtmean_hen_w_hap=mean(dt_hen_w_hap);
```

```
dtmean_hen_I_hap=mean(dt_hen_I_hap);
dtmean_sacfm_hap=mean(dt_sacfm_hap);
dtmean_oacfm_hap=mean(dt_oacfm_hap);
dtmean_rmcfm_e_hap=mean(dt_rmcfm_e_hap);
dtmean_rmcfm_s_hap=mean(dt_rmcfm_s_hap);
dtmean_rmcfm_w_hap=mean(dt_rmcfm_w_hap);
dtmean_rmcfm_I_hap=mean(dt_rmcfm_I_hap);
dtmean_rmtemp_e_hap=mean(dt_rmtemp_e_hap);
dtmean_rmtemp_s_hap=mean(dt_rmtemp_s_hap);
dtmean_rmtemp_w_hap=mean(dt_rmtemp_w_hap);
dtmean_rmtemp_I_hap=mean(dt_rmtemp_I_hap);

%(22) TRACE smallest
dtmin_cool_trace=min(dt_cool_trace);
dtmin_hen_trace=min(dt_hen_trace);
dtmin_sacfm_trace=min(dt_sacfm_trace);
dtmin_oacfm_trace=min(dt_oacfm_trace);
%(23) TRACE largest
dtmax_cool_trace=max(dt_cool_trace);
dtmax_hen_trace=max(dt_hen_trace);
dtmax_sacfm_trace=max(dt_sacfm_trace);
dtmax_oacfm_trace=max(dt_oacfm_trace);
%(24) TRACE mean difference
dtmean_cool_trace=mean(dt_cool_trace);
dtmean_hen_trace=mean(dt_hen_trace);
dtmean_sacfm_trace=mean(dt_sacfm_trace);
dtmean_oacfm_trace=mean(dt_oacfm_trace);

%RMSE calculation
%(25) DOE
rmse_cool_doe=sqrt(mean((dt_cool_doe).^2));
rmse_hen_doe=sqrt(mean((dt_hen_doe).^2));
rmse_hen_e_doe=sqrt(mean((dt_hen_e_doe).^2));
rmse_hen_s_doe=sqrt(mean((dt_hen_s_doe).^2));
rmse_hen_w_doe=sqrt(mean((dt_hen_w_doe).^2));
rmse_hen_I_doe=sqrt(mean((dt_hen_I_doe).^2));
rmse_sacfm_doe=sqrt(mean((dt_sacfm_doe).^2));
rmse_oacfm_doe=sqrt(mean((dt_oacfm_doe).^2));
rmse_rmcfm_e_doe=sqrt(mean((dt_rmcfm_e_doe).^2));
rmse_rmcfm_s_doe=sqrt(mean((dt_rmcfm_s_doe).^2));
rmse_rmcfm_w_doe=sqrt(mean((dt_rmcfm_w_doe).^2));
rmse_rmcfm_I_doe=sqrt(mean((dt_rmcfm_I_doe).^2));
rmse_rmtemp_e_doe=sqrt(mean((dt_rmtemp_e_doe).^2));
rmse_rmtemp_s_doe=sqrt(mean((dt_rmtemp_s_doe).^2));
rmse_rmtemp_w_doe=sqrt(mean((dt_rmtemp_w_doe).^2));
rmse_rmtemp_I_doe=sqrt(mean((dt_rmtemp_I_doe).^2));
%(26) HAP
rmse_cool_hap=sqrt(mean((dt_cool_hap).^2));
rmse_hen_hap=sqrt(mean((dt_hen_hap).^2));
rmse_hen_e_hap=sqrt(mean((dt_hen_e_hap).^2));
rmse_hen_s_hap=sqrt(mean((dt_hen_s_hap).^2));
rmse_hen_w_hap=sqrt(mean((dt_hen_w_hap).^2));
rmse_hen_I_hap=sqrt(mean((dt_hen_I_hap).^2));
rmse_sacfm_hap=sqrt(mean((dt_sacfm_hap).^2));
```

```
rmse_oacfm_hap=sqrt(mean((dt_oacfm_hap).^2));
rmse_rmcfm_e_hap=sqrt(mean((dt_rmcfm_e_hap).^2));
rmse_rmcfm_s_hap=sqrt(mean((dt_rmcfm_s_hap).^2));
rmse_rmcfm_w_hap=sqrt(mean((dt_rmcfm_w_hap).^2));
rmse_rmcfm_I_hap=sqrt(mean((dt_rmcfm_I_hap).^2));
rmse_rmtemp_e_hap=sqrt(mean((dt_rmtemp_e_hap).^2));
rmse_rmtemp_s_hap=sqrt(mean((dt_rmtemp_s_hap).^2));
rmse_rmtemp_w_hap=sqrt(mean((dt_rmtemp_w_hap).^2));
rmse_rmtemp_I_hap=sqrt(mean((dt_rmtemp_I_hap).^2));
%(27) TRACE
rmse_cool_trace=sqrt(mean((dt_cool_trace).^2));
rmse_hen_trace=sqrt(mean((dt_hen_trace).^2));
rmse_sacfm_trace=sqrt(mean((dt_sacfm_trace).^2));
rmse_oacfm_trace=sqrt(mean((dt_oacfm_trace).^2));

%STDERR(D_bar) calculation
nc=length(dt_cool_doe);
df=nc-1; %degree of freedom
fd=1/df; %conversion factor for calculation
%(28) DOE
stde_cool_doe=sqrt(fd*mean((dt_cool_doe - dtmean_cool_doe).^2));
stde_hen_doe=sqrt(fd*mean((dt_hen_doe - dtmean_hen_doe).^2));
stde_hen_e_doe=sqrt(fd*mean((dt_hen_e_doe - dtmean_hen_e_doe).^2));
stde_hen_s_doe=sqrt(fd*mean((dt_hen_s_doe - dtmean_hen_s_doe).^2));
stde_hen_w_doe=sqrt(fd*mean((dt_hen_w_doe - dtmean_hen_w_doe).^2));
stde_hen_I_doe=sqrt(fd*mean((dt_hen_I_doe - dtmean_hen_I_doe).^2));
stde_sacfm_doe=sqrt(fd*mean((dt_sacfm_doe - dtmean_sacfm_doe).^2));
stde_oacfm_doe=sqrt(fd*mean((dt_oacfm_doe - dtmean_oacfm_doe).^2));
stde_rmcfm_e_doe=sqrt(fd*mean((dt_rmcfm_e_doe - dtmean_rmcfm_e_doe).^2));
stde_rmcfm_s_doe=sqrt(fd*mean((dt_rmcfm_s_doe - dtmean_rmcfm_s_doe).^2));
stde_rmcfm_w_doe=sqrt(fd*mean((dt_rmcfm_w_doe - dtmean_rmcfm_w_doe).^2));
stde_rmcfm_I_doe=sqrt(fd*mean((dt_rmcfm_I_doe - dtmean_rmcfm_I_doe).^2));
stde_rmtemp_e_doe=sqrt(fd*mean((dt_rmtemp_e_doe - dtmean_rmtemp_e_doe).^2));
stde_rmtemp_s_doe=sqrt(fd*mean((dt_rmtemp_s_doe - dtmean_rmtemp_s_doe).^2));
stde_rmtemp_w_doe=sqrt(fd*mean((dt_rmtemp_w_doe - dtmean_rmtemp_w_doe).^2));
stde_rmtemp_I_doe=sqrt(fd*mean((dt_rmtemp_I_doe - dtmean_rmtemp_I_doe).^2));
%(29) HAP
stde_cool_hap=sqrt(fd*mean((dt_cool_hap - dtmean_cool_hap).^2));
stde_hen_hap=sqrt(fd*mean((dt_hen_hap - dtmean_hen_hap).^2));
stde_hen_e_hap=sqrt(fd*mean((dt_hen_e_hap - dtmean_hen_e_hap).^2));
stde_hen_s_hap=sqrt(fd*mean((dt_hen_s_hap - dtmean_hen_s_hap).^2));
stde_hen_w_hap=sqrt(fd*mean((dt_hen_w_hap - dtmean_hen_w_hap).^2));
stde_hen_I_hap=sqrt(fd*mean((dt_hen_I_hap - dtmean_hen_I_hap).^2));
stde_sacfm_hap=sqrt(fd*mean((dt_sacfm_hap - dtmean_sacfm_hap).^2));
stde_oacfm_hap=sqrt(fd*mean((dt_oacfm_hap - dtmean_oacfm_hap).^2));
stde_rmcfm_e_hap=sqrt(fd*mean((dt_rmcfm_e_hap - dtmean_rmcfm_e_hap).^2));
stde_rmcfm_s_hap=sqrt(fd*mean((dt_rmcfm_s_hap - dtmean_rmcfm_s_hap).^2));
stde_rmcfm_w_hap=sqrt(fd*mean((dt_rmcfm_w_hap - dtmean_rmcfm_w_hap).^2));
stde_rmcfm_I_hap=sqrt(fd*mean((dt_rmcfm_I_hap - dtmean_rmcfm_I_hap).^2));
stde_rmtemp_e_hap=sqrt(fd*mean((dt_rmtemp_e_hap - dtmean_rmtemp_e_hap).^2));
stde_rmtemp_s_hap=sqrt(fd*mean((dt_rmtemp_s_hap - dtmean_rmtemp_s_hap).^2));
stde_rmtemp_w_hap=sqrt(fd*mean((dt_rmtemp_w_hap - dtmean_rmtemp_w_hap).^2));
stde_rmtemp_I_hap=sqrt(fd*mean((dt_rmtemp_I_hap - dtmean_rmtemp_I_hap).^2));
%(30) TRACE
```

```
stde_cool_trace=sqrt(fd*mean((dt_cool_trace - dtmean_cool_trace).^2));
stde_hen_trace=sqrt(fd*mean((dt_hen_trace - dtmean_hen_trace).^2));
stde_sacfm_trace=sqrt(fd*mean((dt_sacfm_trace - dtmean_sacfm_trace).^2));
stde_oacfm_trace=sqrt(fd*mean((dt_oacfm_trace - dtmean_oacfm_trace).^2));

%Mean ERR Percent Calculation
%(31) DOE
mper_cool_doe=(av_cool_ers - av_cool_doe)*100/av_cool_ers;
mper_hen_doe=(av_hen_ers - av_hen_doe)*100/av_hen_ers;
mper_hen_e_doe=(av_hen_e_ers - av_hen_e_doe)*100/av_hen_e_ers;
mper_hen_s_doe=(av_hen_s_ers - av_hen_s_doe)*100/av_hen_s_ers;
mper_hen_w_doe=(av_hen_w_ers - av_hen_w_doe)*100/av_hen_w_ers;
mper_hen_I_doe=(av_hen_I_ers - av_hen_I_doe)*100/av_hen_I_ers;
mper_sacfm_doe=(av_sacfm_ers - av_sacfm_doe)*100/av_sacfm_ers;
mper_oacfm_doe=(av_oacfm_ers - av_oacfm_doe)*100/av_oacfm_ers;
mper_rmcfm_e_doe=(av_rmcfm_e_ers - av_rmcfm_e_doe)*100/av_rmcfm_e_ers;
mper_rmcfm_s_doe=(av_rmcfm_s_ers - av_rmcfm_s_doe)*100/av_rmcfm_s_ers;
mper_rmcfm_w_doe=(av_rmcfm_w_ers - av_rmcfm_w_doe)*100/av_rmcfm_w_ers;
mper_rmcfm_I_doe=(av_rmcfm_I_ers - av_rmcfm_I_doe)*100/av_rmcfm_I_ers;
mper_rmtemp_e_doe=(av_rmtemp_e_ers - av_rmtemp_e_doe)*100/av_rmtemp_e_ers;
mper_rmtemp_s_doe=(av_rmtemp_s_ers - av_rmtemp_s_doe)*100/av_rmtemp_s_ers;
mper_rmtemp_w_doe=(av_rmtemp_w_ers - av_rmtemp_w_doe)*100/av_rmtemp_w_ers;
mper_rmtemp_I_doe=(av_rmtemp_I_ers - av_rmtemp_I_doe)*100/av_rmtemp_I_ers;
%(32) HAP
mper_cool_hap=(av_cool_ers - av_cool_hap)*100/av_cool_ers;
mper_hen_hap=(av_hen_ers - av_hen_hap)*100/av_hen_ers;
mper_hen_e_hap=(av_hen_e_ers - av_hen_e_hap)*100/av_hen_e_ers;
mper_hen_s_hap=(av_hen_s_ers - av_hen_s_hap)*100/av_hen_s_ers;
mper_hen_w_hap=(av_hen_w_ers - av_hen_w_hap)*100/av_hen_w_ers;
mper_hen_I_hap=(av_hen_I_ers - av_hen_I_hap)*100/av_hen_I_ers;
mper_sacfm_hap=(av_sacfm_ers - av_sacfm_hap)*100/av_sacfm_ers;
mper_oacfm_hap=(av_oacfm_ers - av_oacfm_hap)*100/av_oacfm_ers;
mper_rmcfm_e_hap=(av_rmcfm_e_ers - av_rmcfm_e_hap)*100/av_rmcfm_e_ers;
mper_rmcfm_s_hap=(av_rmcfm_s_ers - av_rmcfm_s_hap)*100/av_rmcfm_s_ers;
mper_rmcfm_w_hap=(av_rmcfm_w_ers - av_rmcfm_w_hap)*100/av_rmcfm_w_ers;
mper_rmcfm_I_hap=(av_rmcfm_I_ers - av_rmcfm_I_hap)*100/av_rmcfm_I_ers;
mper_rmtemp_e_hap=(av_rmtemp_e_ers - av_rmtemp_e_hap)*100/av_rmtemp_e_ers;
mper_rmtemp_s_hap=(av_rmtemp_s_ers - av_rmtemp_s_hap)*100/av_rmtemp_s_ers;
mper_rmtemp_w_hap=(av_rmtemp_w_ers - av_rmtemp_w_hap)*100/av_rmtemp_w_ers;
mper_rmtemp_I_hap=(av_rmtemp_I_ers - av_rmtemp_I_hap)*100/av_rmtemp_I_ers;
%(34) TRACE
mper_cool_trace=(av_cool_ers - av_cool_trace)*100/av_cool_ers;
mper_hen_trace=(av_hen_ers - av_hen_trace)*100/av_hen_ers;
mper_sacfm_trace=(av_sacfm_ers - av_sacfm_trace)*100/av_sacfm_ers;
mper_oacfm_trace=(av_oacfm_ers - av_oacfm_trace)*100/av_oacfm_ers;

%FORMAT for TABLE VALUES
mper_cool=[mper_cool_doe mper_cool_hap mper_cool_trace 0];
stde_cool=[stde_cool_doe stde_cool_hap stde_cool_trace 0];
rmse_cool=[rmse_cool_doe rmse_cool_hap rmse_cool_trace 0];
dtmin_cool=[dtmin_cool_doe dtmin_cool_hap dtmin_cool_trace 0];
dtmax_cool=[dtmax_cool_doe dtmax_cool_hap dtmax_cool_trace 0];
dtmean_cool=[dtmean_cool_doe dtmean_cool_hap dtmean_cool_trace 0];
min_cool=[min_cool_doe min_cool_hap min_cool_trace min_cool_ers];
```

```
max_cool=[max_cool_doe max_cool_hap max_cool_trace max_cool_ers];
av_cool=[av_cool_doe av_cool_hap av_cool_trace av_cool_ers];

mper_hen=[mper_hen_doe mper_hen_hap mper_hen_trace 0];
stde_hen=[stde_hen_doe stde_hen_hap stde_hen_trace 0];
rmse_hen=[rmse_hen_doe rmse_hen_hap rmse_hen_trace 0];
dtmin_hen=[dtmin_hen_doe dtmin_hen_hap dtmin_hen_trace 0];
dtmax_hen=[dtmax_hen_doe dtmax_hen_hap dtmax_hen_trace 0];
dtmean_hen=[dtmean_hen_doe dtmean_hen_hap dtmean_hen_trace 0];
min_hen=[min_hen_doe min_hen_hap min_hen_trace min_hen_ers];
max_hen=[max_hen_doe max_hen_hap max_hen_trace max_hen_ers];
av_hen=[av_hen_doe av_hen_hap av_hen_trace av_hen_ers];

mper_hen_e=[mper_hen_e_doe mper_hen_e_hap  0];
stde_hen_e=[stde_hen_e_doe stde_hen_e_hap  0];
rmse_hen_e=[rmse_hen_e_doe rmse_hen_e_hap  0];
dtmin_hen_e=[dtmin_hen_e_doe dtmin_hen_e_hap  0];
dtmax_hen_e=[dtmax_hen_e_doe dtmax_hen_e_hap  0];
dtmean_hen_e=[dtmean_hen_e_doe dtmean_hen_e_hap  0];
min_hen_e=[min_hen_e_doe min_hen_e_hap  min_hen_e_ers];
max_hen_e=[max_hen_e_doe max_hen_e_hap  max_hen_e_ers];
av_hen_e=[av_hen_e_doe av_hen_e_hap  av_hen_e_ers];

mper_hen_s=[mper_hen_s_doe mper_hen_s_hap  0];
stde_hen_s=[stde_hen_s_doe stde_hen_s_hap  0];
rmse_hen_s=[rmse_hen_s_doe rmse_hen_s_hap  0];
dtmin_hen_s=[dtmin_hen_s_doe dtmin_hen_s_hap  0];
dtmax_hen_s=[dtmax_hen_s_doe dtmax_hen_s_hap  0];
dtmean_hen_s=[dtmean_hen_s_doe dtmean_hen_s_hap  0];
min_hen_s=[min_hen_s_doe min_hen_s_hap  min_hen_s_ers];
max_hen_s=[max_hen_s_doe max_hen_s_hap  max_hen_s_ers];
av_hen_s=[av_hen_s_doe av_hen_s_hap  av_hen_s_ers];

mper_hen_w=[mper_hen_w_doe mper_hen_w_hap  0];
stde_hen_w=[stde_hen_w_doe stde_hen_w_hap  0];
rmse_hen_w=[rmse_hen_w_doe rmse_hen_w_hap  0];
dtmin_hen_w=[dtmin_hen_w_doe dtmin_hen_w_hap  0];
dtmax_hen_w=[dtmax_hen_w_doe dtmax_hen_w_hap  0];
dtmean_hen_w=[dtmean_hen_w_doe dtmean_hen_w_hap  0];
min_hen_w=[min_hen_w_doe min_hen_w_hap  min_hen_w_ers];
max_hen_w=[max_hen_w_doe max_hen_w_hap  max_hen_w_ers];
av_hen_w=[av_hen_w_doe av_hen_w_hap  av_hen_w_ers];

mper_hen_I=[mper_hen_I_doe mper_hen_I_hap  0];
stde_hen_I=[stde_hen_I_doe stde_hen_I_hap  0];
rmse_hen_I=[rmse_hen_I_doe rmse_hen_I_hap  0];
dtmin_hen_I=[dtmin_hen_I_doe dtmin_hen_I_hap  0];
dtmax_hen_I=[dtmax_hen_I_doe dtmax_hen_I_hap  0];
dtmean_hen_I=[dtmean_hen_I_doe dtmean_hen_I_hap  0];
min_hen_I=[min_hen_I_doe min_hen_I_hap  min_hen_I_ers];
max_hen_I=[max_hen_I_doe max_hen_I_hap  max_hen_I_ers];
av_hen_I=[av_hen_I_doe av_hen_I_hap  av_hen_I_ers];

mper_sacfm=[mper_sacfm_doe mper_sacfm_hap mper_sacfm_trace 0];
```

```
stde_sacfm=[stde_sacfm_doe stde_sacfm_hap stde_sacfm_trace 0];
rmse_sacfm=[rmse_sacfm_doe rmse_sacfm_hap rmse_sacfm_trace 0];
dtmin_sacfm=[dtmin_sacfm_doe dtmin_sacfm_hap dtmin_sacfm_trace 0];
dtmax_sacfm=[dtmax_sacfm_doe dtmax_sacfm_hap dtmax_sacfm_trace 0];
dtmean_sacfm=[dtmean_sacfm_doe dtmean_sacfm_hap dtmean_sacfm_trace 0];
min_sacfm=[min_sacfm_doe min_sacfm_hap min_sacfm_trace min_sacfm_ers];
max_sacfm=[max_sacfm_doe max_sacfm_hap max_sacfm_trace max_sacfm_ers];
av_sacfm=[av_sacfm_doe av_sacfm_hap av_sacfm_trace av_sacfm_ers];

mper_oacfm=[mper_oacfm_doe mper_oacfm_hap mper_oacfm_trace 0];
stde_oacfm=[stde_oacfm_doe stde_oacfm_hap stde_oacfm_trace 0];
rmse_oacfm=[rmse_oacfm_doe rmse_oacfm_hap rmse_oacfm_trace 0];
dtmin_oacfm=[dtmin_oacfm_doe dtmin_oacfm_hap dtmin_oacfm_trace 0];
dtmax_oacfm=[dtmax_oacfm_doe dtmax_oacfm_hap dtmax_oacfm_trace 0];
dtmean_oacfm=[dtmean_oacfm_doe dtmean_oacfm_hap dtmean_oacfm_trace 0];
min_oacfm=[min_oacfm_doe min_oacfm_hap min_oacfm_trace min_oacfm_ers];
max_oacfm=[max_oacfm_doe max_oacfm_hap max_oacfm_trace max_oacfm_ers];
av_oacfm=[av_oacfm_doe av_oacfm_hap av_oacfm_trace av_oacfm_ers];

mper_rmcfm_e=[mper_rmcfm_e_doe mper_rmcfm_e_hap  0];
stde_rmcfm_e=[stde_rmcfm_e_doe stde_rmcfm_e_hap  0];
rmse_rmcfm_e=[rmse_rmcfm_e_doe rmse_rmcfm_e_hap  0];
dtmin_rmcfm_e=[dtmin_rmcfm_e_doe dtmin_rmcfm_e_hap  0];
dtmax_rmcfm_e=[dtmax_rmcfm_e_doe dtmax_rmcfm_e_hap  0];
dtmean_rmcfm_e=[dtmean_rmcfm_e_doe dtmean_rmcfm_e_hap  0];
min_rmcfm_e=[min_rmcfm_e_doe min_rmcfm_e_hap  min_rmcfm_e_ers];
max_rmcfm_e=[max_rmcfm_e_doe max_rmcfm_e_hap  max_rmcfm_e_ers];
av_rmcfm_e=[av_rmcfm_e_doe av_rmcfm_e_hap  av_rmcfm_e_ers];

mper_rmcfm_s=[mper_rmcfm_s_doe mper_rmcfm_s_hap  0];
stde_rmcfm_s=[stde_rmcfm_s_doe stde_rmcfm_s_hap  0];
rmse_rmcfm_s=[rmse_rmcfm_s_doe rmse_rmcfm_s_hap  0];
dtmin_rmcfm_s=[dtmin_rmcfm_s_doe dtmin_rmcfm_s_hap  0];
dtmax_rmcfm_s=[dtmax_rmcfm_s_doe dtmax_rmcfm_s_hap  0];
dtmean_rmcfm_s=[dtmean_rmcfm_s_doe dtmean_rmcfm_s_hap  0];
min_rmcfm_s=[min_rmcfm_s_doe min_rmcfm_s_hap  min_rmcfm_s_ers];
max_rmcfm_s=[max_rmcfm_s_doe max_rmcfm_s_hap  max_rmcfm_s_ers];
av_rmcfm_s=[av_rmcfm_s_doe av_rmcfm_s_hap  av_rmcfm_s_ers];

mper_rmcfm_w=[mper_rmcfm_w_doe mper_rmcfm_w_hap  0];
stde_rmcfm_w=[stde_rmcfm_w_doe stde_rmcfm_w_hap  0];
rmse_rmcfm_w=[rmse_rmcfm_w_doe rmse_rmcfm_w_hap  0];
dtmin_rmcfm_w=[dtmin_rmcfm_w_doe dtmin_rmcfm_w_hap  0];
dtmax_rmcfm_w=[dtmax_rmcfm_w_doe dtmax_rmcfm_w_hap  0];
dtmean_rmcfm_w=[dtmean_rmcfm_w_doe dtmean_rmcfm_w_hap  0];
min_rmcfm_w=[min_rmcfm_w_doe min_rmcfm_w_hap  min_rmcfm_w_ers];
max_rmcfm_w=[max_rmcfm_w_doe max_rmcfm_w_hap  max_rmcfm_w_ers];
av_rmcfm_w=[av_rmcfm_w_doe av_rmcfm_w_hap  av_rmcfm_w_ers];

mper_rmcfm_I=[mper_rmcfm_I_doe mper_rmcfm_I_hap  0];
stde_rmcfm_I=[stde_rmcfm_I_doe stde_rmcfm_I_hap  0];
rmse_rmcfm_I=[rmse_rmcfm_I_doe rmse_rmcfm_I_hap  0];
dtmin_rmcfm_I=[dtmin_rmcfm_I_doe dtmin_rmcfm_I_hap  0];
dtmax_rmcfm_I=[dtmax_rmcfm_I_doe dtmax_rmcfm_I_hap  0];
```

```
dtmean_rmcfm_I=[dtmean_rmcfm_I_doe dtmean_rmcfm_I_hap 0];
min_rmcfm_I=[min_rmcfm_I_doe min_rmcfm_I_hap min_rmcfm_I_ers];
max_rmcfm_I=[max_rmcfm_I_doe max_rmcfm_I_hap max_rmcfm_I_ers];
av_rmcfm_I=[av_rmcfm_I_doe av_rmcfm_I_hap av_rmcfm_I_ers];

mper_rmtemp_e=[mper_rmtemp_e_doe mper_rmtemp_e_hap 0];
stde_rmtemp_e=[stde_rmtemp_e_doe stde_rmtemp_e_hap 0];
rmse_rmtemp_e=[rmse_rmtemp_e_doe rmse_rmtemp_e_hap 0];
dtmin_rmtemp_e=[dtmin_rmtemp_e_doe dtmin_rmtemp_e_hap 0];
dtmax_rmtemp_e=[dtmax_rmtemp_e_doe dtmax_rmtemp_e_hap 0];
dtmean_rmtemp_e=[dtmean_rmtemp_e_doe dtmean_rmtemp_e_hap 0];
min_rmtemp_e=[min_rmtemp_e_doe min_rmtemp_e_hap min_rmtemp_e_ers];
max_rmtemp_e=[max_rmtemp_e_doe max_rmtemp_e_hap max_rmtemp_e_ers];
av_rmtemp_e=[av_rmtemp_e_doe av_rmtemp_e_hap av_rmtemp_e_ers];

mper_rmtemp_s=[mper_rmtemp_s_doe mper_rmtemp_s_hap 0];
stde_rmtemp_s=[stde_rmtemp_s_doe stde_rmtemp_s_hap 0];
rmse_rmtemp_s=[rmse_rmtemp_s_doe rmse_rmtemp_s_hap 0];
dtmin_rmtemp_s=[dtmin_rmtemp_s_doe dtmin_rmtemp_s_hap 0];
dtmax_rmtemp_s=[dtmax_rmtemp_s_doe dtmax_rmtemp_s_hap 0];
dtmean_rmtemp_s=[dtmean_rmtemp_s_doe dtmean_rmtemp_s_hap 0];
min_rmtemp_s=[min_rmtemp_s_doe min_rmtemp_s_hap min_rmtemp_s_ers];
max_rmtemp_s=[max_rmtemp_s_doe max_rmtemp_s_hap max_rmtemp_s_ers];
av_rmtemp_s=[av_rmtemp_s_doe av_rmtemp_s_hap av_rmtemp_s_ers];

mper_rmtemp_w=[mper_rmtemp_w_doe mper_rmtemp_w_hap 0];
stde_rmtemp_w=[stde_rmtemp_w_doe stde_rmtemp_w_hap 0];
rmse_rmtemp_w=[rmse_rmtemp_w_doe rmse_rmtemp_w_hap 0];
dtmin_rmtemp_w=[dtmin_rmtemp_w_doe dtmin_rmtemp_w_hap 0];
dtmax_rmtemp_w=[dtmax_rmtemp_w_doe dtmax_rmtemp_w_hap 0];
dtmean_rmtemp_w=[dtmean_rmtemp_w_doe dtmean_rmtemp_w_hap 0];
min_rmtemp_w=[min_rmtemp_w_doe min_rmtemp_w_hap min_rmtemp_w_ers];
max_rmtemp_w=[max_rmtemp_w_doe max_rmtemp_w_hap max_rmtemp_w_ers];
av_rmtemp_w=[av_rmtemp_w_doe av_rmtemp_w_hap av_rmtemp_w_ers];

mper_rmtemp_I=[mper_rmtemp_I_doe mper_rmtemp_I_hap 0];
stde_rmtemp_I=[stde_rmtemp_I_doe stde_rmtemp_I_hap 0];
rmse_rmtemp_I=[rmse_rmtemp_I_doe rmse_rmtemp_I_hap 0];
dtmin_rmtemp_I=[dtmin_rmtemp_I_doe dtmin_rmtemp_I_hap 0];
dtmax_rmtemp_I=[dtmax_rmtemp_I_doe dtmax_rmtemp_I_hap 0];
dtmean_rmtemp_I=[dtmean_rmtemp_I_doe dtmean_rmtemp_I_hap 0];
min_rmtemp_I=[min_rmtemp_I_doe min_rmtemp_I_hap min_rmtemp_I_ers];
max_rmtemp_I=[max_rmtemp_I_doe max_rmtemp_I_hap max_rmtemp_I_ers];
av_rmtemp_I=[av_rmtemp_I_doe av_rmtemp_I_hap av_rmtemp_I_ers];


Db=Bdate;De=Edate;

%OUTPRINT is an program for printout after analysis.
disp('This program(OUTPRINT) creates outputs.')
dirname = 16;
filename;   % call FILENAME for output filename
```

```
cd ..
cd result\statistics;
disp(' ')
fid=fopen(fname,'w');

fprintf(fid,'Cooling energy rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&   DOE2&   HAP&   TRACE&   ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',av_cool);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmean_cool);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f&%10.1f$pm$\n',mper_cool);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',stde_cool);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',rmse_cool);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmin_cool);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmax_cool);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',min_cool);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',max_cool);
fprintf(fid,'\n\n');

fprintf(fid,'Heating energy rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&   DOE2&   HAP&   TRACE&   ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',av_hen);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmean_hen);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f&%10.1f$pm$\n',mper_hen);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',stde_hen);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',rmse_hen);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmin_hen);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmax_hen);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',min_hen);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',max_hen);
fprintf(fid,'\n\n');


fprintf(fid,'East room heating energy rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&   DOE2&   HAP&   ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_hen_e);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_hen_e);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_hen_e);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_hen_e);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_hen_e);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_hen_e);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_hen_e);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_hen_e);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_hen_e);
fprintf(fid,'\n\n');


fprintf(fid,'South room heating energy rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&   DOE2&   HAP&   ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_hen_s);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_hen_s);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_hen_s);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_hen_s);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_hen_s);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_hen_s);
```

```
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_hen_s);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_hen_s);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_hen_s);
fprintf(fid,'\n\n');


fprintf(fid,'West room heating energy rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&      HAP&       ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_hen_w);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_hen_w);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_hen_w);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_hen_w);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_hen_w);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_hen_w);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_hen_w);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_hen_w);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_hen_w);
fprintf(fid,'\n\n');


fprintf(fid,'Interior room heating energy rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&      HAP&       ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_hen_I);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_hen_I);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_hen_I);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_hen_I);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_hen_I);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_hen_I);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_hen_I);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_hen_I);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_hen_I);
fprintf(fid,'\n\n');


fprintf(fid,'Supply air flow rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&      HAP&     TRACE&      ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',av_sacfm);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmean_sacfm);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f&%10.1f$pm$\n',mper_sacfm);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',stde_sacfm);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',rmse_sacfm);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmin_sacfm);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmax_sacfm);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',min_sacfm);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',max_sacfm);
fprintf(fid,'\n\n');


fprintf(fid,'Outside air flow rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&      HAP&     TRACE&      ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',av_oacfm);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmean_oacfm);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f&%10.1f$pm$\n',mper_oacfm);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',stde_oacfm);
```

```
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',rmse_oacfm);
fprintf(fid,'MIN(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmin_oacfm);
fprintf(fid,'MAX(DT)&  %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',dtmax_oacfm);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',min_oacfm);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f&%10.0f$pm$\n',max_oacfm);
fprintf(fid,'\n\n');


fprintf(fid,'East room air flow rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&     HAP&      ACTUAL\n');
fprintf(fid,'MEAN&       %10.0f&%10.0f&%10.0f$pm$\n',av_rmcfm_e);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmcfm_e);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmcfm_e);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmcfm_e);
fprintf(fid,'RMSE&       %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmcfm_e);
fprintf(fid,'MIN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmcfm_e);
fprintf(fid,'MAX(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmcfm_e);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmcfm_e);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmcfm_e);
fprintf(fid,'\n\n');


fprintf(fid,'South room air flow rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&     HAP&      ACTUAL\n');
fprintf(fid,'MEAN&       %10.0f&%10.0f&%10.0f$pm$\n',av_rmcfm_s);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmcfm_s);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmcfm_s);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmcfm_s);
fprintf(fid,'RMSE&       %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmcfm_s);
fprintf(fid,'MIN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmcfm_s);
fprintf(fid,'MAX(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmcfm_s);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmcfm_s);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmcfm_s);
fprintf(fid,'\n\n');


fprintf(fid,'West room air flow rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&     HAP&      ACTUAL\n');
fprintf(fid,'MEAN&       %10.0f&%10.0f&%10.0f$pm$\n',av_rmcfm_w);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmcfm_w);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmcfm_w);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmcfm_w);
fprintf(fid,'RMSE&       %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmcfm_w);
fprintf(fid,'MIN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmcfm_w);
fprintf(fid,'MAX(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmcfm_w);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmcfm_w);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmcfm_w);
fprintf(fid,'\n\n');


fprintf(fid,'Interior room air flow rate: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&     DOE2&     HAP&      ACTUAL\n');
fprintf(fid,'MEAN&       %10.0f&%10.0f&%10.0f$pm$\n',av_rmcfm_I);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmcfm_I);
```

```
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmcfm_I);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmcfm_I);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmcfm_I);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmcfm_I);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmcfm_I);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmcfm_I);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmcfm_I);
fprintf(fid,'\n\n');


fprintf(fid,'East room temperature: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&    DOE2&     HAP&      ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_rmtemp_e);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmtemp_e);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmtemp_e);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmtemp_e);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmtemp_e);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmtemp_e);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmtemp_e);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmtemp_e);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmtemp_e);
fprintf(fid,'\n\n');


fprintf(fid,'South room temperature: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&    DOE2&     HAP&      ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_rmtemp_s);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmtemp_s);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmtemp_s);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmtemp_s);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmtemp_s);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmtemp_s);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmtemp_s);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmtemp_s);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmtemp_s);
fprintf(fid,'\n\n');


fprintf(fid,'West room temperature: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&    DOE2&     HAP&      ACTUAL\n');
fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_rmtemp_w);
fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmtemp_w);
fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmtemp_w);
fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmtemp_w);
fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmtemp_w);
fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmtemp_w);
fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmtemp_w);
fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmtemp_w);
fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmtemp_w);
fprintf(fid,'\n\n');


fprintf(fid,'Interior room temperature: %9i  %9i\n',Db,De);
fprintf(fid,'Statistics&    DOE2&     HAP&      ACTUAL\n');
```

```
  fprintf(fid,'MEAN&      %10.0f&%10.0f&%10.0f$pm$\n',av_rmtemp_I);
  fprintf(fid,'MEAN(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',dtmean_rmtemp_I);
  fprintf(fid,'MEAN ERROR&%10.1f&%10.1f&%10.1f$pm$\n',mper_rmtemp_I);
  fprintf(fid,'STDE(DT)&  %10.0f&%10.0f&%10.0f$pm$\n',stde_rmtemp_I);
  fprintf(fid,'RMSE&      %10.0f&%10.0f&%10.0f$pm$\n',rmse_rmtemp_I);
  fprintf(fid,'MIN(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmin_rmtemp_I);
  fprintf(fid,'MAX(DT)&   %10.0f&%10.0f&%10.0f$pm$\n',dtmax_rmtemp_I);
  fprintf(fid,'MIN&       %10.0f&%10.0f&%10.0f$pm$\n',min_rmtemp_I);
  fprintf(fid,'MAX&       %10.0f&%10.0f&%10.0f$pm$\n',max_rmtemp_I);
  fprintf(fid,'\n\n');

  status=fclose(fid)
  cd ..
  cd ..

  cd programs;

  disp('PRINTOUT run has been done!')
  disp(' ')


%Array for plots
  [r c]=size(date_ers);
  cool_f=[cool2_ers; cool_doe; cool_hap; cool_trace];
  hen_f=[h_ele2_ers; hen_doe; hen_hap; hen_trace];
  hen_e_f=[hele2_e_ers; hen_e_doe; hen_e_hap ];
  hen_s_f=[hele2_s_ers; hen_s_doe; hen_s_hap ];
  hen_w_f=[hele2_w_ers; hen_w_doe; hen_w_hap ];
  hen_I_f=[hele2_I_ers; hen_I_doe; hen_I_hap ];
  sacfm_f=[sacfm_ers; sacfm_doe; sacfm_hap; sacfm_trace];
  oacfm_f=[oacfm_ers; oacfm_doe; oacfm_hap; oacfm_trace];
  rmcfm_e_f=[rmcfm_e_ers; rmcfm_e_doe; rmcfm_e_hap ];
  rmcfm_s_f=[rmcfm_s_ers; rmcfm_s_doe; rmcfm_s_hap ];
  rmcfm_w_f=[rmcfm_w_ers; rmcfm_w_doe; rmcfm_w_hap ];
  rmcfm_I_f=[rmcfm_I_ers; rmcfm_I_doe; rmcfm_I_hap ];
  rmtemp_e_f=[rmtemp_e_ers; rmtemp_e_doe; rmtemp_e_hap ];
  rmtemp_s_f=[rmtemp_s_ers; rmtemp_s_doe; rmtemp_s_hap ];
  rmtemp_w_f=[rmtemp_w_ers; rmtemp_w_doe; rmtemp_w_hap ];
  rmtemp_I_f=[rmtemp_I_ers; rmtemp_I_doe; rmtemp_I_hap ];
  %temp=[dbt_wtr; wbt_wtr];
  %solar=[dnr_wtr; thr_wtr];

  %set axis scales
  coolmax=max(max(cool_f))*1.15;
  coolmin=min(min(cool_f))*0.85;
  henmax=max(max(hen_f))*1.15;
  henmin=min(min(hen_f))*0.85;
  hmax=max(max([hen_e_f hen_s_f hen_w_f hen_I_f]))*1.15
  hmin=min(min([hen_e_f hen_s_f hen_w_f hen_I_f]))*0.85
  cfmmax=max(max(sacfm_f))*1.15
  cfmmin=min(min(oacfm_f))*0.85
  cfmax=max(max([rmcfm_e_f rmcfm_s_f rmcfm_w_f rmcfm_I_f]))*1.15
  cfmin=min(min([rmcfm_e_f rmcfm_s_f rmcfm_w_f rmcfm_I_f]))*0.85
  rmtmax=max(max([rmtemp_e_f rmtemp_s_f rmtemp_w_f rmtemp_I_f]))*1.15
```

```
rmtmin=min(min([rmtemp_e_f rmtemp_s_f rmtemp_w_f rmtemp_I_f]))*0.85

if coolmin < 0 | coolmax < 0
  coolmin=0;
  coolmax=1;
end

%plots
cd ..
cd result\graph;
figure
plot(cool_f'),axis([1 c coolmin coolmax]),legend('actual','doe2','hap','trace',0),grid;
print -dpsc f1

figure
plot(hen_f'),axis([1 c henmin henmax]),legend('actual','doe2','hap','trace',0),grid;
print -dpsc f1

figure
plot(hen_e_f'),axis([1 c hmin hmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f3

figure
plot(hen_s_f'),axis([1 c hmin hmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f4

figure
plot(hen_w_f'),axis([1 c hmin hmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f5

figure
plot(hen_I_f'),axis([1 c hmin hmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f6

figure
plot(sacfm_f'),axis([1 c cfmmin cfmmax]),legend('actual','doe2','hap','trace',0),grid;
print -dpsc f7

figure
plot(oacfm_f'),axis([1 c cfmmin cfmmax]),legend('actual','doe2','hap','trace',0),grid;
print -dpsc f8

figure
plot(rmcfm_e_f'),axis([1 c cfmin cfmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f9

figure
plot(rmcfm_s_f'),axis([1 c cfmin cfmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f10

figure
plot(rmcfm_w_f'),axis([1 c cfmin cfmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f11
```

```
figure
plot(rmcfm_I_f'),axis([1 c cfmin cfmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f12

figure
plot(rmtemp_e_f'),axis([1 c rmtmin rmtmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f13

figure
plot(rmtemp_s_f'),axis([1 c rmtmin rmtmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f14

figure
plot(rmtemp_w_f'),axis([1 c rmtmin rmtmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f15

figure
plot(rmtemp_I_f'),axis([1 c rmtmin rmtmax]),legend('actual','doe2','hap',0),grid;
print -dpsc f16

figure
plot(temp'),axis([1 c 0 80]),legend('dry-bulb','wet-bulb',0),grid;
print -dpsc f17

figure
plot(solar'),axis([1 c 0 350]),legend('direct normal','total horizontal',0),grid;
print -dpsc f18

cd ..
cd ..
cd programs;

disp('PLOTS have been created!')
disp(' ')
```

```
%Array for plots
  [r c]=size(date_ers);
  cool_f=[cool2_ers; cool_doe; cool_hap; cool_trace];
  hen_f=[h_ele2_ers; hen_doe; hen_hap; hen_trace];
  hen_e_f=[hele2_e_ers; hen_e_doe; hen_e_hap ];
  hen_s_f=[hele2_s_ers; hen_s_doe; hen_s_hap ];
  hen_w_f=[hele2_w_ers; hen_w_doe; hen_w_hap ];
  hen_I_f=[hele2_I_ers; hen_I_doe; hen_I_hap ];
  sacfm_ers=rmcfm_e_ers+rmcfm_s_ers+rmcfm_w_ers+rmcfm_I_ers; %sum of cfm
  sacfm_f=[sacfm_ers; sacfm_doe; sacfm_hap; sacfm_trace];
  oacfm_f=[oacfm_ers; oacfm_doe; oacfm_hap; oacfm_trace];
  rmcfm_e_f=[rmcfm_e_ers; rmcfm_e_doe; rmcfm_e_hap ];
```

```
rmcfm_s_f=[rmcfm_s_ers; rmcfm_s_doe; rmcfm_s_hap ];
rmcfm_w_f=[rmcfm_w_ers; rmcfm_w_doe; rmcfm_w_hap ];
rmcfm_I_f=[rmcfm_I_ers; rmcfm_I_doe; rmcfm_I_hap ];
rmtemp_e_f=[rmtemp_e_ers; rmtemp_e_doe; rmtemp_e_hap ];
rmtemp_s_f=[rmtemp_s_ers; rmtemp_s_doe; rmtemp_s_hap ];
rmtemp_w_f=[rmtemp_w_ers; rmtemp_w_doe; rmtemp_w_hap ];
rmtemp_I_f=[rmtemp_I_ers; rmtemp_I_doe; rmtemp_I_hap ];
temp=[dbt_wtr; wbt_wtr];
solar=[dnr_wtr; thr_wtr];

%set axis scales
coolmax=max(max(cool_f))*1.15;
coolmin=min(min(cool_f))*0.85;
henmax=max(max(hen_f))*1.15;
henmin=min(min(hen_f))*0.85;
hmax=max(max([hen_e_f hen_s_f hen_w_f hen_I_f]))*1.15
hmin=min(min([hen_e_f hen_s_f hen_w_f hen_I_f]))*0.85
cfmmax=max(max(sacfm_f))*1.15
cfmmin=min(min(oacfm_f))*0.85
cfmax=max(max([rmcfm_e_f rmcfm_s_f rmcfm_w_f rmcfm_I_f]))*1.15
cfmin=min(min([rmcfm_e_f rmcfm_s_f rmcfm_w_f rmcfm_I_f]))*0.85
rmtmax=max(max([rmtemp_e_f rmtemp_s_f rmtemp_w_f rmtemp_I_f]))*1.15
rmtmin=min(min([rmtemp_e_f rmtemp_s_f rmtemp_w_f rmtemp_I_f]))*0.85

if coolmin < 0 | coolmax < 0
  coolmin=0;
  coolmax=1;
end

x=1:c;
%plots

cd ..
cd result\graph;
figure
plot(x,cool2_ers,'k-',x,cool_doe,'k-.',x,cool_hap,'k--',x,cool_trace,'k:'),axis([1 c coolmin
coolmax]),legend('actual','doe2','hap','trace',0),grid;
 xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tpf1

figure
plot(x,h_ele2_ers,'k-',x, hen_doe,'k-.',x, hen_hap,'k--',x, hen_trace,'k:'),axis([1 c henmin
henmax]),legend('actual','doe2','hap','trace',0),grid;
 xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tpf2

figure
plot(x,hele2_e_ers,'k-',x, hen_e_doe,'k.:',x, hen_e_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
 xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tpf3

figure
```

```
plot(x,hele2_s_ers,'k-',x, hen_s_doe,'k.:',x, hen_s_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
  xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tpf4

figure
plot(x,hele2_w_ers,'k-',x, hen_w_doe,'k.:',x, hen_w_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
  xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tpf5

figure
plot(x,hele2_I_ers,'k-',x, hen_I_doe,'k.:',x, hen_I_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
  xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tpf6

figure
plot(x,sacfm_ers,'k-',x, sacfm_doe,'k-.',x, sacfm_hap,'k--',x, sacfm_trace,'k.:'),axis([1 c cfmmin
cfmmax]),legend('actual','doe2','hap','trace',0),grid;
  xlabel('Hour'),ylabel('CFM');
print -dpsc tpf7

figure
plot(x,oacfm_ers,'k-',x, oacfm_doe,'k-.',x, oacfm_hap,'k--',x, oacfm_trace,'k.:'),axis([1 c cfmmin
cfmmax]),legend('actual','doe2','hap','trace',0),grid;
  xlabel('Hour'),ylabel('CFM');
print -dpsc tpf8

figure
plot(x,rmcfm_e_ers,'k-',x, rmcfm_e_doe,'k.:',x, rmcfm_e_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
  xlabel('Hour'),ylabel('CFM');
print -dpsc tpf9

figure
plot(x,rmcfm_s_ers,'k-',x, rmcfm_s_doe,'k.:',x, rmcfm_s_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
  xlabel('Hour'),ylabel('CFM');
print -dpsc tpf10

figure
plot(x,rmcfm_w_ers,'k-',x, rmcfm_w_doe,'k.:',x, rmcfm_w_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
  xlabel('Hour'),ylabel('CFM');
print -dpsc tpf11

figure
plot(x,rmcfm_I_ers,'k-',x, rmcfm_I_doe,'k.:',x, rmcfm_I_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
  xlabel('Hour'),ylabel('CFM');
print -dpsc tpf12

figure
```

```
plot(x,rmtemp_e_ers,'k-',x, rmtemp_e_doe,'k.:',x, rmtemp_e_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
 xlabel('Hour'),ylabel('F');
print -dpsc tpf13

figure
plot(x,rmtemp_s_ers,'k-',x, rmtemp_s_doe,'k.:',x, rmtemp_s_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
 xlabel('Hour'),ylabel('F');
print -dpsc tfp14

figure
plot(x,rmtemp_w_ers,'k-',x, rmtemp_w_doe,'k.:',x, rmtemp_w_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
 xlabel('Hour'),ylabel('F');
print -dpsc tpf15

figure
plot(x,rmtemp_I_ers,'k-',x, rmtemp_I_doe,'k.:',x, rmtemp_I_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
 xlabel('Hour'),ylabel('F');
print -dpsc tpf16

%figure
%plot(x,wbt_wtr,'k-.',x,dbt_wtr,'k-'),axis([1 c 0 80]),legend('wet-bulb','dry-bulb',0),grid;
%xlabel('Hour'),ylabel('F');
%print -dpsc twf1

%figure
%plot(x,dnr_wtr,'k-',x,thr_wtr,'k-.'),axis([1 c 0 350]),legend('direct normal','total horizontal',0),grid;
% xlabel('Hour'),ylabel('Btu /Hr.Ft^2');
%print -dpsc twf2


cd ..
cd ..
cd programs;

disp('PLOTS have been created!')
disp(' ')




%Array for plots
[r c]=size(date_ers);
cool_f=[cool2_ers; cool_doe; cool_hap; cool_trace];
hen_f=[h_ele2_ers; hen_doe; hen_hap; hen_trace];
hen_e_f=[hele2_e_ers; hen_e_doe; hen_e_hap ];
hen_s_f=[hele2_s_ers; hen_s_doe; hen_s_hap ];
hen_w_f=[hele2_w_ers; hen_w_doe; hen_w_hap ];
hen_I_f=[hele2_I_ers; hen_I_doe; hen_I_hap ];
sacfm_ers=rmcfm_e_ers+rmcfm_s_ers+rmcfm_w_ers+rmcfm_I_ers; %sum of cfm
sacfm_f=[sacfm_ers; sacfm_doe; sacfm_hap; sacfm_trace];
```

```
oacfm_f=[oacfm_ers; oacfm_doe; oacfm_hap; oacfm_trace];
rmcfm_e_f=[rmcfm_e_ers; rmcfm_e_doe; rmcfm_e_hap ];
rmcfm_s_f=[rmcfm_s_ers; rmcfm_s_doe; rmcfm_s_hap ];
rmcfm_w_f=[rmcfm_w_ers; rmcfm_w_doe; rmcfm_w_hap ];
rmcfm_I_f=[rmcfm_I_ers; rmcfm_I_doe; rmcfm_I_hap ];
rmtemp_e_f=[rmtemp_e_ers; rmtemp_e_doe; rmtemp_e_hap ];
rmtemp_s_f=[rmtemp_s_ers; rmtemp_s_doe; rmtemp_s_hap ];
rmtemp_w_f=[rmtemp_w_ers; rmtemp_w_doe; rmtemp_w_hap ];
rmtemp_I_f=[rmtemp_I_ers; rmtemp_I_doe; rmtemp_I_hap ];
temp=[dbt_wtr; wbt_wtr];
solar=[dnr_wtr; thr_wtr];

%set axis scales
coolmax=max(max(cool_f))*1.15;
coolmin=min(min(cool_f))*0.85;
henmax=max(max(hen_f))*1.15;
henmin=min(min(hen_f))*0.85;
hmax=max(max([hen_e_f hen_s_f hen_w_f hen_I_f]))*1.15
hmin=min(min([hen_e_f hen_s_f hen_w_f hen_I_f]))*0.85
cfmmax=max(max(sacfm_f))*1.15
cfmmin=min(min(oacfm_f))*0.85
cfmax=max(max([rmcfm_e_f rmcfm_s_f rmcfm_w_f rmcfm_I_f]))*1.15
cfmin=min(min([rmcfm_e_f rmcfm_s_f rmcfm_w_f rmcfm_I_f]))*0.85
rmtmax=max(max([rmtemp_e_f rmtemp_s_f rmtemp_w_f rmtemp_I_f]))*1.15
rmtmin=min(min([rmtemp_e_f rmtemp_s_f rmtemp_w_f rmtemp_I_f]))*0.85

if coolmin < 0 | coolmax < 0
  coolmin=0;
  coolmax=1;
end

x=1:c;
%plots

cd ..
cd result\graph;
figure
plot(x,cool2_ers,'k-',x,cool_doe,'k-.',x,cool_hap,'k--',x,cool_trace,'k:'),axis([1 c coolmin
coolmax]),legend('actual','doe2','hap','trace',0),grid;
orient landscape;xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tf1

figure
plot(x,h_ele2_ers,'k-',x, hen_doe,'k-.',x, hen_hap,'k--',x, hen_trace,'k:'),axis([1 c henmin
henmax]),legend('actual','doe2','hap','trace',0),grid;
orient landscape;xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tf2

figure
plot(x,hele2_e_ers,'k-',x, hen_e_doe,'k-.',x, hen_e_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tf3
```

```
figure
plot(x,hele2_s_ers,'k-',x, hen_s_doe,'k-.',x, hen_s_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tf4

figure
plot(x,hele2_w_ers,'k-',x, hen_w_doe,'k-.',x, hen_w_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tf5

figure
plot(x,hele2_I_ers,'k-',x, hen_I_doe,'k-.',x, hen_I_hap,'k--'),axis([1 c hmin
hmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('Btu / Hr');
print -dpsc tf6

figure
plot(x,sacfm_ers,'k-',x, sacfm_doe,'k-.',x, sacfm_hap,'k--',x, sacfm_trace,'k:'),axis([1 c cfmmin
cfmmax]),legend('actual','doe2','hap','trace',0),grid;
orient landscape;xlabel('Hour'),ylabel('CFM');
print -dpsc tf7

figure
plot(x,oacfm_ers,'k-',x, oacfm_doe,'k-.',x, oacfm_hap,'k--',x, oacfm_trace,'k:'),axis([1 c cfmmin
cfmmax]),legend('actual','doe2','hap','trace',0),grid;
orient landscape;xlabel('Hour'),ylabel('CFM');
print -dpsc tf8

figure
plot(x,rmcfm_e_ers,'k-',x, rmcfm_e_doe,'k-.',x, rmcfm_e_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('CFM');
print -dpsc tf9

figure
plot(x,rmcfm_s_ers,'k-',x, rmcfm_s_doe,'k-.',x, rmcfm_s_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('CFM');
print -dpsc tf10

figure
plot(x,rmcfm_w_ers,'k-',x, rmcfm_w_doe,'k-.',x, rmcfm_w_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('CFM');
print -dpsc tf11

figure
plot(x,rmcfm_I_ers,'k-',x, rmcfm_I_doe,'k-.',x, rmcfm_I_hap,'k--'),axis([1 c cfmin
cfmax]),legend('actual','doe2','hap',0),grid;
orient landscape;xlabel('Hour'),ylabel('CFM');
print -dpsc tf12
```

```
  figure
  plot(x,rmtemp_e_ers,'k-',x, rmtemp_e_doe,'k-.',x, rmtemp_e_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
  orient landscape;xlabel('Hour'),ylabel('F');
  print -dpsc tf13

  figure
  plot(x,rmtemp_s_ers,'k-',x, rmtemp_s_doe,'k-.',x, rmtemp_s_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
  orient landscape;xlabel('Hour'),ylabel('F');
  print -dpsc tf14

  figure
  plot(x,rmtemp_w_ers,'k-',x, rmtemp_w_doe,'k-.',x, rmtemp_w_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
  orient landscape;xlabel('Hour'),ylabel('F');
  print -dpsc tf15

  figure
  plot(x,rmtemp_I_ers,'k-',x, rmtemp_I_doe,'k-.',x, rmtemp_I_hap,'k--'),axis([1 c rmtmin
rmtmax]),legend('actual','doe2','hap',0),grid;
  orient landscape;xlabel('Hour'),ylabel('F');
  print -dpsc tf16

  %figure
  %plot(x,wbt_wtr,'k-.',x,dbt_wtr,'k-'),axis([1 c 0 80]),legend('wet-bulb','dry-bulb',0),grid;
  %print -dpsc twf17

  %figure
  %plot(x,dnr_wtr,'k-',x,thr_wtr,'k-.'),axis([1 c 0 350]),legend('direct normal','total horizontal',0),grid;
  %print -dpsc twf18


 cd ..
  cd ..
  cd programs;

  disp('PLOTS have been created!')
  disp(' ')




%FILENAME shows file names that will be processed in the program
if dirname == 10
  Bdate = 990328;
  Edate = 990331
elseif dirname == 11
  m990328ers;
elseif dirname == 12
```

```
  m990328doe;
 elseif dirname == 13
  m990328hap;
 elseif dirname == 14
  m990328trace;
 %elseif dirname == 15
  %TESTWTR;
 elseif dirname == 16
  fname = '990328.dat';
 elseif dirname == 33
  variable;
 end


%CALLVAR arrays variable names for systems and testrooms for Master Program
if varname == 11 %for ERS DATA
  date_ers(j)=ers(i,1);
  time_ers(j)=ers(i,2);
  cool2_ers(j)=ers(i,3);
  h_ele2_ers(j)=-ers(i,4);
  hele2_e_ers(j)=-ers(i,5);
  hele2_s_ers(j)=-ers(i,6);
  hele2_w_ers(j)=-ers(i,7);
  hele2_I_ers(j)=-ers(i,8);
  sacfm_ers(j)=ers(i,9);
  oacfm_ers(j)=ers(i,10);
  rmcfm_e_ers(j)=ers(i,11);
  rmcfm_s_ers(j)=ers(i,12);
  rmcfm_w_ers(j)=ers(i,13);
  rmcfm_I_ers(j)=ers(i,14);
  rmtemp_e_ers(j)=ers(i,15);
  rmtemp_s_ers(j)=ers(i,16);
  rmtemp_w_ers(j)=ers(i,17);
  rmtemp_I_ers(j)=ers(i,18);
elseif varname == 12 % for DOE2 DATA
  date_doe(j)=doe(i,1);
  time_doe(j)=doe(i,2);
  cool_doe(j)=doe(i,3);
  hen_doe(j)=-doe(i,4);
  hen_e_doe(j)=-doe(i,5);
  hen_s_doe(j)=-doe(i,6);
  hen_w_doe(j)=-doe(i,7);
  hen_I_doe(j)=-doe(i,8);
  sacfm_doe(j)=doe(i,9);
  oacfm_doe(j)=doe(i,10);
  rmcfm_e_doe(j)=doe(i,11);
  rmcfm_s_doe(j)=doe(i,12);
  rmcfm_w_doe(j)=doe(i,13);
  rmcfm_I_doe(j)=doe(i,14);
  rmtemp_e_doe(j)=doe(i,15);
  rmtemp_s_doe(j)=doe(i,16);
  rmtemp_w_doe(j)=doe(i,17);
  rmtemp_I_doe(j)=doe(i,18);
```

```
elseif varname == 13 % for HAP DATA
  date_hap(j)=hap(i,1);
  time_hap(j)=hap(i,2);
  cool_hap(j)=hap(i,3);
  hen_hap(j)=hap(i,4);
  hen_e_hap(j)=hap(i,5);
  hen_s_hap(j)=hap(i,6);
  hen_w_hap(j)=hap(i,7);
  hen_I_hap(j)=hap(i,8);
  sacfm_hap(j)=hap(i,9);
  oacfm_hap(j)=hap(i,10);
  rmcfm_e_hap(j)=hap(i,11);
  rmcfm_s_hap(j)=hap(i,12);
  rmcfm_w_hap(j)=hap(i,13);
  rmcfm_I_hap(j)=hap(i,14);
  rmtemp_e_hap(j)=hap(i,15);
  rmtemp_s_hap(j)=hap(i,16);
  rmtemp_w_hap(j)=hap(i,17);
  rmtemp_I_hap(j)=hap(i,18);

elseif varname == 14 %for TRACE DATA
  date_trace(j)=trace(i,1);
  time_trace(j)=trace(i,2);
  cool_trace(j)=trace(i,3);
  hen_trace(j)=-trace(i,4);
  sacfm_trace(j)=trace(i,5);
  oacfm_trace(j)=trace(i,6);

elseif varname == 15 %for WEATHER DATA
  date_wtr(j)=wtr(i,1);
  time_wtr(j)=wtr(i,2);
  dbt_wtr(j)=wtr(i,3);
  wbt_wtr(j)=wtr(i,4);
  dnr_wtr(j)=wtr(i,5);
  thr_wtr(j)=wtr(i,6);
end
```

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IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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